Developing an Environmentally Appropriate, Socially Acceptable and Gender-Sensitive Technology for Safe-Water Supply to Households in Arsenic Affected Areas in Rural Bangladesh

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Table of contents

List of Tables

List of Figures

1

Introduction

1.1 Introduction

In Bangladesh about 95 percent of the people depend on tube-well water drawn from alluvial aquifers underlying the Ganges and Brahmaputra delta. However, a large proportion of the groundwater from the shallow tube wells is contaminated with high concentrations of naturally occurring arsenic (As). Options to abate this problem are extraction from deeper aquifers, return to the use of surface water and arsenic removal systems at household level. The last option is most feasible on a short term basis. Although a number of household-level removal systems have been developed – such as those based on adsorption, chemical oxidation in combination with adsorption, ion exchange, chemical oxidation and coagulation – the non-technical aspects, relevant to the introduction and safe application of the appliance, have been largely glossed over. For this reason the implementation of these systems is as yet not very successful.

There is a knowledge gap between what we know of the technical features of these technologies and the lack of knowledge about the suitability of the technologies for rural households and rural women in a specific socio-cultural context. This study intends to address this knowledge gap. Therefore, the overall goal of the proposed study is to contribute to finding feasible, socially appropriate and gender-sensitive household-level technological solutions to the problem of arsenic groundwater contamination in rural Bangladesh. To achieve this goal, an innovative interdisciplinary study design was used.

As this study focused on the technological and social acceptability of the safe water supply options, it contributes to the development of knowledge about solutions for arsenic-contaminated water supplies. Until now, in Bangladesh the research about and development of appropriate options for As-affected areas did not progress enough, as many promoted options show minimum scope for decreased vulnerability risks because of poor performance by the systems as well as their non-acceptability for the users in villages. Fact is that common villagers, mostly poverty-burdened people, had to invest substantially in installing their tube wells only a few years ago. Now, when too many changes are suggested based on incomplete information, they become confused. The lack of research support, repeated mistakes, low recognition of local experts and inadequate interest in developing appropriate technological options, contribute to the problem.

Therefore, in this study development of an appropriate technology is considered from local perspectives, in addition to being based on sound science.

To assess the suitability of the technologies in relation to their social and domestic context a sociological approach was applied, taking the adjusted model by Spaargaren and Van Vliet (2000) as a starting point. According to this model for an ecological innovation to be appropriate and acceptable to households, the technology should be compatible with the way of life (life style) and the domestic time-space structures of the household concerned, with culturally defined standards of convenience, cleanliness and safety, and should make use of an acceptable mode of provision. In the model this is worked out in four slots, to which I have a fifth, namely that of compatibility with the household's economic resource base. Furthermore, the compatibility and the appropriateness were viewed from a gender perspective, since access to safe water is an important practical gender need of women, directly relating to their domestic or reproductive role.

1.2 Background

Millions of wells are drilled into Ganges alluvial deposits for the public water supply in Bangladesh and West Bengal (Nickson et al., 1998; Chakraborti et al., 2003). The release of arsenic from the arsenic-bearing aquifer sediments may have polluted millions of existing wells in Bangladesh. The latest national survey by the Government of Bangladesh and the British Geological Survey found that about 27 and 46 percent of the tested shallow tube wells exceeded the Bangladesh standard and WHO guideline values, respectively (BGS, 2001). It is estimated that of the 125 million people of Bangladesh between 35 million and 77 million are at risk of drinking contaminated water (BGS, 2001a; Smith et al., 2000).

The range of As-concentrations found in groundwater is large, ranging from less than 0.5 mgL^{-1} to more than 5000 mgL^{-1}. Generally As-concentration in freshwater or surface water are less than groundwater ranges 10 mgL^{-1} to >1 mgL^{-1} (Smedley and Kinniburgh, 2002). Arsenic availability in the groundwater of Bangladesh ranges between 10-1000μgL^{-1} (Nickson et al., 1998). Alluvial Ganges aquifers are polluted with naturally occurring of arsenic, which adversely affects the health of millions people in Bangladesh and India particularly in West Bengal (Ahmed et al., 2006; Mandal and Suzuki, 2002). The source of arsenic in groundwater is still debated. Explanations put forward are: oxidation of arsenic rich pyrite (Das et al., 1994); the overdraft of groundwater for irrigation and drinking purposes (Chowdhury et al., 1999); or the anoxic reductive dissolution of arsenic rich ferric iron hydroxides in the sediments to ferrous iron in the alluvial aquifers of the Ganges delta, thereby releasing the adsorbed arsenic in the groundwater (Nickson et al., 1998; Nickson et al., 2000) and the surrounding environment (Silva et al., 2007). Arsenic release into the groundwater of the Bengal basin is facilitated by the microbial metabolism of organic matter contained in river floodplains and delta deposits. The toxicity and mobility of arsenic varies with its valence state; the chemical form As(III) is generally more toxic to humans and four to ten times more soluble in water than As(V) (EPA, 2002; Petrusevski et al., 2007). There is a distinct regional pattern to the As-contamination in Bangladesh: according to the British Geological Survey the highest contamination is found in the southern and southeastern parts of Bangladesh and the least in the northwestern part, the mountainous areas and north-central Bangladesh (BGS, 2001a).

The arsenic contamination of groundwater is an enormous problem in Bangladesh, since 97 percent of the people depend on groundwater for drinking and cooking. There are several options to abate this problem:

Extraction from deeper aquifers. This can be achieved by using electrical or diesel driven pumps. Because the rate of recharge of this valuable water resource is very low, it is not a realistic option. It is also only possible in areas where there is a clear barrier between the shallow and deep aquifers.
The use of surface water. This is a possibility and entails a return to the former situation. However, currently there are some bottlenecks. The number of surface water ponds suitable for drinking water production has declined during the last years. Surface water has also been polluted by inorganic and organic contaminants from industrial effluents.
Arsenic removal at the community level. This is possible either by using uncontaminated groundwater sources or by using high capacity arsenic removal systems. In many cases this requires a long-term development of a suitable infrastructure in combination with an education program.
Arsenic removal at the household level. This approach fits with the current practice of water self-dependence by means of personal wells. It focuses on solving the problem at household level.

The first three solutions require time and have to be considered as long-term solutions. To mitigate the problem on the short term and to create time for the development of a long-term solution, safe household-level systems have to be developed and implemented at present.

There has been a remarkable national and international effort to develop household-level arsenic removal options. However, till now solutions have fallen short of the technological and social feasibility standards set by the Government of Bangladesh. Research shows that the technical systems that were tried out were not appreciated by the users for technological and social reasons, as well as for reasons of efficiency and convenience (Hoque, et al., 2004a). In the proposed research project the linkages between the technical and socio-cultural dimensions of the feasibility and efficacy of household-level technological solutions to the problem of the arsenic contamination of ground water will be investigated.

Technical options and their feasibility from a technological point of view
There are several technical options to abate the problem of ground water arsenic contamination. The main techniques for the removal of arsenic from groundwater are based on co-precipitation or sorption.

Co-precipitation is a process in which compounds present in the water like iron are forced to precipitate by changing the chemical conditions. Arsenic is bound to solid phase that is formed during the precipitation. After separating the solids from the water the concentration of arsenic in the remaining water fulfils the desired standards. Co-precipitation processes are more successful in removing As(V) than in removing As(III). Arsenic in anaerobic groundwater is largely present as As(III). Therefore, the co-precipitation process needs a pre-treatment to oxidize As(III) to As(V). There are several options for this:

Oxidation with oxygen. The water is vigorously shaken in order to dissolve oxygen from the air into the water. After several hours the oxidation process is completed.
Photo-chemical oxidation. The oxidation with oxygen can be enhanced by applying a photo-catalytic process in which sunlight and iron flocks act as a catalyst. Water is kept for

several hours in PET bottles that are exposed to the sun. During the oxidation iron flocks are formed that acts as both a catalyst and as the precipitate to capture arsenic.
Oxidation with potassium permanganate. Instead of oxygen other oxidation reagents can be used like potassium permanganate. Disadvantages are the higher costs and color formation.

Several precipitates are capable of removing arsenic from water during co-precipitation. The most important ones are:
Iron. Iron is commonly present in groundwater. During oxidation it precipitates as iron hydroxide flocks that efficiently remove As(V) and partially As(III).
Alum. This only removes As(V), so the oxidation should be very effective. Needs the use of chemicals and remaining aluminum in the water is toxic.
Lime. This needs commonly available chemicals. The arsenic removal efficiency is very sensitive to pH changes.

After the co-precipitation process the flocks need to be separated from the water. This can be done by sedimentation (time-consuming), a cloth filter or a sand filter (rapid but sensitive to microbial pollution). Co-precipitation is an effective technique that can be carried out on a household scale. However, because of the several treatment steps needed it is very elaborate and time-consuming.

In a *sorption process* the water passes a packed bed of coarse grained solid particles. Arsenic is bound to the particles and the water leaves the process with a low arsenic concentration. Once the sorption capacity of the solid is saturated (break-through) the solid has to be replaced or regenerated. Due to this break-through phenomenon the clean water should be periodically monitored for the presence of arsenic. Several solids are used as a sorption medium:
Activated alumina. This is a solid that has proven to give very good results. The efficiency, however, is very pH-dependent.

- *Iron coated sand*. This solid is much cheaper than activated alumina, so no regeneration is needed. The saturated solid should be treated as chemical waste.

Ion exchange resins. The use of these resins lead to a very efficient removal of arsenic. However the resins are expensive, while their regeneration is complicated and difficult to be carried out at the household level.
Sorption processes are more convenient to use than co-precipitation processes, but the need for monitoring can be a draw back.

In general, all systems differ from one another with respect to the efficiency of the arsenic removal, the costs, the risks of microbiological contamination, the ease and comfort of the operating principles and procedures, the required expertise, the acceptability, the availability, and the safety aspects in general. All technologies that remove arsenic from groundwater will produce arsenic waste, either as a solid or as a liquid waste sludge. From simple calculations, it is apparent that the yearly household production of arsenic contained in residues is likely to be very small (2-3 g maximum), based on the assumption that the filtrate from the systems will be used for drinking and cooking only.

The shortcomings of a narrow technological approach
However, considering all these technological developments and these, sometimes very sophisticated, systems, it is remarkable that the non-technical aspects, relevant to the introduction and safe application of these household tools, till so far are largely glossed over (Hoque et al., 2004a; Tomizawa, 2001).. These aspects are strongly related to social and cultural factors and economic constraints. Furthermore, geographical factors will to a large extent determine the feasibility and efficiency of technical solutions in a specific area.

The social and cultural factors include household characteristics and features of domestic production, particularly those that require the use of water. These are contingent upon women's practical gender needs, since women play a key role in domestic production (Moser, 1994). Gender roles are culturally defined, as are decision-making patterns and standards of convenience and safety. These all play a role in the adoption of technological innovations by households. Economic constraints have to be placed in a holistic livelihood perspective because they refer to the allocation of scarce household resources (Huq, 2000; Niehof and Price, 2001). For a safe and effective use of household arsenic removal systems it is necessary in the assessment of the applicability of various systems to pay sufficient attention to these aspects. In fact this is a real knowledge gap.

A socio-technological and gendered approach

To assess the appropriateness of the technologies in relation to their social and domestic context the model by Spaargaren and Van Vliet (2000) can be used as a starting point. Spaargaren and Van Vliet argue that for an ecological innovation to be appropriate and acceptable to the households that have to use it, the technology should score well with regard to four slots. The first slot (S1) is the lifestyle slot. It refers to the compatibility with the users' lifestyle, convictions, and social identity with respect to other lifestyle segments than the technology directly appeals to. The second slot (S2) addresses the suitability of the technology with regard to domestic time-space structures. The third slot (S3) is the acceptability of the technology in terms of standards of comfort, cleanliness and convenience. The fourth slot (S4) deals with the modes of provision and production of the technology. This last slot is related directly to the technical and economic features of the technology itself and to the possible constraints these can imply for households.

When seeing the household as a productive unit rather than just as a unit of consumption, the focus comes to lie on the dynamics of domestic production, the resources required for it, and the outputs yielded. These outputs can be defined in terms of a certain level of well-being of the household and its members (Casimir, 2001; Niehof, 2002). A similar conceptualization of household underlies the household-production-of-health model (HHPH) formulated by Berman et al. To address public health issues, they propose an approach aimed at understanding the "process by which inputs to households become outputs in terms of health improvement" (Berman et al, 1994: 206). In their model, the division of labour and the access to and allocation of resources in households largely determine health outcomes. The working definition of household applied in this research follows Rudie, who describes the household as a "co-residential unit, usually family-based in some way, which takes care of resource management and primary needs of its members" (Rudie, 1995: 228). For two reasons, especially the last part of this description is important. First, because safe water is counted as a primary need. Second, because the description points to resources and resource management needed for domestic production, which makes it fit well into a livelihood approach to household economics (Niehof and Price, 2001).

Domestic processes and structures are gender-sensitive. Women's responsibilities in domestic production, especially with regard to child care and family nutrition, have three types of implications for this research. First, women's multiple tasks in the household constrain women's time and labour allocation. Any technology that leads to an additional burden for women is just not appropriate. It is amazing how long it took to develop a gendered perspective on domestic technology in Europe. The authors of a book on the subject speak about "male designers and *imagined* women" (Cockburn and Dilic, 1994). In a recent article on household-level technologies for arsenic removal in Bangladesh (Sutherland et al., 2001) the gender aspect is still lacking, while numerous publications have pointed to the importance of including it in development projects (Kabeer, 1994). Second, the feasibility of a technological innovation is – in the end – judged by its users, in this case primarily women. Women have to be convinced that the innovation is useful for them and that they can handle it. The latter refers to women's actual and perceived control of household resources and decision-making. If women think they do not have this control, which might indeed actually be the case (Tomizawa, 2001), they will not be inclined to adopt a new technology, even though they may be convinced of its merits. Ajzen (1988) was the first to point out the importance of such control beliefs for understanding decision-making processes. Third, access to safe water is immensely important for women in carrying out their domestic tasks. It belongs to women's practical gender needs (Moser, 1994). This is why in a research project on community water services approaches were developed to reach women in particular (Van Wijk-Sijbesma, 2001). Therefore, in this research, the gender aspects are explicitly and specifically addressed.

Combining the perspectives outlined above with the four slots in the model by Spaargaren and Van Vliet yields the following scheme for investigating the compatibility of technological solutions with the problem of arsenic ground water contamination:

Slot S1: Life style compatibility can be formulated as socio-cultural compatibility, implying an assessment of the compatibility of procedures, actions, and information required by the technology with the way of life of the households concerned, particularly with regard to gender roles, *purdah*, class, participation in social organizations, and level of education.

Slot S2a: Domestic time-space structures, implying the need to assess the procedures, time use, and space requirements of the technology in relation to the characteristics of domestic production and women's practical gender needs. This needs to be done by an objective and a subjective (control beliefs) assessment.

Slot S3: Standards of comfort, cleanliness, and convenience, to which safety has to be added. Assessing standards of safety and the contribution of the technologies to enhancing water safety is obviously part of the research. These standards are defined by (have to be elicited from) the people themselves, and might well differ for men and women. Women's definitions will relate to their reproductive role (Slot 2). Included in this slot is the assessment of the amount and form of the contaminated waste produced by the appliance.

Slot S4: Modes of provision, which implies the assessment of the way the technologies are introduced and the providers facilitate their implementation.

To these a fifth slot needs to be added, namely:

Slot S2b: The household resource-base, which implies an assessment of the requirements of the technology in relation to the household's economic resources, especially considering the costs of the operation and maintenance of the technology concerned. This slot may overlap with Slot 2a, because of the economic significance of time allocation.

These five slots provide the basis for a socio-technological and gender compatibility assessment.

1.3 Objectives of the study and research questions

The overall goal of the study is to contribute to finding feasible, socially appropriate and gender-sensitive household-level technological solutions to the problem of arsenic groundwater contamination in rural Bangladesh. First, the study first has evaluated the performance of three existing community-based systems for the extraction of water from deep aquifers, because such systems are part of the long-term solution to the problem. Subsequently, the study has focused on the development and trial of a filter for arsenic removal at the household level. More specifically the objectives of the study are:
To provide the evidence to date of the option of community-level arsenic-free extracted groundwater from deep aquifers.
To provide an overview of the practically available options for household-level technologies aimed at removal of arsenic, describing and evaluating these options from a technical, social, economic, gender, and environmental point of view.
Providing an overview of currently implemented household-level technologies for the removal of arsenic, describing and evaluating their strengths and weaknesses from a practical technical, social, economic, gender, and environmental point of view.
On the basis of (2), and by means of a multi-criteria analysis, to select the most promising options for treatment technologies at the household level.
The further development of the most promising treatment methods for practical and gender-sensitive applications at household level.

The theoretical objective of the study is to contribute to the interdisciplinary field of the development of socially appropriate and gender-sensitive household-level technologies, by identifying the crucial linkages between technological and sociological frameworks and by developing an interdisciplinary tool to assess the appropriateness of such technologies.

The following research questions were addressed in this study:

Question 1: What is the performance of community-based pipeline water supply systems using deep aquifers in terms of their technological and economical sustainability, as well as their social and gender appropriateness*?*

Question 2: What household-level Arsenic removal technologies for drinking water are available, and which of these have currently been implemented in rural households in Bangladesh?

Question 3: What are the weaknesses, limitations, strengths and advantages of the selected technologies in terms of:

a. The socio-economic class and lifestyle of the household, particularly with regards to gender roles;

b. Household time allocation patterns, availability of space, and compatibly with the characteristics of domestic production and women's practical gender needs;

c. Socially accepted standards of convenience, comfort, cleanliness, hygiene and safety;

d. The mode of provision, accessibility of the provider, training requirements, and availability of parts of the device;

e. The cost-effectiveness of their installation, operation and maintenance.

Question 4: What is the most promising arsenic removal option for the rural households in terms of technological performance and social acceptability and suitability from a gender perspective?

1.4 Study area

The study areas of this research comprise three different locations in Bangladesh. In this study, three community based pipeline water supply systems were compared, located in severely arsenic affected areas in Bangladesh. Two of them located in the villages of Baka and Khashial in Kalia sub-district in the district of Narail (Study Area 1), while the third is located in Pakundia village in the Sonargaon sub-district in the district of Narayanganj (Study Area 2).

For the development of the household-level filter for As removal another area was selected. A, field laboratory was set up in the Kalia sub-district in Study Area 1 and another one was set up in Kumarbhog village in the , Louhajang sub-district, located in the district of Munshiganj. It is here (Study Area 3) that the trial and evaluation of the performances of the filters at the household levels was carried out.

Study Area 1
The Baka and Khashial villages are located in the Kalia sub-district in the Narail district. The Narail district is located in the Khulna division, taking up an area of 990.23 sq km, and is bounded by the Magura district on the north, the Khulna district on the south, the Faridpur and Gopalganj districts on the east, and the Jessore district on the west. The annual average temperature is at maximum 37.1°C, and at minimum 11.2 °C; the annual rainfall is 1467 mm. The main rivers are the Madhumati, Nabaganga, Bhairab, Chitra and Kajla. There are many oxbow lakes (*beels*), like the Chachuri beel. The total land area is 973 km^2, the cultivable area is 714 km^2, the fallow land amounts to 102 km^2, the irrigated area to 147 km^2, the river area to 35 km^2, and there is some forest land.

Narail one of the worst affected districts in Bangladesh; in the national survey about 93 percent of tube wells sampled were found to be As contaminated (BGS, 2001b). In 2001, the Environment and Population Research Center (EPRC) started a community-based capacity-building arsenic mitigation water supply project in Kalia. The project is funded by the United Nations International Children's Emergency Fund (UNICEF) and the Bangladesh Department of Public Health Engineering (DPHE). Various As mitigation committees at village, union, and sub-district levels were formed to drive and coordinate the communication campaign as well as the mitigation efforts (Hoque et al., 2004b). A total of 12,094 tube wells were tested for As, and 73.3 percent of them were found to be contaminated with arsenic above the Bangladesh standard of 0.05 mg/l. Since late 2002 several options have been tried out to address these problems, both household-based and community-based. These activities are on-going, but still thousands of households do not have access to safe water.

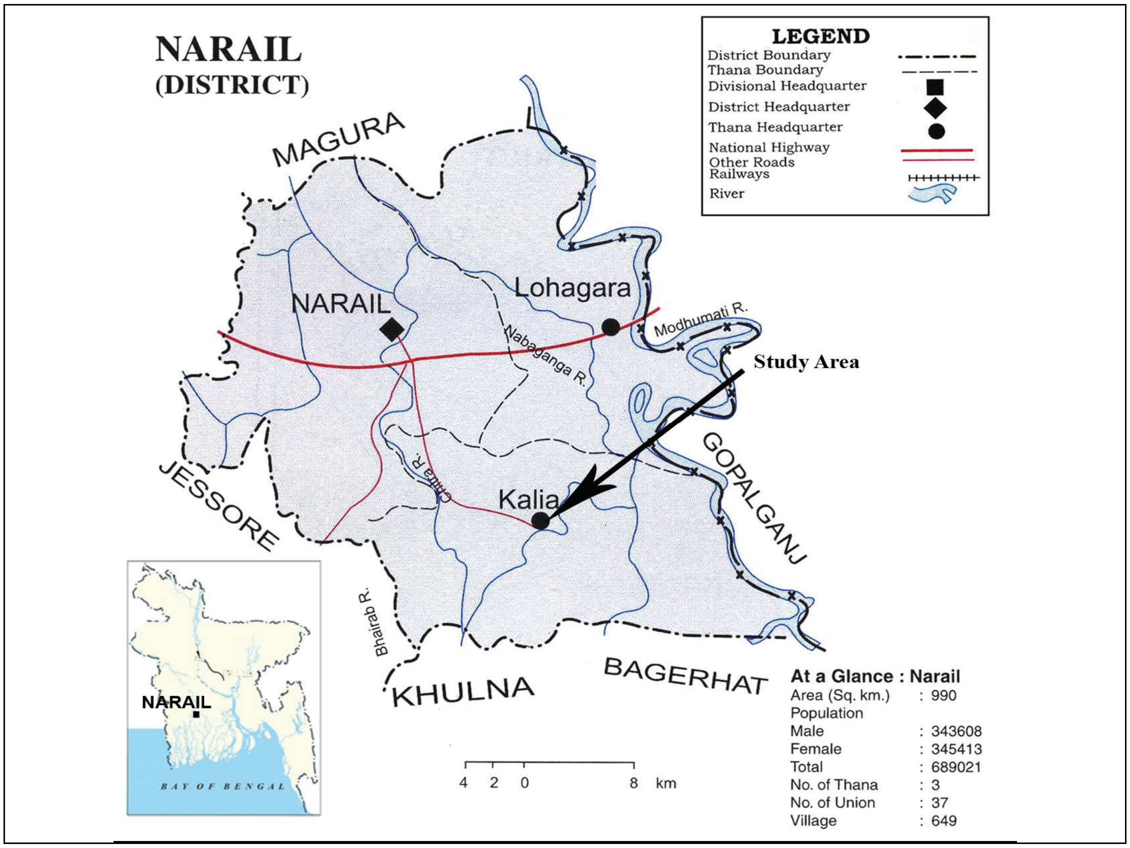


Figure 1.1 Map of Study Area 1 in Narail district.

Study Area 2

Pakundia village is situated in the Sonargaon sub-district of the district of Narayanganj, located in central Bangladesh near the capital Dhaka. The district is bounded by the districts of Gazipur and Narsingdi on the north, Brahmanbaria and Comilla on the east, Munshiganj on the south, and Dhaka on the west. Geologically, the area lies on the edge of the Madhupur Tract. Holocene floodplain deposits form the aquifer. The total area of the district is 759.57 km², of which 48.56 km² is riverine and 0.60 km²is under forest. The annual average temperature is at maximum 36°C, minimum 12.7°C; the annual rainfall is 2376 mm.

t total temperature 2376 mm.

About 80 percent of the shallow tube wells in the Study Area 2 were identified as arsenic-contaminated. The Bangladesh Rural Advancement Centre (BRAC) implemented the Pakundia Multipurpose Rural Water Supply Project in collaboration with the DPHE, with UNICEF providing financial support for the project.

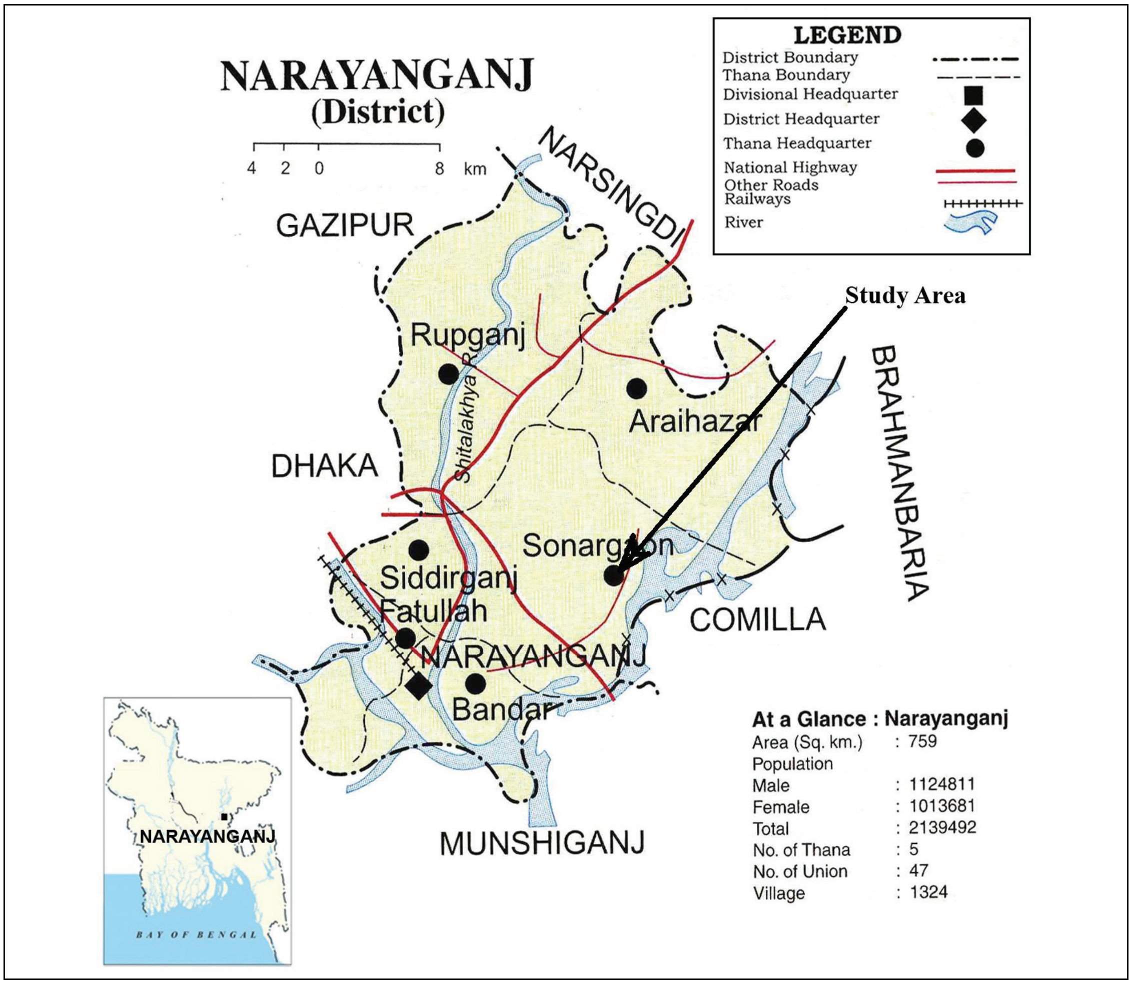


Figure 1.2 Map of Study Area 2 in Narayanganj district.

Study Area 3

Kumarbhog village is located in the Louhajang sub-district in the district of Munshiganj in central Bangladesh. The Munshiganj district is bounded by the districts of Dhaka and Narayanganj on the north, Madaripur and Shariatpur on the south, Comilla and Chandpur on the east, and Dhaka and Faridapur on the west. The area of the district is 954.96 km^2. The main rivers are the Padma, the Meghna and Dhaleswari, and the Ichhamati and Shitalakhya. The river Padma (Ganges) passes at the southern and eastern parts of the district. The annual temperature is at maximum 36°C and at minimum 12.7 °C; the total rainfall is 2376 mm and the humidity is 88. The total land area is 954 km^2, out of which 560 km^2 is arable and 23 km^2 is fallow land. It has no forest area. The irrigated land area is 163 km^2, while 106 km^2 is taken up by the 14 rivers, with a total length of 155 km.

The main source of the drinking water in Study Area 3 is groundwater extracted by shallow tube wells. Munshiganj is another severely affected district in Bangladesh. About 83 percent of the all the tube wells sampled were found to be As-contaminated. In Kumarbhog village 90 percent of the shallow tube wells were found to be As-contaminated (BGS, 2001b).

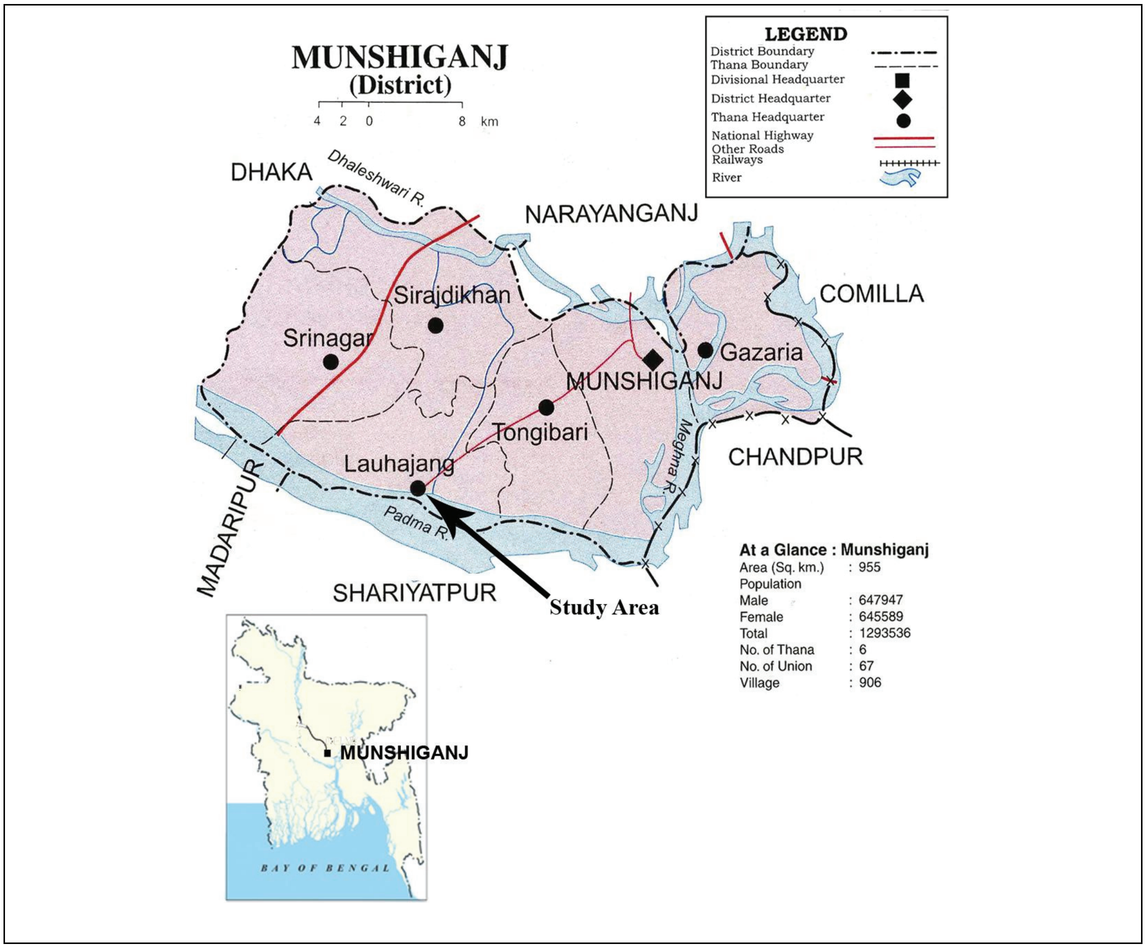


Figure 1.3 Map of Study Area 3 in Munshiganj district.

1.5 Study design and research methods

The study design included a three-fold structure:
A diagnostic phase, which addressed the objectives (1) to (5) and research questions (1), (2) and (3);
A trial phase, in which the conclusions from the diagnostic phase were validated by implementing the most promising option in a field trial, addressing in particular objective (5) and research question (4);
A multi-perspective and participatory evaluation of the trial to provide the final answer to research question (4).

A technical validation on the performance of the most promising systems was carried out by means of laboratory research. In this lab-scale research the following aspects were addressed: efficiency, robustness, operational convenience, safety and feasibility. The social science research methods that were used in the study included: participant observation, systematic observation, time allocation studies, focus group discussions, a household survey, key informant interviews, and case studies. The methods used for data collection and analysis are discussed in detail in Chapter 3.

1.6 Structure of the thesis

The thesis consists of seven chapters apart from the present chapter. Chapter 2 provides an overview on the arsenic problem in Bangladesh. Chapter 3 presents the methodological framework of the study, comprising the methods of the technological validation and social science approaches. Chapter 4 highlights the performance of community-based pipeline water supply systems that extract water from deep aquifers of three community-based pipeline water supply systems in three different villages. Chapter 5 describes available and currently implemented arsenic removal technologies in Bangladesh. The technologies are evaluated in terms of their As-removal efficacy, advantages, disadvantages and social acceptance, based on the available information and laboratory experience. Chapter 6 documents the development of a technology for an arsenic removal filter for household use and describes the characteristics of the prototype. Chapter 7 deals with the evaluation of the performance of the developed filter at the household level in Kumarbhog village in the district of Munshiganj. Chapter 8 provides a synthesis of the research findings and a general discussion of their significance. It concludes with a discussion of the policy implications of the research and presents some recommendations.

2

The Arsenic Problem in Bangladesh, an Overview

2.1 Background and location of Bangladesh

The name Bangladesh means "Country of Bengal" in the Bengali language. Bangladesh was ruled by Hindu Kings until the 13^{th} century, followed by the rule of Muslim kings and the Mogul dynasty for about 250 years. Europeans began to set up trading posts in the area of Bangladesh in the 16th century and the British colonized and ruled Bangladesh (then Bengal) for 200 years, and then Pakistan for 24 years. In 1947, after the partition of Pakistan and India, Bangladesh became part of Pakistan as an eastern wing (East Pakistan) about 1,600 km from West Pakistan across India. Discrimination and political unfairness as well as economic neglect and deprivation led to demonstrations and agitation by the people of East Pakistan against West Pakistan. The People's Republic of Bangladesh became independent on 16 December 1971, with the help India, after a bloody war against the Pakistani rulers and at the cost of three millions lives. Bangladesh is the most densely populated developing country, ranking seventh in the top ten highest populated countries in the world. In 2008, the total population of Bangladesh was 162.2 million, 72 percent of them living in rural areas (UNFPA, 2009). The population density is about 888 persons per km^2. The illiteracy rates of males and females above 15 years are 41 and 52 percent, respectively. The rural population is more or less evenly distributed throughout the 64 administrative districts in the country. About 83 percent are Muslim and 16 percent Hindu. Ninety-eight percent of the population is Bengali; the remaining two percent comprises indigenous tribal groups and non-Bengali (Bihari) Muslims (CIA, 2009).

Bangladesh is located in the Southern region of Asia, bordered by the Bay of Bengal in the south, Myanmar (Burma) 193 km to the far southeast, while the rest of its parts form a 4,053 kilometers long border with India (Figure 2.1). It is situated on a deltaic plain and has three mighty rivers, the Ganges (local name *Padma*), the Brahmaputra (*Jamuna*) and the *Meghna*, complete with numerous tributaries. The total area of the country is about 144,000 square kilometers, extending 820 kilometers north to south and 600 kilometers east to west. There is a 580 kilometer long irregular deltaic coastline in the south, on the Bay of Bengal. The country is mostly flat alluvial plain but is hilly in the southeastern part.

2.2 Geology, morphology and climate

Bangladesh is located at the Bay of Bengal, which is one of the largest sedimentary basins of the world, lying between 20° 23' and 26° 39' north latitude and 80°41' and 92° 41' east longitude. The Bengal Basin is surrounded by an uplifted block of Precambrian Shield (Shillong Plateau) in the north, a Precambrian basement complex (Indian Shield) in the west, and the Indo-Burman range in the east. A more than 16 kilometers thick layer of synorogenic cenozoic sediments is deposited in the basin, derived from the Himalayan and Indo-Burman range. Tertiary sediments mainly include sandstone and shale sequences, whereas the Pleistocene sediments are comprised by clay, overlain by Holocene alluvium (Ahmed et al., 2004). The Ganges, Brahmaputra and Meghna river systems transport a huge amount of sediments and converge at the lower reaches to form the great delta complex, the Ganges-Brahmaputra-Meghna (GBM) Delta. Various geomorphologic units in the Holocene plain lands included piedmont plains, flood plains, delta plains and coastal plains.

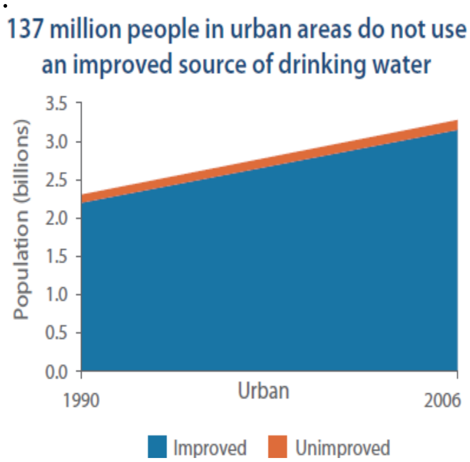
Figure 2.1 Bangladesh map.

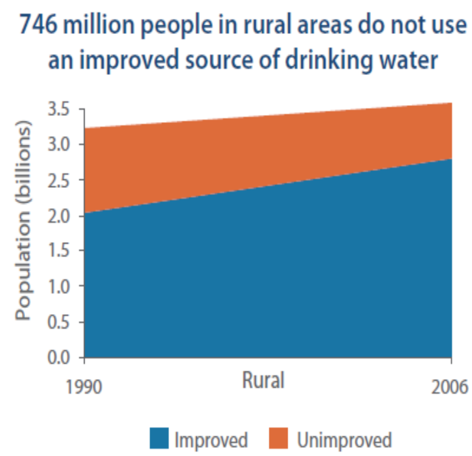
The geomorphologic units in the Holocene landmasses within the Bangladesh part of the GBM delta include fan deltas of the Tista and Brahmaputra; fluvial flood plains of the Ganges, Brahmaputra, Tista and Meghna rivers; the delta plain of the lower GBM system south of the Ganges and Meghna valleys, including the moribund Ganges delta and the Chandina plain; the Pleistocene Terraces (Barind and Madhapur Tracts), the subsiding basins in the eastern Ganges tidal delta, and the Sylhet basin adjacent to the Dauki Fault (Ahmed et al., 2004; BGS, 2001a).

Bangladesh has a tropical monsoon climate; mild winter (October-March), hot, humid summer (March-June), and a warm rainy monsoon (June-October). During the monsoon period most of the parts of the country are normally inundated by water at a level of three to four meters, most of it coming down from India. Generally, tropical cyclones in May-November, with violent thunderstorms (during March-May) and tornados (during March-October), storms and tidal surges aggravate the already vulnerable situation in Bangladesh. Drought is another natural hazard.

2.3 Worldwide arsenic occurrences in groundwater

In 2006, about 13 percent of the world's population did not have to access to clean and safe drinking water (UNICEF-WHO, 2008). In 2006, 87 percent of the world population was using improved water sources, which is on schedule for achieving the drinking water target of the Millennium Development Goals (MDG). The trend of urban and rural drinking water coverage by population (Figures 2.2 and 2.3) indicates that, in 2006, about 137 million people in urban areas and 746 million in rural areas in the world did not have access to improved sources of drinking water.





Source: UNICEF/ WHO report , UNICEF-WHO, 2008.

Figure 2.2 Trends in urban drinking water coverage by population, 1990-2006

Figure 2.3 Trends in rural drinking water coverage by population, 1990-2006

The improved sources of drinking water include groundwater from tube wells, boreholes, and protected dug wells. Arsenic contamination is one of the factors that jeopardize the quality of sources of drinking water. In many countries in the world, arsenic contamination of groundwater is found. More than 100 million people world-wide in countries like Argentina, Bangladesh, Chile, China, Germany, Hungary, India, Japan, Mexico, Mongolia, New Zealand, the Philippines, Taiwan, Vietnam and even the United States, are affected by naturally occurring elevated levels ($> 10 \mu L^{-1}$) of arsenic in groundwater in a variety of alluvial aquifers (Bang et al., 2005; Nickson et al., 2000; Saunders et al., 2005; Smith et al., 2000). Groundwater resources in many countries contain As concentrations of above 10 $\mu g L^{-1}$, the recommended drinking water standard of the WHO, as well as the maximum contamination level of the USEPA for drinking water. Prolonged intake of drinking water containing arsenic concentrations of $50 \mu g\ L^{-1}$ or more, may lead to high mortality from cancer (Hossain et al., 2005; Jessen et al., 2005).

Arsenic in drinking water is now attracting world-wide attention because of considerable concentrations of As in drinking water sources all over the world (Saunders et al., 2005a). Exposure to As-contaminated drinking water causes acute and chronic illness in countries like Bangladesh, China, India, Mongolia and Taiwan (Shih, 2005). In 1968, the first case of a large-scale health problem caused by naturally occurring arsenic was identified and recorded in Taiwan. During the 1970s Chile's case of arsenic contamination became recognized. In late 1970s and 1980s the problems in West Bengal in India, as well as in Ghana, Mexico and several other countries were documented. In West Bengal, a concentration of As in groundwater exceeding the allowable limit 50 μgL^{-1} (WHO, 1993) for human drinking water was recorded in 1978. The first case of arsenic poisoning in a patient was diagnosed in 1983 (Jessen et al., 2005). In the early 1990s, Bangladesh first experienced As contamination in tube wells water, and patients from the western part of Bangladesh started to cross the border to visit hospitals in Kolkata, West Bengal, for treatment. The problem was officially recognized in 1995.

High As concentrations in groundwater are due to anthropogenic activities and natural weathering processes (Bang et al., 2005; Violante et al., 2006). Mining, the use of arsenical pesticides and herbicides, industrial effluents, and the disposal of chemical waste are the main causes of anthropogenic As pollution of groundwater. In addition, in different countries volcanogenic sediments, closed basin lakes, thermal springs, and so on, also cause As contamination of groundwater. In south and southeastern Asia, As contamination is characterized by redox changes, paleogeography, tectonic setting and biological processes, whereby uplift bedrock containing As-rich minerals is weathered, rapidly eroded and deposited in Holocene alluvial basins (Lowers et al., 2007; Saunders et al., 2005b).

Estimations of the size of the populations probably exposed to arsenic in the world, maximum pollution ranges, reasons and environmental condition are presented in Table 2.1.

Table 2.1 Arsenic contaminated countries in the World with affected population, reasons of pollution and environmental condition.

Name of country	Year of Pollution	Population affected by As	Maximum Range of Pollution ($mg\ L^{-1}$)	Reason of Pollution/ Environmental condition
Argentina	1938–1981	200,000	0.1–9.9	Natural: loess and volcanic rocks, thermal springs, high alkalinity occurrence of As in groundwater.
Bangladesh	1993–2000	30,000,000	0.052–4.727	As release from naturally present As-bearing iron(hydro)oxide under reductive condition and over-exploitation of groundwater (pyrite oxidation), alluvial deltaic sediments.
Bolivia	-	50,000	-	Natural: similar to Chile and parts of Argentina.
Brazil	-	*	0.04-0.035	Gold mining.
Chile	1957–1969	400,000	0.1–1.3	Natural and anthropogenic: Volcanogenic sediments, closed basin lakes, thermal spring and mining. River cutting through arsenic bearing formation.
China	1953–1993	1,546	0.04–0.75-	Natural: alluvial sediments anthropogenic; Use of coal as fuel.
Germany	-	*	<0.01-0.15	Natural: mineralized sandstone.
Ghana	-	<100,000	<0.01-0.175	Natural and anthropogenic: gold mining.
Greece		150,000	-	Natural and anthropogenic: thermal springs and mining.
Hungry, Romania	400,000	*	<0.02 - 0.176	Natural: alluvial sediments; organics.
India (West Bengal)	1978–1998	600,000	0.05–3.7	Anthropogenic: Over-exploitation of groundwater (pyrite oxidation); Natural: Alluvial deltaic sediments.
Japan	1945–1995	217	-	Metal and coal mines.
Mexico	1963–1983	100,000 - 600000	0.08–0.6	Natural and anthropogenic: Oxidation of arsenic bearing minerals.
Mongolia (Inner)	1962–1989	1,774	0.1–0.24	Anthropogenic: over-irrigation in an arid region; Natural: alluvial and lake sediments.
New Zealand	1978	Not identified	>0.1 in lakes and surface water	Geogenic and anthropogenic sources.
Philippines	1992–1995	39	-	Geothermal power plant.
Spain	-	>50,000	<0.01-0.1	Natural: alluvial sediments.
Taiwan	1961–1985	100,000 - 200,000	0.01-1.8	Natural: coastal zones, black shells, oxidation of pyrite.
Thailand	1987–1998	18,000*	* 0.05–5.0	Anthropogenic: A tin mine dredged alluvium.
Vietnam	1999-2008	>1000,000	0.05–3.05	Natural occurrence of As in groundwater, alluvial sediments.
United Kingdom	-	-	<0.01-0.08	Mining in southwest England.
USA	1972–1982	3,000,000*	0.045–0.092	Natural and anthropogenic: mining, pesticides, As_2O_3 stockpiles, a thermal spring, alluvial, closed basin lakes, rocks.

* = Population at risk, actual affected is unknown and - = data not available.

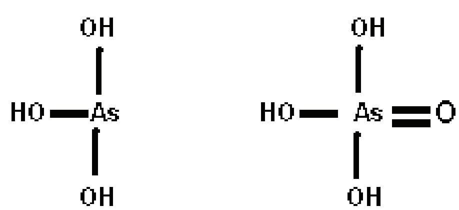
Source: BGS, 1999; SOES-DCH, 2000; Fazal, et al., 2001; Hug et al., 2008; Robinson, 2004; Nordstrom, 2002.

Arsenic occurrence in groundwater

Arsenic is a heavy metalloid with the atomic number 33, atomic weight 74.9216, in Group Va of the periodic table of elements (Fazal et al., 2001). It is one of the ubiquitous natural toxic elements widely occurring in water, rocks and soils (Hussam et al., 2002; Shih, 2005) The average presence of arsenic in the earth's crest is 3 mg kg^{-1}, which is toxic for humans, animals and plants (Violante et al., 2006). Arsenic can not be easily eliminated from the environment; it can only be converted into another form or transformed in insoluble compounds in combination with other elements. Usually, it naturally co-exists with other elements like iron, copper, or zinc, as sulfide or oxide ores. Arsenic and its compounds are mobile in the environment. About 150 species of arsenic-bearing minerals exist in nature as compounds of iron, oxygen, chloride, sulfur, carbon, hydrogen, lead, mercury, gold, etc. The most important natural arsenic ores are Realgar or arsenic sulfide (AsS), Orpiment or arsenic tri-sulfide (As_2S_3) and Arseno-pyrite or ferrous arsenic sulfide (FeAsS) (Bang et al., 2005).

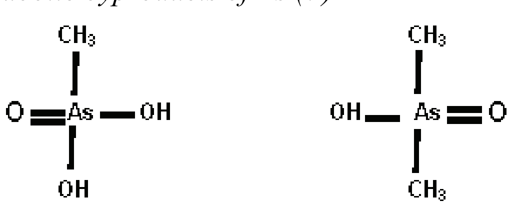
Arsenic is present both in organic and inorganic forms in the biosphere. The predominant forms in water are inorganic compounds with different oxidation states as trivalent arsenite As (III) and pentavalent arsenate As (V). About 50 percent of the total arsenic is found in the form of arsenite, which is more mobile and more toxic than As(V) (Choonga et al., 2007; Fazal et al., 2001; Ramaswami et al., 2001). The predominate forms in organic-As compounds are organic methyl arsenic acid, dimethyl arsenic acid, and arsenocholine arsenobetaine. Arsenic accumulation in the human body due to exposure to As in drinking water and food, takes various forms,.

Toxic natural occurring As species (predominated in groundwater)



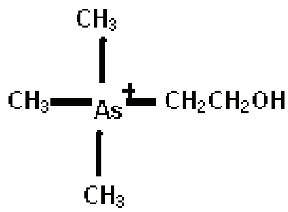
Arsenic (III)   Arsenic (V)

Metabolic byproducts of As (V)

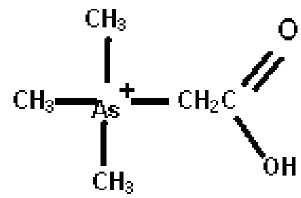


Monomethyl arsenate   Dimethyl arsenic acid

Non-toxic species of As in food supply (predominated organoarsenical in the marine animals)

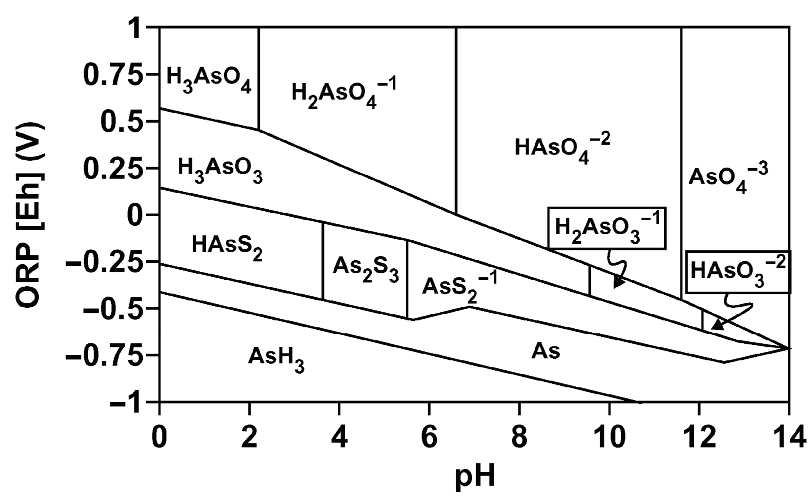


Arsenocholine



Arsenobetaine

Arsenic occurrences, distribution, forms, and mobility in the groundwater depend on the interplay of several geochemical factors, such as reduction-oxidation reactions, pH levels, distribution of other ionic species, aquatic chemistry, and microbial activity (Shih 2005). Inorganic As can exist in four valence states (-3, 0, +3, and +5), depending upon environmental conditions. The distribution of As-species in water is mainly dependent on redox potential or oxidation- reduction potential (Eh) and pH conditions. The Eh–pH diagrams of arsenic (Figure 2.4) indicates that under oxidizing conditions, the predominant species is the pentavalent form, As(+5), which is mainly present with the oxyanionic forms ($H_2AsO^-_4$, $HAsO_4{}^{2-}$) with pKa ~ 2:19 and pKa ~6:94, respectively, and is common in surface water. Under mildly reducing conditions, such as in groundwater, As (+3) is the thermodynamically stable form, which at pH values of most natural waters is present as non-ionic form of arsenious acid (H_3AsO_3, pKa ~ 9:22) (Katsoyiannis and Zouboulis, 2004). Some groundwater has been found to have either only As (III) or only As (V), while in other cases both forms have been found in the same water source (Petrusevski et al., 2007). In moderate reducing conditions, As often combines with S and Fe to form As sulfides or FeAsS, which are found insoluble in water and immobilized in the environment. In strongly reducing or anaerobic environments, elemental As (0) or H_3As [-3] can exist, but found to be unusual in the environment (Jones, 2007).



ORP = oxidation reduction potential;
AsO_4 = arsenate compounds, As (+5)
AsO_3 = arsenite compounds, As (+3)
AsS_2 = arsenic disulfide compounds, As (+3)
As = elemental arsenic, As (0)
AsH_3 = arsine, As (-3)

Figure 2.4 Distribution of As species at various redox potential (Eh) and pH conditions (adapted from Jones, 2007).

Research findings indicate that in groundwater As is found to be mobilized under Fe-reducing conditions in shallow aquifers (depth of <35m), presumably of Holocene age, and remained mobile under SO_4-reducing conditions (Acharyya et al., 1999; Nickson et al., 1998). The redox state of the water contains O_2, NO_3^-, Mn^{2+}, Fe^{2+} concentrations, and SO_4^{2-}/Cl^- ratios. Highly dissolved As (> 50 µg/l) is always accompanied by highly dissolved HCO_3^-. Groundwater rich in As (200–800 µg/l) and phosphate (30–100 µM) but relatively low in dissolved Fe (5–40 µM) probably resulted from re-oxidation of reducing As-and Fe enriched water. Generally, As is not mobilized in Pleistocene aquifers, both shallow (30–60m) and deep (150–270m), because conditions may be lacking of sufficient O_2 demand in the environment (Zheng, 2003). The concentration of phosphorous present in the region is 1.5-3mgL^{-1} (Leupin and Hug, 2005; Sarkar et al., 2008). Arsenic appears to occur adsorbed onto new formed iron hydroxide-coated sand grains and clay minerals and is transported in soluble form and co-precipitated with, or scavenged by, Fe(III) and Mn(IV) in the sediments (Acharyya et al., 2000; Jessen et al., 2005). Reduction dissolve of the Fe(III) oxyhydroxide is driven by the microbial metabolism of sedimentary organic matter, which is present in concentrations as high as six percent of carbon. Release of As is done by reduction of Fe-oxyhydroxide coatings, where most of the iron is retained on the solid form (Horeman et al., 2004). A study confirmed that both Fe and Mn reduction process are dominant mechanisms for release of Arsenic in groundwater (Goswami et al., 2008).

However, although it is clear that arsenic poisoning of groundwater has geological causes, there is debate on the man-made hazards due to the overexploitation of groundwater for irrigation and drinking water since the last two decades, the indiscriminate use of chemical fertilizers and pesticides, and the improper disposal of industrial wastage. In the GMB delta plains the following two mechanisms may play a role in As-contamination:

Oxy-hydroxide reduction process: anoxic conditions permits reduction of iron oxy-hydroxides (FeOOH) and release of sorbed arsenic to solution (Nickson et al., 1998; Nickson et al., 2000).

The reduction of FeOOH is common and intense in the GBM aquifers. The reduction mechanisms, driven by the microbial metabolism of organic matter, may be as follows:

$$\mathbf{8FOOH + CH_3C00^- + 15\ H_2CO_3 \rightarrow 8Fe^{2+} + 17HCO_3^- + 12\ H_2O}$$

This observation has been supported by the available data that high concentrations of dissolved iron ($\geq$ 24.8 mgL^{-1}) as noted by BGS (2000), and $\geq$ 29.2 mgL^{-1} as noted by Nickson et al. (2000), and bicarbonate concentrations of above 200mgL^{-1} indicate a weak correlation between iron and bicarbonate (McArthur et al., 2001).

Pyrite oxidation process: Arsenic is released by oxidation of arsenical pyrite in the alluvial sediment as the aquifer drawdown permits atmospheric oxygen to invade the aquifer (Chowdhury et al., 1999).

Arsenopyrite may be the source of arsenic pollution in Bangladesh. Arsenic derived from the oxidation of arsenic-rich pyrite in the aquifer sediments as atmospheric oxygen invades the aquifer in response to a lowering of the water level by abstraction during over-extraction of groundwater for irrigation and drinking water. Consequently, As contamination occurs in shallow aquifers in Bangladesh and the India Delta Basin (Mandal et al., 1998). The following mechanism may be involved in the decomposition of arsenic rich in pyrite FeS_2:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2Fe^{2+} + 4HSO_4^-$$

$$4Fe_2^{+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

The Fe^{3+} ions formed act as a catalyst for the further decomposition of pyrite. However, Nickson et al. (2000) and McArthur et al. (2001) say that the arsenic released by oxidation of arsenopyrite (FeAsS) when water levels are drawn down and air enters the aquifer, only negligibly contributes to the severe problem of As pollution in groundwater.

McArthur et al. (2001) found that the application of fertilizers only slightly contributes to the releases of arsenic in groundwater. However, Acharrya et al., (1999) claimed that arsenic contamination occurs due to the over-application of fertilizers to the surface soils. This happens due to arsenic anions sorbed to aquifer minerals into solution by competitive exchange of phosphate anions derived from the over-application of fertilizers. Therefore, in the deltaic plain arsenic concentrations above $50 \mu g L^{-1}$ in groundwater are due to microbially reduced FeOOH releases of sorbed arsenic into the groundwater. Neither arsenopyrite oxidation nor competitive anion exchange with fertilizer phosphate seem to contribute to arsenic pollution (McArthur et al., 2001).

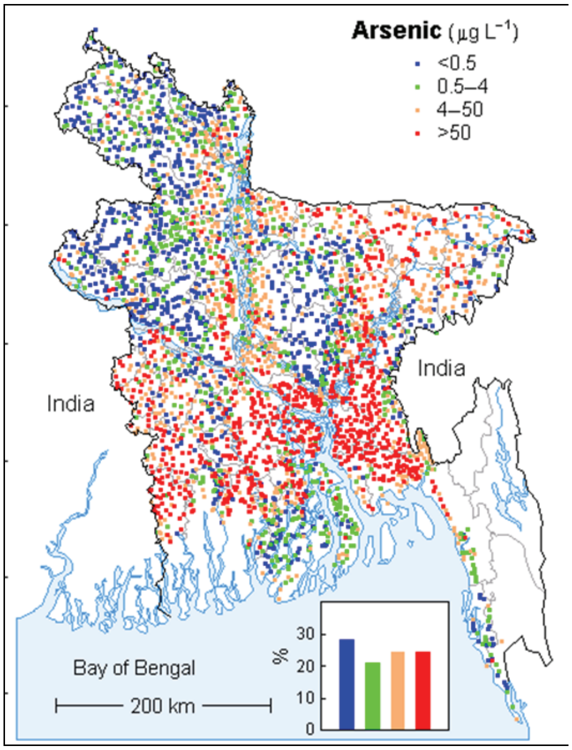
2.4 The arsenic situation in Bangladesh

Access to improved drinking water sources in Bangladesh was 80 percent in 2006, 85 and 80 percent in urban and rural areas, respectively (UNICEF/WHO, 2008), and in 2008 was 75 percent (UNFPA, 2009). In Bangladesh arsenic may occur in groundwater mostly naturally by geological weathering rather than as an anthropogenic source (Ahmed et al., 2006a). Tectonic, geochemical and biological processes lead to natural arsenic contamination of groundwater in Holocene alluvial aquifers (Saunders et al, 2005). Scientists think that arsenic derives from the reductive dissolution of arsenic-rich iron oxyhydroxides, which in turn are derived from weathering of base-metal sulphides (Acharyya et al., 1999; McArthur et al., 2001; Nickson et al., 1998).

Geo-morphologically, Bangladesh can be divided into four regions: the deltaic region including the coast; the flood plain; the tableland; and the hill tracts. The groundwater of dissected terraces of Pleistocene hill tracts and tableland, including early Holocene deposits, are almost free of arsenic contamination. Groundwater in the Ganges flood plain (GFP) contains low arsenic concentration, where high Mn concentrations indicate redox buffering by reduction of Mn(IV)-oxyhydroxides. The presence of low concentrations of DOC, HCO_3^- and NH_4^+ and high NO_3^- and SO_4^{2-} in the groundwater reflects an elevated redox characteristic in the GFP aquifers. Whereas, flood plain low-lying areas in the Bengal Basin and the Ganges Delta Plain including the coast belt (middle Holocene), contain high concentrations of arsenic with high Fe and low Mn content (Chakraborti et al., 1999; Jessen et al., 2005). Moderate to high As concentrations and low Mn concentration are identified in the Meghna flood plain (Hasan et al., 2007). In the groundwater of Bangladesh, the predominant arsenic forms are inorganic arsenate As (V) and arsenite As (III), and the ratio of As (III) to As (V) varies significantly ranging from less than 0.1 to above 0.9 (Ahmed, 2001). The sensitivity of As to mobilization at the pH values typically found in the groundwater (pH 6.5–8.5) occurs in both oxidizing and reducing conditions.

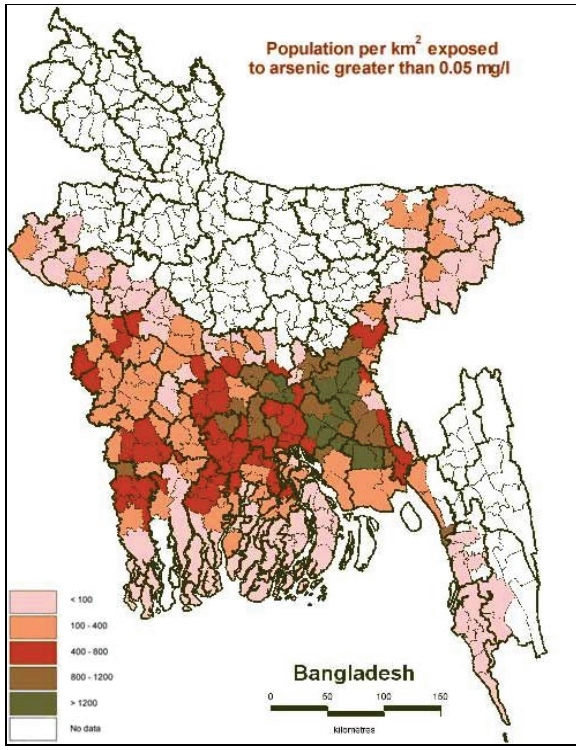
In addition, most of the Bangladesh groundwater contains high concentrations of iron and manganese. Of about 65 percent of the shallow tube wells the water contains iron concentration higher than 2 mgL^{-1}, whereas in some areas the concentrations of dissolved iron are higher than 10 mgL^{-1}. Much groundwater also contains high concentrations of phosphorous and silica, whereas nitrate and sulfate concentrations are normally low.

Figures 2.5 and 2.6 picture the distribution of As contamination in Bangladesh. In some parts of the country more than 1200 population per km^2 are exposed to arsenic levels higher than 50μgL^{-1}. An estimation shows that out of 140 million people in Bangladesh, between 77 and 95 million people are drinking groundwater from contaminated tube wells (Hussam and Munir, 2007). The findings of the British Geological Survey (BGS, 1999) indicate that groundwater in the 61 districts out of 64 districts in the country is As-contaminated.



Source: {DPHE/BGS/DFID, 2000.

Figure 2.5 As- conc. in Groundwater in Bangladesh.



Source: {DPHE/BGS/DFID, 2000.

Figure 2.6 Population exposure to As >0.05mgL^{-1} As conc.

The groundwater table in the most parts of country is high: about less than seven meters below ground level. The shallow aquifer is the most extensively used source for drinking water in the rural areas. The estimated number of tube wells in Bangladesh is around 6 to11 millions. The majority of these are shallow tube wells, which extract water from shallow alluvial aquifers to depths typically of 10 to 60 meters. The deep tube wells extract groundwater from depths of 150 meters or more. Chowdhury et al. (1999) found that shallow aquifer tops at depths of between 6.4 and 9.7 meters were less contaminated than deeper down. Previous studies state that As-concentration increases with depth in wells found in the districts of Manikganj, Faridpur and Gopalgonj (Nickson et al., 1998), but these findings may be site-specific, whereas other studies indicate that arsenic concentration increases with depth for depths of less than 22 meters and decreases at depths of over 22 meters (Acharyya et al., 1999). The highest concentration of dissolved As has been reported at depths between 28 and 40 meters at some locations in the Ganges plain (McArthur et al., 2001). Dug wells are found mostly arsenic-free at depths of less than five meters. In the southern part of the country, the coastal region and in the Sylhet Basin in the northeast, most of the deep tube wells have been installed to avoid the high salinity of the shallower aquifer (Ahsan et al., 2008).

Arsenic-contaminated drinking water causes multisystem diseases to humans by chronic and acute exposure (Mandal and Suzuki, 2002). Prolonged exposure to arsenic is a well-documented human carcinogen, which affects numerous organs (Ratnaike, 2003; Saha et al.,1999). It potentially threatens millions of people in Bangladesh (Chen and Ahsan, 2004). It takes more than ten years for clear symptoms of arsenic poisoning to appear, for which there is no effective treatment. Visible signs are lesions on the skin and spotting of hand palms and feet. Studies have indicated that the majority of the identified clinical manifestations of arsenicosis are in women (Ahmad et al., 1997). The duration of clinical manifestations of arsenicosis varies from one to 12 years and for the majority of patients its duration is four to six years (Ahmad et al., 1999; Alam et al., 2002). Arsenicosis is also an economic burden to the villagers of Bangladesh. It was shown that the rural poorest suffer the most; they are likely to lose a significant amount of productive time and financial resources (WHO, 2000).

In Bangladesh, arsenic is not only toxic to human health but arsenic poisoning also causes negative social impacts. Arsenicosis patients are suffering from many social problems, such as stigma, because many people believe arsenic poisoning is contagious or a curse. The study by Hassan et al. (2005) revealed that only one out of four parents would allow their son or daughter to marry an arsenicosis patient (it was one in 20 in 2001 survey data). Children are not allowed to play with children suffering from the disease. When people die from arsenicosis, some local clerics will refuse to give them a Muslim burial (Hassan et al., 2005). There is a gender dimension to the problem of arsenicosis as well. When women get skin lesions, in the male-dominated society of Bangladesh they risk being divorced. It was reported that one women patient attempted to commit suicide by taking poison when she failed to be cured and a married woman suffering from arsenicosis was sent back to her parent’s house. A case of premature delivery of a woman suffering from arsenicosis in a rural area with highly As-contaminated drinking water was reported as well (Chakraborti, et al., 2003; Das et al., 1994). While women suffer more than men from the clinical manifestations of arsenicosis (cf. Ahmad et al., 1997), unfortunately women are also less likely to receive early diagnosis and treatment.

2.5 Initiatives by the government of Bangladesh

According to the mid-term progress report on the meeting the Millennium Development Goals of Bangladesh, the proportion of the rural population without safe drinking water increased from 6.9 percent in 1991 to 21.4 percent in 2006, due to the As contamination of groundwater, whereas the proportion of the urban population without access to safe drinking water had declined to 0.1 percent (MDG, 2007). Measures to contain As contamination have been introduced by the government since 1993, when As in groundwater in Bangladesh was first detected by the Department of Public Health and Engineering (DPHE). Subsequently, the issue was highlighted as a major natural calamity or disaster during 1995.

Over the past three decades millions of tube wells have been installed by the United Nations Children's Fund (UNICEF) in collaboration the DPHE to provide safe, bacterial-free water for cooking and drinking for the population in the GBM basin (Horeman et al., 2004; Smith et al., 2000). Though in Bangladesh tube wells have been installed since 1940, most people used to drink surface water, which was severely contaminated with micro-organisms. To prevent significant morbidity, mortality and suffering of infants and children from acute gastrointestinal diseases, after 1972 huge tube wells were installed. After discovering the As contamination of the drinking water in the mid-nineties, the government took initiatives to combat the arsenic poisoning of drinking water. During the past decade, a number of governmental technical and advisory committees have been formed. These include the Governmental Arsenic Co-ordination Committee, headed by the Minister of Health and Family Welfare (MHFW), and several technical committees in collaboration with interested external financial and consulting support agencies. So far, many initiatives to confront the As crisis have been taken by the governments of Bangladesh and West Bengal in India, the World Bank, UNICEF, WHO and other international aid agencies along with national non-governmental organizations (NGOs).

The efforts have been focused on water quality testing and control with a view to supplying arsenic-free drinking water, thereby reducing the risk of further arsenic-related disease. This was done in the framework of a two-phased program, founded in 1997. Emphasis in the first phase was on the identification of contaminated tube wells by using field testing kits. The provision of safe drinking water to the affected people is part of the second phase. One of the positive outcomes of this collaboration has been the testing of new types of treatment technologies. Remarkable research is being done on the arsenic removal technologies and many studies are carried out to evaluate and assess the different technologies for their efficacy of arsenic removal at household as well as community level. Several technologies are currently being promoted for application in Bangladesh by governmental organizations and NGOs. These are all new and in a developmental stage. The effectiveness, viability and sustainability of the technologies under field conditions have yet to be ascertained, before they can be adopted and scaled up. Furthermore, so far only a few proven sustainable non-removal alternatives are available to provide safe drinking-water to the arsenic-affected areas. These include obtaining low-arsenic concentration ($<50 \mu gL^{-1}$) groundwater by identifying safe shallow groundwater or deeper aquifers (>200 m), dug wells, rain water harvesting, pond-sand-filtration (PSF) and a piped water supply from safe or treated sources.

With the assistance of UNICEF, the DPHE has installed more than 40 community-based As-removal plants in different parts of Bangladesh. In 1999, the British Geological Survey conducted a nation-wide survey on the As contamination in groundwater, in collaboration with the DPHE and funded by DFID-UK. During 2001, the government of Bangladesh conducted an assessment of the currently available As-removal technologies at household and community levels through the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), which was funded by DFID (BAMWSP/DFID/WaterAid, 2001a; BAMWSP/DFID/ WaterAid, 2001b). The performance of As-removal technologies is evaluated by the Bangladesh Council of Scientific and Industrial Research in collaboration with donors (BCSIR, 2003). So far, the government of Bangladesh has approved the promotion of four As-removal options and rejected some others (BCSIR, 2008). Chapter 5 provides details of the technologies concerned. However, most of the arsenic removal technologies have not yet been proven successful in Bangladesh, although many researchers are working on the technologies to make them user friendly, gender sensitive, low cost, simple and robust, as well easily applicable in the context of rural society.

3

Materials and Methodology

3.1 Study Design

In the framework of this research, I carried out an analysis of the achievements and non-achievements, strengths and weaknesses of the existing available arsenic removal technologies. The aim was to identify the bottlenecks and prioritize ways for their abatement in the application of treatment technologies at household level. For this analysis I used a socio-technological and gendered approach. Furthermore, I explored the feasibility and efficacy of alternative technological solutions, using the same approach. For this purpose, a three-phase study design was considered. The time schedule was as follows:

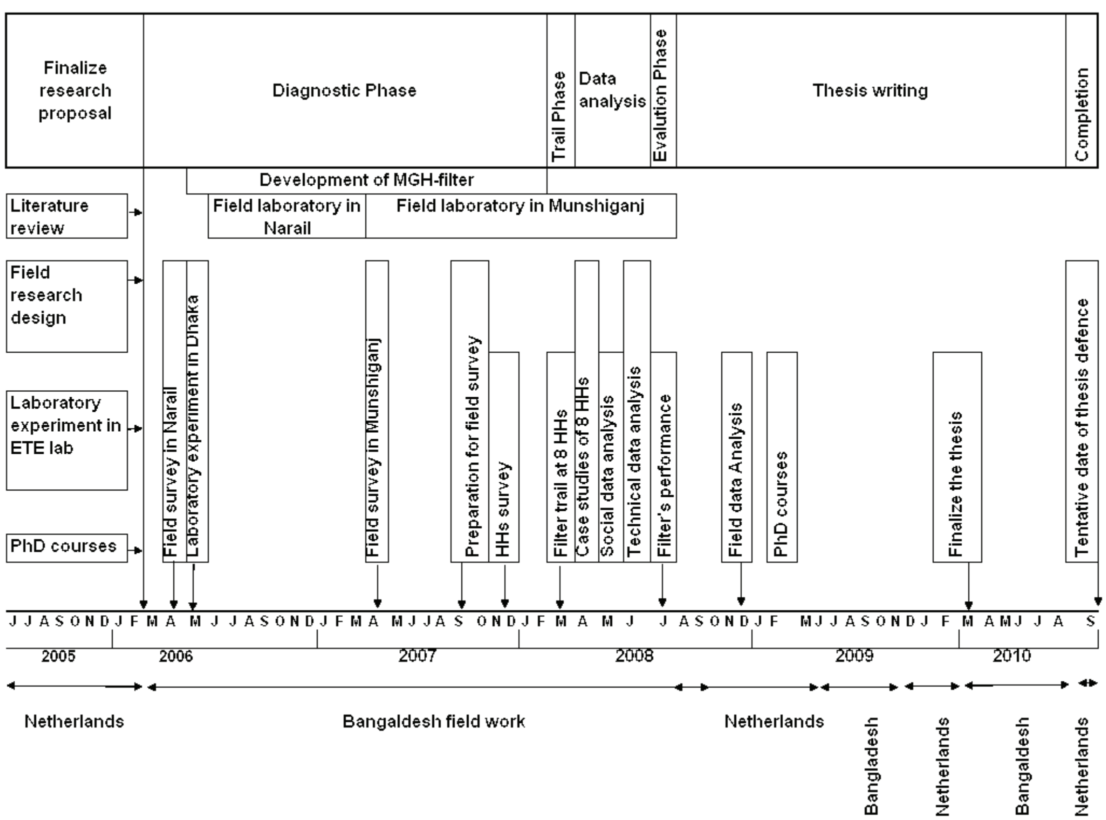


Figure 3.1 Time schedule of the study.

Diagnostic phase: This phase addressed the research questions 1 and 2 (see Chapter 1) to provide a comparison of three community-based piped water supply options and an overview of the available arsenic removal technologies for drinking water at the household level in As-affected areas. It also explored the currently implemented household-level technologies for removal of arsenic in Bangladesh. The technologies are evaluated in terms of their performance on the As-removal efficacy, their strong and weak points, including social acceptance, based on a literature review. I applied a multiple criteria analysis (MCA) approach to select among the identified available technologies those with a potential for further development for household-level use. The MCA was carried out by applying interdisciplinary criteria regarding both technical and social aspects, to address the research question 3 (see Chapter 1). The further development of a selected arsenic removal technology was carried out through conducting experiments in the laboratory and in the field in Bangladesh (research question 4, Chapter 1).

An assessment and comparison of three community-based pipeline drinking water supply systems in Bangladesh was carried out as part of the diagnostic phase. Since the deep aquifers are identified in most parts of Bangladesh as As-free water, governmental and non-governmental organizations, with assistance from donor agencies, have been constructing deep tube wells and community-based pipeline water supply systems in rural areas to provide safe water. The study was conducted based on a literature review, observation of the three systems, interviewing and focus group discussions with beneficiaries and relevant representatives of the implementing agencies. The three community-based pipeline water supply systems considered for this study were:

- the Baka community-based pipeline water system with overhead tank;
- the Khasia community-based pipeline water system without overhead tank;
- and the Pakundia community-based pipeline water system with overhead tank.

Community-based pipeline drinking water supply systems in Bangladesh are a solution for the long term, but they are expensive. A short-term solution for rural households in Bangladesh is a suitable, simple and low cost As-removal technology at household level. In this study, the emphasis is on the household-level As-removal technology.

Trial phase: This phase included the conclusions from the diagnostic phase, which were validated by implementing the developed As-removal filter in a field trial. In this phase, the research work comprised assessing the technical performance of the developed filter through laboratory analysis of the feed water and treated water, as well as assessing its suitability and appropriateness from a social and gender perspective. This was done by trying out the filter in eight selected households. Additionally, the filter operation was systematically observed, interviews with the users were conducted, while during my stay in the village I engaged in informal discussions with users and other villagers.

Evaluation Phase: This phase included the multi-perspective and participatory evaluation of the trials of the filter in the selected households. The evaluation was done after three months of implementation of the filter. It comprised technical validation (the As-removal efficacy and bacterial contamination status) and social and gender validation. The purpose of the trial and its evaluation was to find a gender-sensitive, socially acceptable, effective and safe arsenic removal technology for application at the household level in rural areas.

3.2 Criteria for the selection of technologies for further development

The selection of the technologies for groundwater treatment was carried out by assessing them in terms multiple criteria, including arsenic removal efficacy, use of chemicals, biological contamination, cost and social acceptability for the users. In the assessment two types of criteria were considered: technical and social criteria.

3.2.1 Technical criteria

A technology is feasible if it is efficient, effective, reliable and technically manageable. The feasibility criterion was further elaborated to include a variety of indicators and variables needed for the feasibility assessment. The following indicators were considered:

- efficacy;
- chemical use;
- pre-treatment needs;
- chemical problems created by the technology;
- bacteriological problems associated with the process;
- the adequate production of As-free drinking water;
- reliability;
- the management requirements of the system;
- installation and equipment cost;
- the lifetime of the installation
- the local availability of required chemicals and filter materials;
- the generation of As-toxic waste/sludge.

These indicators were defined as follows:

Efficacy: Refers to the ability of the technology to comply with the permissible limit according to the Bangladesh standard for drinking water of As-contamination, which is below < 50µgL-^{1}.

Chemical use: Indicates the extent to which additional chemicals need to be used in the treatment process.

Pre-treatment needs: Indicates possible chemicals needed before treating the contaminated water for the removal of As, such as the addition of oxidant agents for the oxidation of As(III) into As(V), or treating the filter-bed materials (sand) with chemicals.

Chemical problems created by the technology: Indicates whether the addition of chemicals during treatment changes the water quality parameters, or produces residual in the treated water that exceed the drinking water quality standards.

Bacteriological problems associated with the process: Refers to whether the technology produces or enhances the bacteriological contamination of the treated water, such as 0 cfu/100 mL^{-1} of the Feacal coliform (FC) and 0 cfu/100 mL^{-1} of Total coliform (TC).

Adequate production of As-free water: Refers to whether the filter has a high flow rate and produces adequate volumes of safe water, sufficient for a household.

The adequate production of As-free water: Refers to whether the filter has a high flow rate and produces adequate volumes of safe water, sufficient for a household.

Reliability: Refers to whether the technology is vulnerable to risk associated with errors in operation and handling the chemicals, such as dosing the chemicals, spillage of chemicals, etc., and to the time needed to restart the system after a breakthrough or maintenance operation.

Management requirements of the system: Refers to whether the operation and maintenance of the system is complicated, for instance because of needing additional chemicals, pre-treatment, re-generation of filter media and resin, the monitoring of the breakthrough point of filter, as well as frequent washing the filter-bed material to prevent clogging, etc. Furthermore, it refers to its dependence on infrastructural services, such as electricity and electrical equipment.

Installation and equipment cost: The costs associated with the technology, e.g. whether it requires imported chemicals and equipment. This is not a purely technical criterion.

The lifetime of the installation: The sustainability of the appliance in terms of its lifetime.

The local availability of chemicals and filter materials: Refers to whether the required chemicals, spare parts and filter materials are available in rural areas.

The generation of As-toxic waste/sludge: Refers to whether the technology produces a large amount and toxic As-rich waste and creates problems of disposal.

3.2.2 Social criteria

Technologies may be simple or complex, cheap or expensive, employment-generating or not, locally-based or imported, and appliances may be big or small. Because of the gendered division of labour in every society, technologies are never gender-neutral and have different impacts on men and women. Technologies affect the ways the people do things, and as systems of knowledge they affect the ways in which people think about how to use them. They influence activities through the inputs of labour and time they require, which have to be assessed using a gender perspective. Obviously, impacts on women relative to men and the gendered division of labour are issues that relate to cultural values and social norms. For example, in Bangladesh women have different patterns of mobility from men because of certain cultural and religious traditions and the associated societal norms.

All technologies have a series of definable characteristics that influence their transfer from one context to another. Therefore, for technologies to be appropriate they have to fit into the local context and have to be adaptable to the physical and social characteristics of the recipient environment. Though people often think that ‘an appropriate technology’ is always cheap and simple, this is not necessarily true. Its appropriateness implies a link to several external factors and a judgment about its suitability in relation to factors such as a gender, resources, values, scale, time allocation, as well as comfort, convenience and safety. Like in many other countries in the world, also in Bangladesh women are the water carriers and users, as part of their reproductive role. Hence, gender is a crucial issue in the development of filters for the removal of arsenic from groundwater. In this research, apart from the technical criteria also social criteria, including those relating to gender, were taken into account in assessing the potential of arsenic removal technologies.

The framework for the social assessment in this study was developed based on an adjusted version of the model by Spaargaren and Van Vliet (2000) for research on ecological modernization at household level. The following slots are part of the adjusted model:

Slot S1: Refers to life style compatibility or socio-cultural compatibility, implying assessing the compatibility of procedures, actions, and information required by the technology with the way of life of the households concerned, particularly with regard to gender roles, *purdah*, class, participation in social organizations, and level of education.

Slot S2a: This slot is about domestic time-space structures, implying the need to assess procedures, time and space requirements of the technology in relation to the characteristics of domestic production and women's practical gender needs.
Slot S2b: Refers to the household resource-base, implying the assessment of the requirements of the technology in relation to the household's economic resources, especially considering the costs of operation and maintenance. It overlaps with Slot 2a, because of the economic significance of time allocation.

Slot S3: This slot is about standards of comfort, cleanliness, and convenience, to which safety has to be added. Assessing safety standards and the contribution of the technologies to enhancing water safety is obviously part of the research. These standards are defined by (have to be elicited from) the people themselves, and are especially important for women because of their reproductive role and involvement in domestic work. Included in this slot is the assessment of the amount and form of contaminated waste produced by the appliance.

Slot S4: Refers to the modes of provision, implying the assessment of the way in which the technologies are introduced and their implementation is facilitated by the providers.

Based on the slots the following social indicators were developed:

- the acceptability by users;
- operation and maintenance time;
- the size of the devise;
- the installation cost;
- the operation and maintenance cost;
- the simplicity of operation and maintenance;
- the disposal of As waste;
- the required training and discipline.

I defined these indicators as follows:
The acceptability by users: This refers to whether the technology compatible with rural lifestyles in Bangladesh and the values and norms pertaining to rural women's behavior, notably with regard to their mobility (*purdah*). The indicator relates to Slot 1.

Operation and maintenance time: Refers to the suitability of the technology in terms of the time women have to spend on its operation and maintenance as part of their household time allocation (Slot 2a).

The size of the device: Refers to whether the appliance is suitable in terms of the available space. It should be small and well-structured, so that it can be easily placed and handled by women (Slot 2a).

The installation cost: Indicates the financial feasibility of the installation of the materials needed for the appliance and whether poorer households can afford its installation (Slot 2b).

Operation and maintenance cost: Indicates whether the operation and maintenance of the technology is feasible in terms of affordability for poorer households (Slot 2b), especially whether spare parts and required materials are affordable and locally available.

The simplicity of operation and maintenance: Refers to whether rural women users can operate and maintain the system easily and conveniently (Slot 3).

The disposal of As waste: Refers to whether the technology is safe in terms of a safe, clean and convenient disposal of the system's As-rich waste. The less the amount of waste and the less toxic it is, the better for women's safe, clean and convenient handling of it (Slot 3).

The required training and discipline: Indicates whether the technology is simple in terms of the training and discipline it requires for proper use. Simplicity is considered an essential feature of the operation and maintenance of any appropriate technology. The technology should not rely on extensive training and prolonged motivation by the providers (Slot 4).

3.3 Overall conceptual model of the study

Figure 3.2 pictures the overall conceptual model of the study that was used to guide the research and answer the research questions (see Chapter 1).

The figure shows how different environmental factors, including socio-cultural ones, are related to groundwater contamination and the problem of safe drinking water. A system's approach underlies the model depicted in the figure, which is adapted from the application of a system's approach to household food security (Niehof, 1998). In the case of this study, not household food security but safe drinking water is the system's output. At the center of the model is the household, because it is either a matter of household access to community-based water supply or the household is the place for positioning the arsenic removal technology. In this study, the emphasis is on the latter, but the first option was evaluated as well. In the model depicted by the figure a distinction is made between inputs, throughputs and outputs. Inputs are arsenic removal technologies and their technical and social performance (see criteria discussed above), household resources and assets, and women's time and labour. The throughputs include resource management strategies, operation and maintenance procedures, and decision-making. The output is safe, As-free, good quality drinking water.

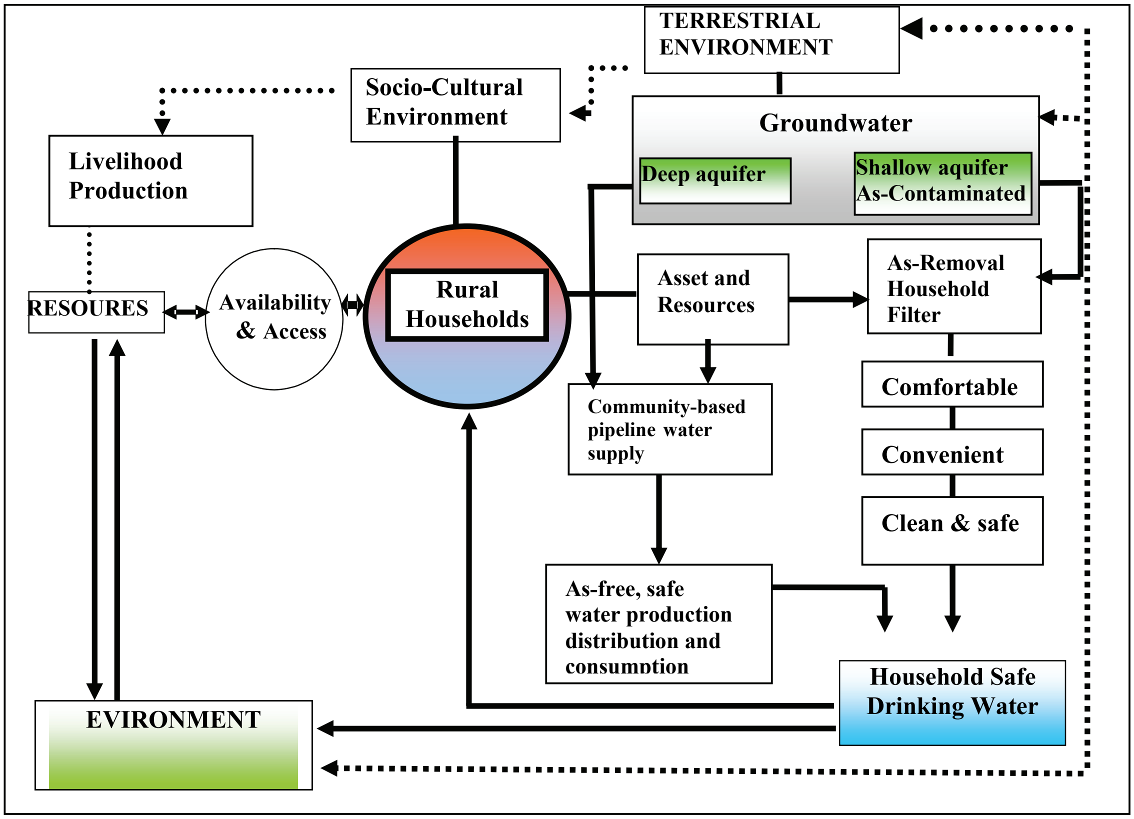


Figure 3.2 Conceptual model of As- free safe drinking water as an outcome of domestic production of rural households (adapted from Niehof, 1998).

The overall conceptual framework and the research questions of this research include a number of concepts that need further clarification. I will define and discuss the main concepts relating to the social aspects of the research below.

Socio-economic class: "An economic class is comprised of persons who have a similar level and source of income and type of occupation, and a similar share of societal wealth and economic and occupational power and authority" (Theodorson and Theodorson, 1969: 49). In this research, the following variables and indicators relating to the concept were considered: household income, land ownership, housing type, and occupation of household head. Based on the household income, I made the following classification of households into five categories of socio-economic class: very poor, poor, rural lower middle class, rural upper middle class and rich.

Households: "A co-residential unit, usually family based in some way, which takes care of resources management and primary needs of its members"(Rudie, 1995: 228). In Bangladesh a household in Bangladesh is "usually a part of a house […] or homestead. A homestead can consist of four to five huts […] in a single courtyard" (Ali, 2005: 43). In Bangladesh, in the past people lived together as one extended family on a homestead, which was the household. Now, the breakdown of the extended family and its splitting into nuclear families over time has led households to be a part of homesteads. The inhabitants of a homestead are now members of several households, living in separate huts or houses, though still based on the patrilineal family system (Chen, 1990). Homesteads now comprise a mix of inhabitants including relatives, affines and non-related . In this research the following variables related to the concept of household were investigated: household composition, size and headship, and the tangible and intangible resources and assets of households. With regard to household composition, age and sex of household members as well as their relationship to the household head were documented.

Life style: "Lifestyle refers to the specific form of integration brought about by social actors. In their lifestyles, people realize a- partial- integration of the variety of social practices that span their daily lives. Actors 'bind' their distinct (set of) social practices into a reasonably coherent 'unity' […] With each lifestyle there is a corresponding life *story,* in the sense that by creating a specific unity of practices the actor expresses who he or she or wants to be. The lifestyle serves to express a person's individual identity, a narrative of the self" (Spaargaren and Vliet, 2000: 55). Giddens (1991: 81) refers to lifestyle as "a more or less integrated set of practices which an individual embraces, not only because such practices fulfill utilitarian needs, but because they give material form to a particular narrative of self-identity". Additionally, "a lifestyle sector concerns a time space 'slice' of an individual's overall activities, within which a reasonably consistent and ordered set of practices is adopted and enacted" (Giddens, 1991: 83).

In this research, the focus was on women's role in water provision and use as a "time space slice" of their overall activities, and the way in which women carry out this role as relating to their identity as rural Muslim women in Bangladesh. Hence, key variables relating to the concept of lifestyle in this research are religion, marital status, social and religiously underpinned norms about women's mobility (*purdah*), and responsibilities that are part of women's reproductive role (see also discussion on gender below).

Gender: "Social expectations about behavior regarded as appropriate for the members of each sex [and] socially formed traits of masculinity and femininity" (Giddens, 1997: 582). In this research, the emphasis was on the gender division of labour, especially domestic labour. Women's activities as part of their reproductive role include providing drink and food for the family, cleaning and washing, and, therefore women as part of their gender role are the main actors in water provision and handling. Hence, women's tasks and duties in the domestic context were investigated, also in comparison to other family members.

Practical and strategic gender needs: For women to be able to carry out their reproductive role, their 'practical gender needs' have to be met. "Practical gender needs are a response to immediate perceived necessity, identified within a specific context. They are practical in nature and often are concerned with inadequacies in living condition such as water provision, health care, and employment" (Moser, 1993: 40). Practical gender needs have to be distinguished from strategic gender needs. Moser (1993: 39) defined these as follows: "Strategic gender needs are the needs women identify because of their subordinate position to men in their society. Strategic gender needs vary according to particular contexts. They relate to gender divisions of labour, power and control and may include such as issues as legal rights […]. Meeting strategic gender needs helps women to achieve greater equality. It also changes existing roles and therefore challenges women's subordinate position".

In this research women's practical gender needs were identified for their ability to carry out their reproductive role with regard to water provision and use, more specifically with regard to time allocation for water provision and distance and access to safe water sources. With respect to strategic gender needs, more specifically this research looked at women's role in decision making vis-à-vis the husband at household level and, at community level, at women's participation and voice in the committees of water users.

Domestic production: Activities aimed at providing for the basic needs of household members. In this research this included, apart from reproductive activities, participation in community activities, water collection and use, and improving drinking water quality.

***Household space structures*:** In this research: available space for a safe setting of the filter in the house, in relation the size and the type of house.

***Time allocation pattern*:** In this research: domestic tasks performed by the household members and the time allocated to these tasks, specifically time allocated to water collection and operation of the filter.

Resource allocation: "Resource allocation much depends on who in the household determines the way in which resources are allocated and who has access to which resources. Patterns of resources allocation within households may change according to the changes in the wider society and with changing involvements by its members in external networks" (Pennartz and Niehof 1999: 69). In this research the main variables relating to resource allocation were management of the household budget and household expenditures.

Socially acceptability: In this research, this was defined in terms of comfort, cleanliness and convenience by the users. These have the important advantage that they link strongly with the way people organize their daily lives. Comfort is "bound up with routine and habit and with the use as much as the acquisition of tools, appliances, and household infrastructures" (Shove, 2003: 395). "Convenience relates to the use and meaning of time and the value placed on different activities. Labour saving devices or commodities are typically intended to reduce the time and effort an individual spends on a specific (some-times unpleasant) task" (Shove, 2003: 161). Cleanliness relates to treated water and the appliance, which should be clean and free from arsenic, chemicals and bacteria. It also refers to As-rich sludge and water, and the cleanliness of the space where the filter is placed. Cleanliness is linked to hygiene, which refers to keeping oneself and one's surroundings clean, especially to prevent illness or the spread of infection (Boot and Cairncross, 1993). Thus, the idea of hygiene comprises two concerns, "the avoidance of dirt and the prevention of disease" (Curtis, 1998: 12).

In this research, I formulated questions relating to convenience and comfort in terms of labour, time and effort involved in operating and maintenance of the filter, as well as in the disposal of waste. I assessed cleanliness and hygiene by questions and observation about hand washing practices, cleanliness of the filter, the place in which it is installed, and the way the water is transported. In the household survey, questions were included about the occurrence of diseases in the household during last one year and five years.

Safety: Operational safety and risks related to the design of the filter, such as its size and height, chemical toxicity, bacteriological contamination and environmental safety hazards in the disposal of waste. These variables were all checked, using observation and a TCLP test.

Modes of provision: The operation and performance features of the technology, including way the technologies are introduced. In this research, the technology was introduced by the researcher. The main question relating to the mode of provision in this case refers to availability of the required materials and chemicals in the local market and the training and monitoring requirements of the technology.

Costs: The costs of the technology (in relation to the household's economic resources) in this research included more especially operational and maintenance costs, including the economic significance of time allocation. The relevant variables are: installation cost, operation and maintenance costs related to filter materials, and the time requirements of changing or refilling the filter materials. Also for the community-based safe water supply systems, discussed in Chapter 4 and in the overview of the As removal technologies in Chapter 5, the costs of installation and maintenance are part of the assessment.

3.4 Selection of As removal technology for further development

Several arsenic removal filters have been tried out for use at household level, and most of them are being implemented on a trial basis in the field by the governmental and non-governmental organizations, with the assistance of donors. Yet, many technologies were neither implemented nor observed at field level for a whole year round nor evaluated for their practical acceptability and social and gender suitability. In this research, an inventory of the available arsenic removal technologies for household use was carried out. Forty removal technologies were screened for their removal efficacy, cost, advantages and disadvantages, including social acceptance (see Chapter 5). With some limitations, all technologies could remove arsenic from contaminated water, but they need further development, considering the size and magnitude of the problem as well as the variety of social contexts. Therefore, there is scope for further study. The following two technologies were selected in this research for further development: the GARNET homemade filter-Passive Oxidation process and the SORAS, the Solar Radiation Oxidation process.

In the diagnostic phase, on both technologies experiments were conducted in the laboratories of the sub-Department of Environmental Technology, Wageningen University, the Netherlands, and the Environment and Population Research Centre (EPRC) in Dhaka. The results showed insignificant removal of arsenic from synthetic and real As-contaminated water by treatment with the SORAS technology. Therefore, the GARNET technology was selected for further development in this research. Appendix 1 presents a summary of the results of the SORAS experiments.

3.5 Methods of Data Collection and Analysis

In this research both quantitative and qualitative data were collected. The technological data collected were primarily quantitative in nature. To address the social issues both quantitative and qualitative methods of data collection were used. Quantitative data were collected by means of laboratory testing and a household survey, the qualitative data through various methods: observation, case study, focus group discussions (FGD) and in-depth interviews. Observation and case studies were conducted to get an insight into the gendered patterns of time allocation and handling, operation and maintenance of the filters installed in the households. Focus Group Discussions (FGDs) and in-depth interviews were used to get an insight into the performance of the community-based safe water supply systems. The following steps were carried out to data collection in the field.

3.5.1 Field reconnaissance and selection of the research villages

The field reconnaissance was carried out during April 2006 in the sub-district of Kalia, in the Narail district, and during April 2007 in the sub-district of Louhaganj, in the Munshiganj district. I visited five villages in the Kalia sub-district district: Panch Kahania, Baka, Nawagram, Kolabaria, and Mirzapur. There is no bus or other motorized public transport in this area. In the Louhaganj sub-district two villages were visited: Uttar Kumarbhog and Dakkhin Kumarbhog. In the area of Louhaganj there are mini-busses. During the field visits, I had preliminary discussions with water users on the water quality, maintenance and operation of the existing options for safe water, such as deep tube wells, rainwater harvesting, dug wells, a community-level pond sand filtration system, and a community-based pipeline water supply system. The selection of the study villages was based on the observations and discussions during the field reconnaissance and available information from the offices of DPHE and EPRC regarding the level of As contamination of the tube wells located in the villages in both areas.

Finally, four villages were selected. Three villages were selected for conducting the comparative study of three community-based piped water supply systems: Baka and Khasial in the sub-district of Kalia and Pakundia village in the sub-district of Sonargaon, in the Narayanganj district. Kalia Sadar was selected to set up a field laboratory to work on the development of the arsenic removal filter during the diagnostic phase. The village of Dakkhin Kumarbhog was selected for the trial of the developed filter because it is not too far from Dhaka, so that transportation cost of carrying the water samples from Kalia to Dhaka could be limited.

3.5.2 Technological data collection

Laboratory experimentation

The technical validation for the development of the As-removal filter was done in laboratories in the Netherlands and in Bangladesh. Two types of arsenic removal technologies were studied: the GARNET filter (a passive coagulation process) and the SORAS (a photo-oxidation process, which in the laboratory in the Netherlands was done through UV radiation and in the laboratory in Dhaka using sunlight). The laboratory analyses addressed the efficiency, robustness, operational convenience, and safety (of waste disposal), and evaluated the performance of the filters in the field trial. In 2005, a preliminary laboratory experiment was carried out in the laboratory of the sub-Department of Environmental Technology at Wageningen University, for which synthetic arsenic-contaminated (demineralized) water samples were prepared. The results, though not conclusive, contributed to setting up the experimental work at field level in Bangladesh.

In Bangladesh, the laboratory experiments initially started in mid-May 2006 at the EPRC laboratory in Dhaka. For the research purpose, two field laboratories were set up, one in Kalia and the other one in Kumarbhog village. In July 2006, the field-level experimentation was started in Kalia. In May 2007 the laboratory work was moved to Kumarbhog village, where the trial and evaluation phases were carried out. One research assistant was employed in the EPRC laboratory, Dhaka, on a half-time basis for two months (June-July 2006). After that, this research assistant became the assistant researcher for the field laboratory for the development of the As-removal filter.

3.5.3 Social data collection and analysis

Socio-economic data of the study area as well as other quantitative date were collected primarily through a household survey. Qualitative information was gathered through participant observation, systematic observation, time allocation studies, and informal meetings with filter users on operation and maintenance of the filter. Eight case studies were carried out by site-specific, systematic and participatory observation, and conducting interviews and group discussions. One female field assistant assisted the researcher in collecting qualitative data as well as by taking notes during discussions with women filter users. She also supervised the household survey**.** Data analysis was done manually and by using SPPS (version 15.0) and Microsoft Excel.

Household survey: During the month of November 2007, 108 households were surveyed, 75 of which were in Dakkhin Kumarbhog and 33 in the village of Uttar Kumarbhog. At the time, the villages counted 151 and 208 households, respectively (BBS, 2006a). The settlement pattern shows clusters of houses in homesteads and houses lying along the village roads. The households were selected from homesteads by randomly selecting a first household in the homestead and then selecting every fifth or sixth households in a systematical and clock-wise order. Six enumerators with previous field experience were selected for conducting the household survey. A two-day orientation was provided to the enumerators on the objectives and methodology of the survey. Then a pre-test of the questionnaire was carried out, the results of which were discussed with the enumerators (see Appendix 2 for the survey questionnaire).

Observation: Many issues cannot be dealt with properly by the survey method, in which case observation is a useful tool to get detailed and realistic insights about actual situations, including actions, conversations, and physical descriptions (Ali, 2005). As many have said, science begins with observation and must ultimately return to observation for its final validation (Goode and Hatt, 1952:119). Regarding observation, Neuman (1997: 361) said that "a great deal of what researchers do in the field is to pay attention, watch, and listen carefully. They use all the senses, noticing what is seen, heard, smelled, tasted, or touched. The researcher becomes an instrument that absorbs all sources of information". In this research, systematic observation at household level was done on the use, operation and handling of the filters and disposal of As-waste, during the trial and evaluation phases. In addition, people's daily life, use of water, management of assets and resources, and division of labour were observed. The field research assistant followed each household for a month to observe the above activities, using a checklist. Special attention was paid to the gender division of labour and time allocation with regard to household chores as well as the operation of the filter.

The case studies: Eight case studies were performed, to answer the "how" and "why" questions relating to water collection and use and the operation of the filter by women. According to Yin (2003) the case study is an empirical inquiry that investigates a phenomenon within its real-life context. In this research, the case study method was chosen because of its holistic approach to the description and explanation of the observable facts of a given research. The observable facts were about households' acceptance and handling of the filters, cleaning the appliance and disposal of As-rich waste, water use practices, resource use and time allocation within the domestic domain, and so on. Eight filters were distributed to different households in the study area. The case households were selected purposively, based on socio-economic status and willingness to collaborate. Their houses were near the river but far away from the nearest deep tube well.

4

Performance of Community-based Pipeline Water Systems Using Deep Aquifers

Abstract
This paper presents the assessment and comparison of three community based pipeline drinking water supply systems in Bangladesh. Since the deep aquifers are identified in most parts of Bangladesh as arsenic free water, with assistance of donor agencies the governmental and nongovernmental organizations, have been constructing community-based deep tube wells and community-based pipeline water supply systems in rural areas to provide safe water from arsenic-free deep aquifers. Although the installation of deep tube wells are a preferable alternative option, the community based pipeline water supply systems play an important roles in supplying arsenic-free safe water to arsenic-affected rural people. In this study, a comparison was carried out of three programs for community-based pipeline water supply located in severely arsenic affected areas in Bangladesh. Efficacy, management, sustainability and social appropriateness of the three programs were analyzed. Since access to safe water is an important practical gender need of women that directly relates to their domestic and reproductive role, the compatibility and appropriateness of the systems were viewed from a gender perspective.

The study was conducted based on literature reviews, observation of the three water pumping systems, interviews and focus group discussions with beneficiaries of the water supply systems and relevant representatives of the implementing agencies. Study findings indicated that the community-based pipeline water systems were successful in providing arsenic-safe drinking water and were within the affordability of the rural community, as 80-90 percent of the cost was subsidized by the government and only 10-20 percent was contributed by the users. The people concerned considered pipe water an acceptable and robust option for water access. The system was found to gender-friendly, convenient and providing equal access to the beneficiaries. Beneficiaries, particularly women, appreciated the use of the piped water supply system because the water is easy to collect, collecting water is not time consuming, and the physical burden is less compared to fetching water from deep tube wells or other sources.

There are some drawbacks and challenges for community-based pipeline water supply systems, such as power failures, which stop the water supply to the community due

to frequent electricity disruptions. Not all villagers have access to the facility; the poorest people, in particular, are not included in the programs because they cannot afford it. The successful operation of the community-based pipeline water systems that extract water from deep aquifers needs a properly trained management group and actively participating users. There is, however, a grave concern about the sustainability of the system. The water is extracted from deep aquifers, the sustainable use of which depends on a number of hydro-geological factors that need to be well understood. Overexploitation of the groundwater pumped up from deep layers could induce downward migration of dissolved arsenic (As) from shallow aquifers. As a consequence, the deep water resources maybe permanently destroyed in long run.

Keywords: Arsenic; groundwater; piped water; rural households; efficacy; operation and maintenance; social appropriateness; sustainability.

4.1 Introduction

This chapter reviews the performance of community-based pipeline water supply systems that extract water from deep aquifers in three arsenic affected villages. By performance it refers to technological and economic sustainability, efficacy, management and social and gender appropriateness based on the users' perspective.

The problem of arsenic (As) contamination of groundwater has become a grave concern during recent years, because of its adverse effects on human health. In Bangladesh, people depend on tube well water drawn from alluvial shallow aquifers underlying the Ganges and Brahmaputra delta. Most of the wells were sunk by the United Nations Children's Fund (UNICEF) during the 1970s and 1980s (Clarke, 2001). Since then, the groundwater use has increased. About four to five million tube wells have been installed to provide safe drinking water to about 97 percent of the people in Bangladesh. BGS (2000) estimates that around 27 percent of the tested shallow tube wells, affecting about 35 million people in the country, have an As-concentration above the upper permissible limit for the Bangladesh drinking water standard (50mgL^{-1}). About 57 million people are drinking water containing arsenic levels above the allowable limit of the WHO and USEPA standard (As level above 10 µgL^{-1}). About 36 percent were children younger than 17 (Zheng et al., 2005). These staggering figures are changing repeatedly as the total population of Bangladesh has increased from 129 million in 2000 to more than 161 million now (UNFPA, 2008). Several studies have documented that chronic As-intoxication affects numerous organs and causes dermal lesions (pigmentation, hyper-kerotoses and ulceration), respiratory problems and internal cancers (Dhar et al., 1997; Mandal and Suzuki, 2002; Ratnaike, 2003; Saha et al., 1999). At least one hundred million people in Bangladesh and other Asian countries are getting slowly poisoned by As-contaminated wells (Stute et al., 2007).

Generally, groundwater is free from pathogenic microorganism. A high proportion of the groundwater is extracted from the shallow aquifers which are contaminated with high concentrations of naturally occurring As (Hussam and Munir, 2007; Mandal and Suzuki, 2002). Since the past ten years there has been a remarkable national and international effort to provide safe drinking water to As-affected people in rural areas. With donors' assistance the government and non-governmental agencies have implemented many As-removal technologies for households and communities, as pilot projects or on a field trial basis. Most of those have failed, except for a few that are in operation at the field level for promotion purposes. The evaluation of the performance of these arsenic removal technologies indicates that most of them were not appreciated by the users for lack of technical and social appropriateness, removal efficiency and users convenience and management (Hoque et al., 2004a).

Confronted with this situation, the government of Bangladesh has been promoting alternative options for providing safe drinking water in the As-affected areas. These include surface water treatment, pond sand filters, rainwater harvesting, protected hand-dug wells and extraction from deep aquifers. Several studies have shown As-contamination in the shallow aquifers in Holocene sediments of recent geological origin, whereas deep aquifers in Pleistocene sediments for most of the part of Bangladesh are free from As (BGS, 2000; Nickson et al., 2000). According to a hydrological study in Bangladesh only one percent of deep wells with a depth greater than 150 meters, are contaminated with As-higher than 50 µgL^{-1}, and five percent of tube wells have As-contents above 10 µgL^{-1} (BGS, 2000). As-concentration has been found to decrease with increasing depth (Acharyya et al., 1999).

Therefore, installation of community based pipeline water supply extraction from deep tube wells is considered a good option to ensure safe water for As-affected people. The national Bangladesh policy of 2004 emphasized on the use of surface water or very shallow groundwater in villages where less than 40 percent of the tube wells are As-contaminated, instead of opting for As-mitigation by alternative deep tube wells (DTW). Practical application in the field level indicates that DTWs that pump water from various depths (depending on the local geological conditions) are the best solution for providing safe water in the arsenic affected areas. Although comparatively expensive, the cluster-based piped water system is preferred by most village people over household- or community-based As-removal technologies (Ahmad et al., 2006; Hoque et al., 2004a). Field experience shows that community people are accustomed to using underground water for both drinking and cooking purposes. Nearly 10,000 of the DTWs have been installed by the government and by non-governmental organizations (NGOs) (Ahmed et al., 2006). Piped water supply systems serve only 10 percent of the total population living in the large agglomeration of urban areas in Bangladesh. Only, recently some deep-aquifer based rural piped water systems are being installed in arsenic affected areas. A recent report (Visoottiviseth and Ahmed, 2008) estimates that for a hundred households the installation costs are $8,000 and the yearly costs of operation and maintenance $500.

In this study, I assessed the performance of three community-based pipeline water supply systems using deep aquifers: the Baka Overhead Pipeline Water Supply System, the Khasial Pipeline Water Supply System, and the Pakundia Multipurpose Rural Water Supply system. These three systems are implemented in different parts of the country by three different organizations: the governmental organization DPHE in Khashial, and two non-governmental organizations, EPRC in Baka and BRAC in Pakundia. All three organizations also offered alternative safe water options to the villagers, such as based on dug wells, rain-water harvesting, surface and groundwater. However, there was an overwhelming preference of the rural people for the piped water system rather than the alternatives.

This chapter will investigate the performance of the community-based pipeline water supply system using deep aquifers in the three villages. It addresses the first of the research questions listed in Chapter 1: *What is the performance of community-based pipeline water supply systems using deep aquifers in terms of their technological and economical sustainability as well as social and gender appropriateness?*

4.2 Groundwater characteristics in Bangladesh

Bangladesh is located in the Bengal Basin of the Bay of Bengal – the largest sedimentary basin of the world (Ahmed et al., 2004). The three mighty rivers – the Ganges, the Brahmaputra and the Meghna – transport a huge amount of sediments and converge at the lower reaches to form the great Ganges-Brahmaputra-Meghna (GBM) delta. Geochemically As-is washed from the sediments of the Himalayas due to weathering, and accumulated in the silt beneath the Bengal Delta for at least 2 million years (Clarke, 2003; Fendorf, 2008). Tectonic, geochemical and biological processes lead to natural arsenic contamination of groundwater in Holocene alluvial aquifers (Saunders et al., 2005). The Holocene alluvial Ganges aquifers are extensively polluted with naturally occurring As, which adversely affects the health of millions of people in Bangladesh and India, particularly in West Bengal (Brömssen et al., 2007; Mandal and Suzuki, 2002; Nickson et al., 2000).

The alluvial sediments are the sources for groundwater; they are characterized by fining, upward sequences of sand, silt and clay. A surface layer of silty clay forms a semi-confining layer and a lower clay layer sometimes separates the shallow and deep aquifers. In the aquifer a thick layer of black to grey sediments overlies an oxidized formation of yellow-grey to reddish-brown sediments. Generally, black sediments indicated the most reducing anoxic environment; it is characterized by high concentrations of As, NH_4^+, DOC, Fe and P and low Mn and SO_4^{2-}, whereas off-white and red sediments indicated high concentrations of Mn and low As, NH_4^+, DOC, Fe and P (Brömssen et al., 2007). The mobilization of As is distributed heterogeneously in the Fe-phases in the sediment that coat aquifer sands. Anoxic conditions may not be required for the release of As from reducing gray-colored sediments (Geen et al., 2004).

Geologically, Bangladesh is characterized by two aquifer systems. One of them consists of the shallow aquifers, extending from less than 10 meters to more than 100 meters below ground level, from which drinking water is extracted by shallow tube wells (STW). The other consists of deep aquifers that extend to below about 150 meters, from which drinking water is extracted by deep tube wells (DTW). In most places ordinary hand pumps are able to extract water from the shallow aquifers, whereas in deep aquifers one can drill through the unconsolidated sediments within a couple of days by hand down to depths of 800 meters or more. Extraction of the water from deep aquifers can be done by electric or diesel-powered pumps. In some parts of the country water extraction from deep aquifers is not possible due to rock formations.

4.3 Methodology

This study is based on interdisciplinary approaches to evaulate the performance of the piped water supply system in technical as well as in social terms. The study was carried out by observing the three systems, interviewing beneficiary households and representatives of the implementing agencies, and conducting focus group discussions (FGD) with beneficiaries, particularly women. Altogether eight focus group discussions were held at the three project sites. They were arranged as shown in Table 4.1.

Table 4.1 Focus group discussions held in three project sites.

Community-based pipeline water Project	No. FGD held	Venue	Participants of discussion	No of participants	Agenda of discussion for all FGDs
Baka community-based pipeline water supply	1.1	House of president of the committee	Mixed men and women groups	Women-15 Man-6 President & Care cater	*Water quality *O&M of the system *O&M cost *Adequacy of water supply *Care-taker responsibility *Money collection from beneficiaries *Awareness of As-contamination *Access to water *Constraint and system *Benefit of the system *Previous water supply provision, etc.
	1.2	Near to over head tank	Women (beneficiaries) Care taker	Women 8-9 Care taker NGO staff	
	1.3	EPRC Office	EPRC staff, Care taker village elites beneficiaries	Men-12	
Khasial community-based pipeline water supply	2.1	Beneficiaries' house	Mixed men and women groups	Women-7 Man-6 Care cater, villagers 5-7	
	2.2	Beneficiaries' house	Mixed men and women groups	Women 8-9 Men-6 villagers 5-6	
Pakundia Multipurpose rural water supply	3.1	Primary school	School teachers, headmaster, beneficiaries, care taker, villagers, students	Men-25 Women-2 (school teachers)	
	3.2	Beneficiaries' house	Women groups	Women-9	
	3.3	Near pump room	Men group (local people), BRAC staff	Men -12	

In assessing technological and social performance of the systems, the following criteria were used:

Technological efficacy and sustainability

- Water quality (chemical and pathogenic safe water);
- Water quantity (sufficient production and access to water at peak times);
- Operation and maintenance;
- Operational safety (potential for accidental misuse, physical and chemical safety, robustness);
- Life expectancy of the electric pump and the pipeline network;
- Environmental risks (sludge disposal, excess water and drainage issues).

Sustainability of deep aquifers for long term use

- Over extraction from deep aquifers

Economic sustainability

Affordability of the costs of installation, operation, and maintenance of the system for rural, low-income households. Reportedly, the demand for piped water in As-affected areas increases with income and declines when tariffs go up (Ibrahim, 2004).

Social appropriateness

The social appropriateness of the systems in this study refers equity and gender.

Equity: Equal right of access to safe water is a vital issue. In rural Bangladesh, class and location affect access. Sometimes, wealthier women have better access to safe water than poor women (Crow and Sultana, 2002). Regarding equity, two types of equity may be distinguished: internal equity and external equity. *Internal equity* refers possible unequal access of the people who have a pipeline connection through the formation of a community group and contributed money for the installation of the system. *External equity* refers to lack of access of those villagers who do not have a pipeline connection due to lack of capability to contribute money for the installation or were unwilling to do so at the time but now cannot be connected anymore, even though they would be willing to pay now.

The appropriateness of the system was viewed from a gender perspective, since access to safe water is an important practical gender need of women, directly relating to their domestic and reproductive role (Moser, 1994). Particularly in rural areas, obtaining water for household purposes is hard and time consuming work, which is not equally shared between men and women (Crow and Sultana, 2002). Women and girls usually spend long hours collecting water from local sources, which is why easy access to safe water is a practical gender need. In the domestic domain water requirements include adequate quantity and quality of water and reliability of the water provision system, for the user households, enterprises and other stakeholders. Hence, water and women are linked together in more than one way. Women are the 'domestic water managers' with specific water-related needs and interests (Singh et al., 2003).

4.4 Study Area

One community-based pipeline water system is located in Baka village and the other is in Khasial village. Both villages can be found in the Kalia sub-district, in the district of Narail, which is located in the north-eastern part of Bangladesh. The third community pipeline water system is located in Pakundia village, in the Sonargaon sub-district, the district of Narayanganj, which is in the eastern part of the country.

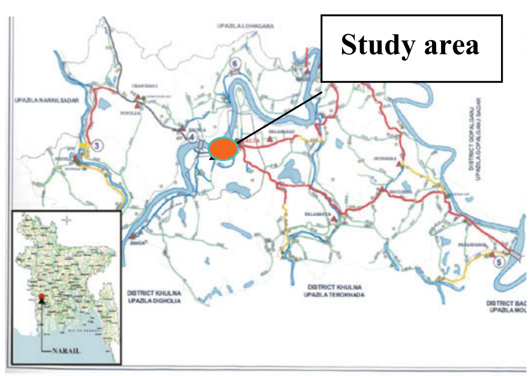


Figure 4.1 Map of the study area in Kalia.

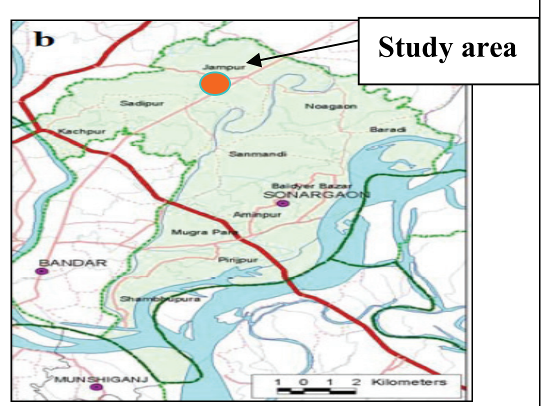


Figure 4.2 Map of the study area in Sonargaon.

4.5 Three community-based pipeline water supply systems

4.5.1 The Baka community-based pipeline water supply system

The Baka pipeline water supply system was installed by the Environment and Population Research Centre (EPRC) in the village of Baka as a part of an action research project on the community-based arsenic mitigation water supply, commissioned by the Directorate of Public Health Engineering (DPHE) of the government of Bangladesh and UNICEF. The project was conducted during 2003-2005. The system includes an overhead water tank and a pipeline network. The storage capacity of the water tank is 10,000 liters. The tank rests in a steel frame, which is connected to the pump house. The total length of the pipeline length is 3,721 meters, with a pipeline trench of 3 feet. About 3,669 meters of buried pipeline is divided into five branches throughout the village. There are 32 water tap standpoints, each serving four to eight member households. The village management committee has 11 members and 32 sub-committees have been formed to handle the whole system. A care-taker was appointed to look after the pump's operation and maintenance and the water distribution, to monthly collect money from the connected households, and to arrange meetings with the users and the management committee.

Baka village
Baka village is located in the Salamabad administrative union of Kalia sub-district, about 3 kilometers from the sub-district headquaters. The estimated population of Kalia according to the 2001 population census was 208,024 (Table 4.2). The sex ratio was 102 and the population density was 654 per km². The literacy rate was 38.4 percent for men and 25.3 percent for women.

Table 4.2 Demographic characteristic of the study areas in Kalia in 2001.

Items	Sub-district	Union	Village
	Kalia	**Salmabad**	**Baka**
Area (km²)	317.64	22.8	-
Total Households	41,413	2875	239
Total Population	208,024	14616	1347 1652*
Male	105158	7514	711 860*
Female	102,866	7102	636 792*

Sources: BBS, 2006b; * Survey by EPRC

According to population census of 2001, the estimated total population of Baka village was 1347, whereas the surveyed population by EPRC was 1652. All the people of this study area were drinking arsenic contaminated water from shallow tube wells before the first phase of the Arsenic Mitigation program of the DPHE/UNICEF, because in this area there are salinity problems with surface water, such as in rivers and ponds. Yet, in some places, tube well water even has more salinity than surface water, which compels people to use water from ponds or rivers for consumption. Many people in the village still cook with pond water without boiling it since that requires wood fuel and is time consuming. The Madhumati and the Nawaganga rivers flow through the sub-district.

The history of Baka community based pipeline water supply project

In 2001, in Kalia, a community-based capacity-building Arsenic Mitigation Water Supply Project was conducted by the EPRC. This was done in two phases. The first phase mainly included creation of awareness, mobilization of local communities, the testing of the tube wells, and community education on safe water options. The second phase was action research on a community-based arsenic mitigation of the water supply.

At the time of the tube-well testing the estimated population of the study area was 319,029. Most of the tube wells in the Kalia sub-districts were found to be 80-90 percent As-contaminated above the Bangladesh standard (50 μgL^{-1}) for the drinking water. Out of 12,034 shallow tube wells, about 11,116 tube wells were found in working condition and of them 7,431 were As-contaminated with more than 0.05 mgL^{-1} As. About 80 deep tube wells and 20 dug wells were tested (Hoque et al., 2004b). The depth of the tube wells ranged from 308 to 1,200 feet and about six percent of the deep tube wells had water that contained more than 0.05 mgL^{-1} of arsenic. These deep tube wells were used by only 6 percent of the estimated population. A significant number of the deep tube wells were not easily accessible by the common people. Survey data indicated that all households in Kalia, amounting to about 208,300 persons, used contaminated tube well water for drinking and cooking. In the Salmabad Union, out of the 667 tube wells only 0.9 percent tube wells were found arsenic-free and 60.5 percent were found highly arsenic-contaminated (>0.05-0.1 mgL^{-1}) (Figure 4.3).

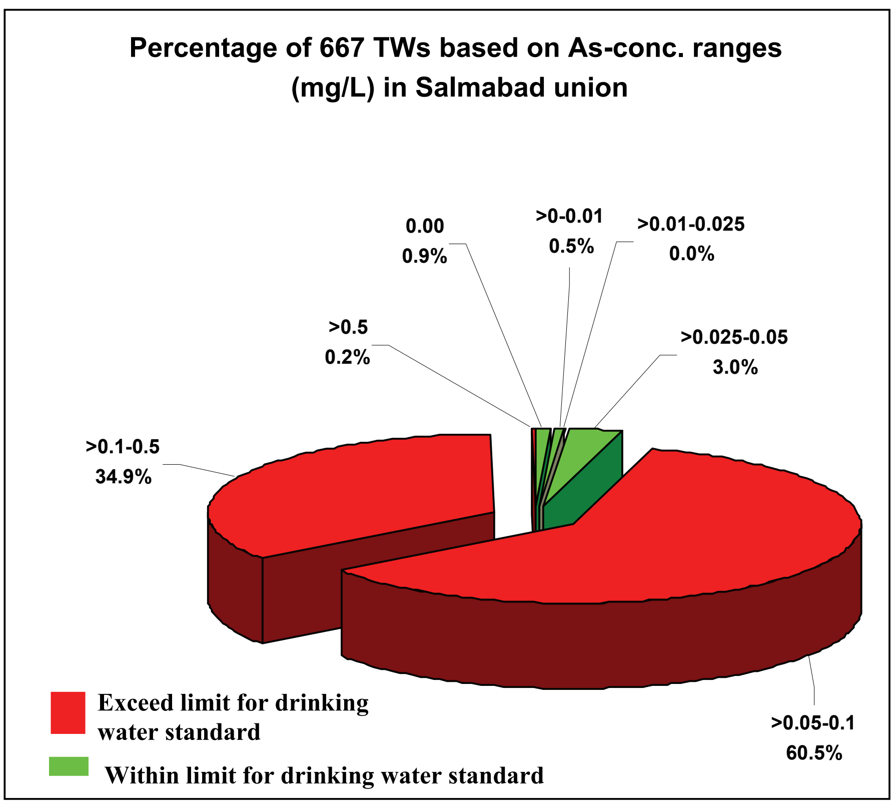


Figure 4.3 Tubewells status in the Salmabad union (Hoque et al., 2004b).

To provide safe water to the affected population 110 deep tube wells, 194 dug wells, 196 rainwater harvesters, 25 Shallow Shrouded tube wells (SST), six Pond Sand Treatment (PST) systems and one community-based piped water supply system were installed. These had to meet the urgent need to provide safe drinking water from 80 to100 percent of the As-contaminated villages in Kalia sub-district.

In Baka village almost all shallow tube wells were highly As-contaminated and no other As-removal options were in operation during 2002. There were about 84 tube wells, including two non-operational ones, during first phase of the project. Figure 4.4 shows the critical status of the tube wells in the village. Only one out of 84 installed tube wells was found to be arsenic-free. There were 12 shallow tube wells for irrigation purposes, but all these were identified as As-contaminated. Since late 2002, under the project, several options were tried to address these problems, both household-based and community-based.

During the planning phase in Baka village, the local leaders first asked the local government for deep tube wells rather than dug wells, and As-treatment by pond sand filters. Thus, the community-based pipe water supply system was installed in response to the demand of the villagers. Before its installation, Union Committees and Ward Committees were formed according to government rules, the former comprising 19 to 21 members, and the latter eight members. Following the advice of DPHE and UNICEF, representatives of the local government were included in the committees. DPHE and UNICEF also suggested inclusion of a few teachers and about 30 percent of women members, but there are practically no women members in the committees. A village committee, comprising 17 members, was formed for the community-based pipeline water supply system. Its task was to carry out activities, such as identification of beneficiaries, the formulation of the water distribution network, and motivation of the villagers to make use of the system and share in the costs.

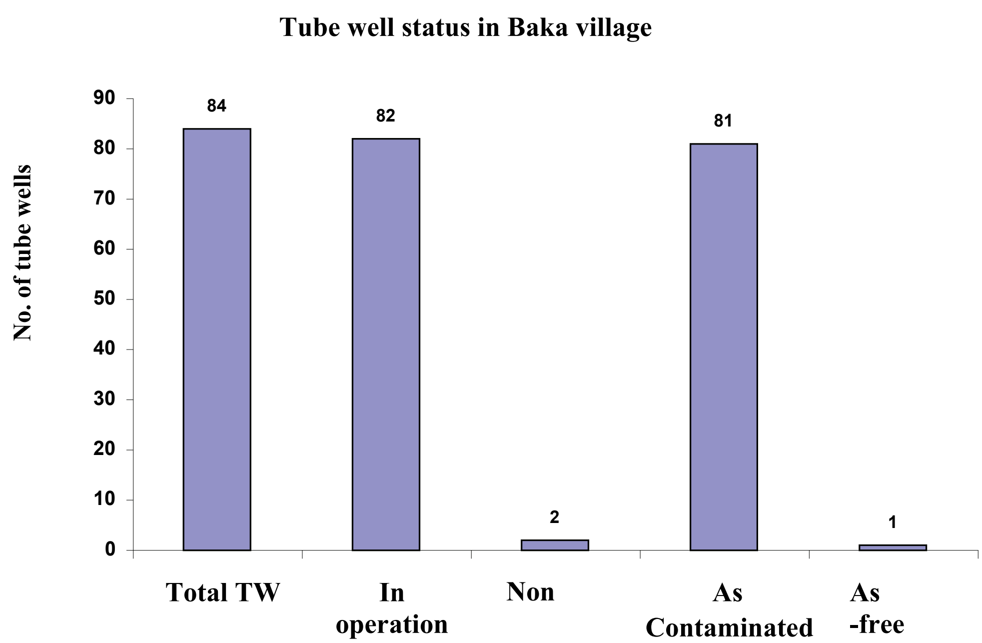


Figure 4.4 Tubewells status in Baka villages (Hoque et al., 2004b). Installation cost, operation and maintenance of the system.

The non-recurring installation costs or the total capital cost (TCC) of the pipeline system included the cost of the materials such as the water pump, the infrastructure, and transportation and construction costs. The initial TCC of the installation in Baka amounted to Taka (Tk) 0.82 million[1], of which EPRC contributed 90 percent, while the village community's contribution was 10 percent. In Baka, the estimated TCC per household was Tk 468, varying between Tk 50 and Tk 1,000, depending on economic status of the household.

The village committee is responsible for the operation of the system. It is chaired by a retired school headmaster who is a respected village leader. The system comprises 32 pipe water distribution tap points with stands. Each water tap is used by four to six households, and there is a sub-committee for each tap point. These 32 sub-committees are responsible for monitoring the water supply facilities at tap points and, if necessary, to arrange meetings to collect money from the beneficiary households to repair any damage of the pipeline or the tap. A volunteer caretaker was selected for each tap, to supervise the condition of the network connected to the tap and to inform the committee about any problems. One caretaker was trained and deployed for operation and maintenance (O&M) of the overall system.

The O&M costs mainly comprise the electricity bill, mechanical repair costs, and the monthly salary of the caretaker. In addition, the repair and renovation of the head tap and damaged parts of pipeline, which infrequently occurs, are part of O&M as well. Malfunctioning or a breakdown of the water pump is also a rare occurrence. Money is collected monthly from each household to pay for the electricity and the salary of the caretaker. Initially, the total monthly O&M cost was estimated at Tk 4,100, amounting to Tk 18 per household. Presently, the O&M cost has increased, due to the increase of the electricity bill and the cost of water pump spare parts, if required. Each household is now paying about Tk 40-60 per month, but some households pay irregularly. The beneficiaries bear the cost of tap problems.

Users' perception towards the system

Three FGDs were carried in the project sites (see Table 4.1). About 15 women, six men, the president of the committee, the caretaker, two school teachers and some villagers attended the FGD1.1 meeting in June 2008. Two other FGDs (1.2 and 1.3) were conducted during the following months. During the discussions, all participants expressed their happiness and satisfaction about the availability of the As-safe drinking water. The women participants of FGD1.2 were very satisfied because fetching water could now be done with more privacy (*purdah*) and required less labour, leaving them more time for their domestic work. They said that the system reduced the time and the physical burden of collecting safe water. Before the installation of the pipeline water system they had to risk drinking contaminated water from their tube wells because there was no other option. The president of the committee told me that many households in the villages have repeatedly requested to be connected to the system and expressed willingness to pay for it. However, that would require extension of the network and would likely exceed the capacity of the system. All current users of the system are willing to continue paying the monthly O&M cost. According to the caretaker most households pay on time, but the caretaker was unhappy about his monthly salary. The participants of FGD1.3 who do not have access to the facility,

[1] At that time about US $1= Tk 35.00

expressed their interest in it. They are not allowed to collect water from the tap system. Two men pointed out their urgent need for safe, arsenic free drinking water, but they were unable to subscribe and pay the monthly contribution due to their poor economic condition.

The village women are aware of and have knowledge about safe water options, particularly rain water, dug well water and treated surface water. The participating women of the FGDs 1.1 and 1.2 strongly opposed the use of pond water or other surface water for consumption. They claimed that the surface water is becoming poisonous because of fish farming and agricultural pollutants (insecticides). Even when boiled it is not safe. They believe that, in addition, drinking surface water causes waterborne deceases such as diarrhea and cholera. Both the taste and color of the surface water are below quality standards for drinking. All participants of the three FGDs agreed that sharing a tap stand among four to six households is a safer option than drinking water from alternative sources. They said to store rainwater during the monsoon for various domestic purposes, but that for drinking water from the deep tube well is best.

4.5.2 The Khasial community based pipeline water supply system

In 2004, the DPHE constructed the community-based piped water supply system at Khasial village. Data collection on the performance of the system was done in 2007. The system does not include an overhead tank; the water is pumped directly to the tap points of the beneficiary households. There is only one village under this project, which includes ten community tap points from which about 50 to 60 households are fetching water.

Khasial village

Khasial village is part of the Kalia sub-district, in the district of Narail. The village is about three kilometers long. In 2001, according to the census the total population of the village was 2,566: 1,264 men and 1,302 women. The total number of households was 492 (Table 4.3). In Khasial village about 96 percent tube wells were found to be As-contaminated.

Table 4.3 Demographic characteristic of the study area two (in 2001).

Items	Upazila	Union	Village
	Kalia	**Khasial**	**Khasial**
Area (km^2)	317.64	18.9	3.5
Total Households	41,413	2731	492
Total Population	208,024	13300	2566
Male	105158	6765	1302
Female	102,866	6535	1264

Source: BBS, 2006b.

The history of Khasial community based pipeline water supply project

Khasial union has been identified as having one of the highest levels of arsenic groundwater contamination in the Kalia sub-district. Figure 4.5 shows the tube wells' status in Khasial during the 2002-2003 survey. In 2004, before the installation of the community-based piped water supply system, the DPHE formed village committee in Khasial village, consisting of 12 members and a president. There was no female member was on the committee. A caretaker was appointed to look after the pump and the water distribution system. In this project, 60 pipeline connections to households were installed. The selection was done through community participation.

Installation cost, operation and maintenance of the system

The initial TCC of the community-based piped water system project in Khasial was Tk 0.35 million. About 95 percent of the total installation cost of the project was paid by the government through DPHE. Only five percent was contributed by the village community.

Before the system was installed, a village committee was formed to operate and maintain it. The beneficiaries bear the O&M cost, which includes the costs of electricity, the caretaker's salary, and other costs relevant for the operation of the system. The monthly salary of the caretaker varies between Tk1,000 and 2,500, depending on the money saved after meeting the O&M cost. Each household is paying Tk 40-50 per month for their water supply. There were no fixed rates imposed on the beneficiaries, but monthly payment was fixed according to the socio-economic status of the household and the electricity consumption of the system. Households have to pay themselves for repairs on the tap. When the water pump runs well, the caretaker's main job is to collect the money from the beneficiary households. It was reported that till so far, only the pump capacitors were twice out of order, and there were no major complaints. The electricity bill amounts to about Tk 2,000 per month. Presently, about 60 households are connected to the system and none of them was disconnected.

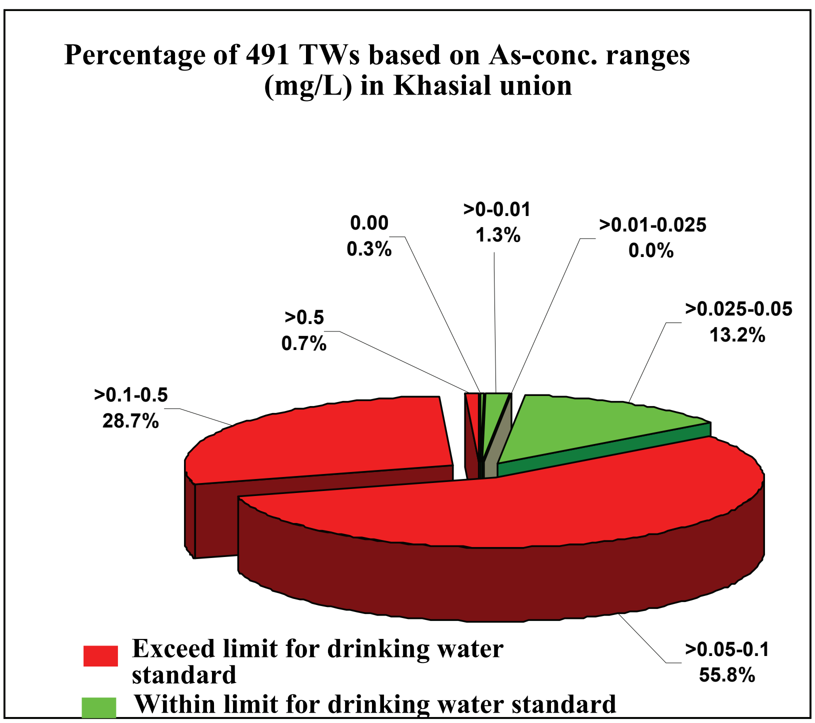


Figure 4.5 Tubewells status in the Khasial union (Hoque et al., 2004b).

Users' perception towards the system

During December 2007, two FGDs were conducted. Participants were village management committee members, the president, about 15 women of beneficiary households, and other villagers (see Table 4.1). All participants had a severe problem with getting safe water before the implementation of the system. Presently, they have easy access to safe water. Regarding the benefits of the pipeline water system the participants of FGDs 2.1 and 2.2 said they are getting safe As-free water while spending less time on its transportation and collection. The system has relieved them of the burden of fetching water from a long distance and/or using an arsenic removal filter. Some women of the FGD2.2 said that the incidence of diseases like diarrhea, indigestion, gastric ulcers and acidity has declined since they are drinking safe water. Eight FGD participants said that sometimes they do not get water when the pump does not work because of a power failure. According to the caretaker (FGD2.1), the relatively poor households are paying their O&M contribution regularly, whereas a few rich households are causing problems by not paying on time. They only pay after many reminders and once in every two to three months. Four women in FGD2.2 were facing the problem of frequent malfunctioning of their tap. Some villagers in FGD2.1 expressed their interest to get facilities for access to the system. Most of them were willing to pay money for the construction of a new connection and could afford the monthly O&M contribution. A few participants said that they would not be able to afford this.

4.5.3 The Pakundia Multipurpose Rural water Supply Project

Starting in 2002, the Bangladesh Rural Advancement Centre (BRAC) has implemented the Pakundia Multipurpose Rural Water Supply Project in collaboration with the DPHE, UNICEF, and the Rural Development Academy (RDA). UNICEF gave financial support and the RDA in the district of Bogra provided overall technical assistance. The overhead tank and pump house are located near the primary school. The storage capacity of the overhead water tank is 35,000 liters. There are two separate lines, one for irrigation water and one for domestic water use. The latter also supplies the primary school and the mosque. Initially, a water supply pipe line with a total length of 2,590 meters was constructed to cover the 190 households of the village. Presently, 437 households headline taps are connected to the system since many households took 4-10 taps in their households. The pipe line to the fields for irrigation has a length of 274 meters. It was planned that gradually the whole of Pakunda village would be covered by the project. Three to four households take water from one tap stand. Reportedly, in some places a headline tap is used by ten households. A few beneficiaries took a water pipeline connection from the system by their own arrangement, which was later informally approved by the management committee. A caretaker was appointed to look after the water supply pump and the water distribution.

Pakundia village

Pakundia village in the Sonargaon sub-district, the district of Narayanganj, lies about 30 km from Dhaka. In 2001, the total population of Pakundia village was 1,288 (2001 census). Presently, it has increased to about 3,000 to 3,500 people. The people of Pakundia village have been facing scarcity of safe water for a long time. The groundwater is severely contaminated with arsenic and iron. About 50 percent of the tube wells were found As-contaminated above the drinking standard limit of Bangladesh ($50 \mu g L^{-1}$). Presently, many tube wells are sealed. The Brahmaputra River passes adjacent to the village. This river is polluted by the industrial waste from the Narayaganj industrial belt.

Table 4.4 Demographic characteristic of the study area three

Items	Upazila	Union	Village
	Sonargaon	Jampur	Pakundia
Area (km^2)	171.66	22	1.04
Total Households	60,805	7092	270
Total Population	305,562	33457	1288
Male	159,613	17529	685
Female	145,949	15928	603

Source: BBS, 2006c.

History of Pakundia multipurpose rural water supply project

BRAC started phase I of the community-based Arsenic Mitigation Project in Sonargaon in June 1999, in collaboration with the DPHE and funded by UNICEF. Starting January 2001, about 10,062 tube wells from Sonargaon in the Narayanganj district were selected to be re-tested in phase II of the project (Figure 4.4). It was reported that monitoring the tube wells for over two years showed no significant decline in the concentration of As in the water. A good number of tube wells were found to be re-sunk by the villagers after their tube wells had been identified as contaminated with As during the first phase baseline survey. About 30 percent of the newly installed tube wells were As-contaminated.

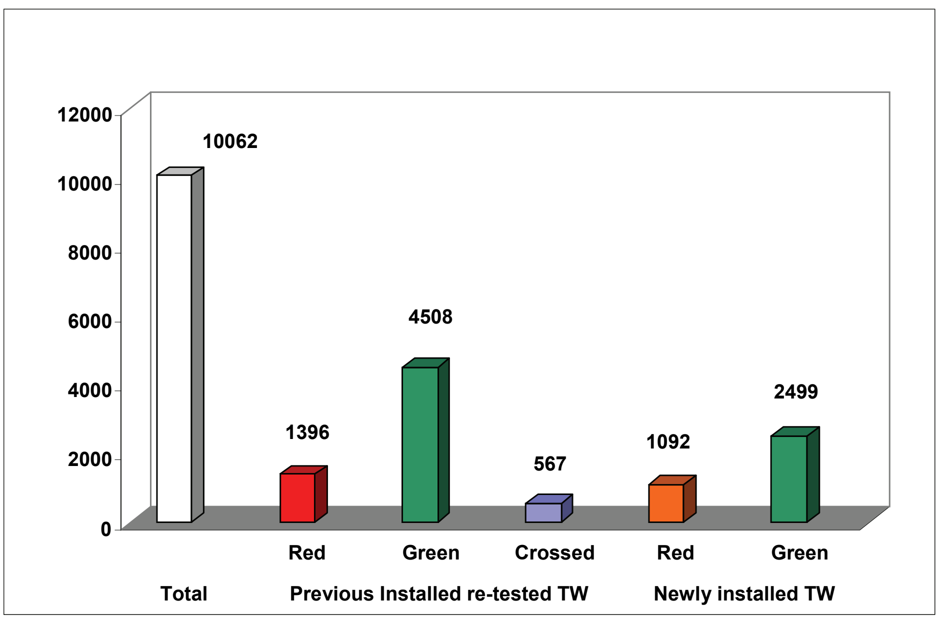


Figure 4.6 Tubewells' status in Sonargaon, (BRAC, 2002).

In Pakundia village, 96 out of 449 households were found using water from the As-contaminated tube wells for drinking, 327 households used drinking water from As-free safe tube wells, and 26 were using water from dug wells (Figure 4.5). Twelve percent of the households were using As-contaminated tube wells for cooking, 87 percent used pond or river water for this purpose (BRAC, 2002).

Pakundia village, is a severely arsenic-affected and flood-prone area. Villagers are aware of the arsenic contamination of the water from tube wells after the awareness campaign by BRAC. To meet the villagers' demand for safe drinking water, the Pakundia community-based water supply system was installed during 2002 with the involvement of community groups in choosing, financing, implementing and maintaining the system.

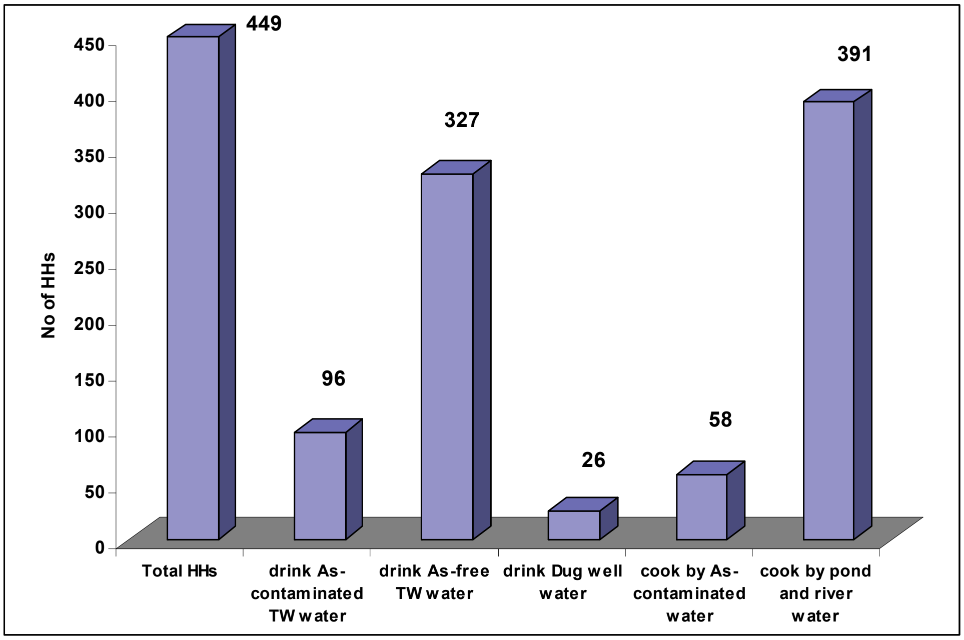


Figure 4.7 Drinking and cooking water facilities in Pakundia village (BRAC, 2002).

Installation cost, operation and maintenance of the system

The installation cost or TCC of the Pakundia pipeline system was Tk 3.2 million. About 7 percent of the TCC was collected from the village community, while the remaining 93 percent was provided by BRAC. The monthly operation and maintenance cost (O&M) would have to be paid by the beneficiaries. A maintenance committee was formed, comprising 13 members including 2 female representatives from the village. The chairman of the committee and one pump operator were appointed by the committee. The monthly O&M includes the costs of electricity, the caretaker's salary, and other relevant cost for operation of the system. The households pay Tk 60 to 200 per month, the exact amount depending on the committee's assessment of the economic status of the household and tap connection. However, a few households do not pay regularly. On average, per month Tk 9,000 needs to be collected from the subscribers, about Tk 5,000-6,000 for electricity and Tk 3,500 for the salary of the caretaker. Initially, electricity was available 24 hours per day and the villagers could get water all day long. Presently, disruption of the electricity supply is a common phenomenon in the project area. If that occurs, the caretaker makes an announcement from the mosque to inform the beneficiary households about duration of the unavailability of water. During 2002, the pump was out of order for a few days. The management committee handled this problem through conducting meetings with committee members and users. About Tk 20,000 was needed to repair the pump. The money was collected from the users. Initially, the pump was automatic, but now it is manually operated by the caretaker.

Users' perception towards the system

Several FGDs (3.1, 3.2, 3.3 in Table 4.1) were carried out in Pakundia village to discuss the efficiency, water quality, and O&M problems of the water supply system. Participants in FGD3.1 were the Pakundia primary school teachers, users of the system, villagers, and BRAC staff. They mentioned that when in 2002 school tube wells were identified as As- and Fe-contaminated, all pupils and teachers went through a lot of trouble to get safe water. After the installation of the system, one distribution pipeline was connected to the premises of the school for free. Since then, four teachers and 475 pupils can drink safe water from this pipeline tap. The participants expressed their satisfaction about the system. Previously, they were drinking a lot of contaminated tube well water, but now they only have to fetch water from the nearby deep tube wells when there is no electricity.

Women participants in FGD3.2 said that now they do not need to drink water from their own or neighbour's contaminated shallow tube well or have fetch drinking water from a deep tube well located far away, which they had to do even during the severe monsoon. Sometimes, it was not possible to fetch water during raining and flooding. As they said, presently, the community-based pipeline water supply saves their life, saves them a lot of time, and relieves them of a burden. People in other villages are interested to have same facility in their village. In FGD3.1, the caretaker complained that a few households always have problems with their monthly payments. So, he has to go to try to collect this money several times a month. He also complained about his poor salary.

4.6 Discussion

In this study, the performance of the three community-based pipeline water supply systems that extract water from deep layer aquifers was assessed. The systems were installed in different geological areas by different organizations: a government organization DPHE in Khasial and two non-governmental organizations, EPRC in Baka and BRAC in Pakundia. In Bangladesh, the government, the DPHE, and international funding organizations (e.g. UNICEF), collaborate with non-governmental organizations, such as EPRC and BRAC, who are key actors in implementing arsenic mitigation projects. The partnership approach by DPHE, UNICEF, EPRC and BRAC worked satisfactorily in the three projects. In the study area, a successful awareness campaign on the dangers of As contamination was conducted to motivate the villagers to drink As-free water from the community-based safe water supply system. Committees at sub-district level to village level were formed to ensure the participation of the different stakeholders in achieving the goal of the project. Village maintenance committees were also formed to ensure maintenance and proper use of the project for long-term sustainability. Social mobilization was considered an important component of the project activities. This was brought about by village meetings, civic drama (*Gano Natok*) and courtyard meetings (*Uthan Baithak*) to make the village people aware of the As poisoning of the groundwater and its adverse effects on their health.

The community-based pipeline water supply systems were implemented in three villages, to meet the villagers' urgent demand for alternative safe water options. All of these three systems adopted community-based approaches and aimed at long-term sustainability of the system. Below, we will discuss aspects of the systems' technological sustainability, in terms of efficacy and management, economic sustainability, and the systems' social and gender appropriateness.

4.6.1 Technological sustainability

Table 4.5 summarizes the technical performance of the three systems.

Infrastructure of water supply and facilities: Table 4.5 shows that the systems in Baka and Pakundia include an overhead tank, while in Khasial there is a direct distribution system from the pump to household tap standpoints. The Baka and Khasial systems are producing arsenic-free drinking water, whereas in Pakundia the system produces arsenic-free water for both drinking and irrigation purposes. Arsenic–free irrigation water is important to protect seed germination and seedling establishment of rice. These are jeopardized by the long-term use of arsenic contaminated irrigation water (Abedin and Meharg, 2002). Rice is more susceptible to As accumulation than other cereals, vegetables and pulses, even though arsenic intake of edible plants from soil and groundwater with elevated arsenic has also been found (Williams et al., 2006; Zhu et al., 2008).

Table 4.5 Infrastructural features, management and performance of the three systems.

Items	Baka community-based pipeline system	Khasial community-based pipeline system	Pakundia community-based pipeline system
Infrastructure of water supply and facilities			
Installation by	EPRC (NGO)	DPHE (GO)	BRAC (NGO)
Year of installation	2003	2004	2002
Total pipeline length	3,844m	2,500	2,581m for domestic 274m for irrigation
Overhead tank	Overhead tank	Directly distributed from pump to tap stand points	Overhead tank
Water Quality			
Source of water	Deep aquifer, > 150m	Deep aquifer, > 150m	Deep aquifer, > 150m
Arsenic contamination	As-free (tested during installation).	As-free (tested during installation).	As-free (tested during installation).
Chlorination to system	Chlorination dose applied regularly: 10 mg/l of $Ca(OCl)_2$	Not applied	Not applied
Iron contamination	Free	Free	Free
Color and taste of the supply water	Transparent and good taste, no stain of iron	Transparent and good taste, no stain of iron	Transparent and good taste, no stain of iron
Water production capacity			
HHs fetch water from each distribution point	3-6 HHs from one point	5-6 HHs from one point	3-5 HHs from one point
Total distribution points	32 tap stand points	10 tap stand points	40 taps connection
Total beneficiary HHs	Approx. 160 HHs	Approx. 55- 60 HHS	190 HHs including one school, one mosque
Operation and Maintenance (O&M)			
Management Committee members	17 34 sub committee	9	12
Monitoring and supervision by	Care taker. Sub-committees	Care taker Committee	Care taker Committee
Problems solves by	Management Committee and care taker, sometimes implementing NGO	Management Committee and care taker, sometimes implementing GO staff	Management Committee and care taker, sometimes implementing NGO
Operational safety			
Training on O&M	Provided to care taker	Provided to care taker	Provided to care taker
Incidence of any accident reported	No	No	No
Motor operation	Manual operation	Manual operation	Auto operation before, manual operation now
Life expectancy			
Damage to distribution pipeline network	Not reported	Not reported	Not reported
Mechanical disturbance of water pump	No major cost for maintenance of pump	Two times capacitor were out of ordered	Water pump broke in 2007
Environmental risk			
Leakages of pipeline	Not reported	Not reported	Not reported
Drainage congestion	Not reported	Not reported	Not reported
Production of sludge	Not applicable	Not applicable	Not applicable
Disposal of sludge	Not applicable	Not applicable	Not applicable

(Source: Field survey 2007)

Groundwater quality: According the BGS survey reports, the groundwater quality of the three study areas is nearly the same (Table 4.6). In Baka village, located in the Salambad union, high salinity in the groundwater is a problem. A high concentration of sodium was found there, but not in the two other areas. Other chemical properties of the groundwater were found within the allowable limits of the Bangladesh drinking water standards. High iron concentrations were found in the sub-district of Kalia and Salambad union, whereas less iron concentration was reported in the Sonargaon sub-district. However, in Pakundia village a high concentration of iron was observed in the tube-well water (BRAC, 2002). All participants in the FGDs mentioned the absence of iron and the good taste of the water supplied by the piped water system. Its users are now less exposed to health risks.

Table 4.6 Groundwater characteristic in the project sites.

Parameters	unit	Narail district Kalia sub-district Salambad (union)	Narayanganj district Sonargaon sub-district Jampur (union)
As-	µg/L	200	<0.5
Al	mg/L	<0.004	<0.04
Fe	mg/L	16.9	0.165-0.673
Mg	mg/L	46.6	23.1-102
Ca	mg/L	177	57.2-239
Na	mg/L	149	80.4-94.2
K	mg/L	6.5	2-3.9
Mn	mg/L	0.154	0.253-4.24
P^-	mg/L	1.5	<0.2- 0.2
Si	mg/L	22.5	30.7-31.2
SO_4	mg/L	<0.2	5-226
B	mg/L	0.07	<0.01-02
Well depth of TW	m	31	25-54

Source: National hydrochemical survey.(DPHE/BGS/DFID, 2001a)

It could be noted that chlorination of the overhead tank of the Baka system is carried out regularly by adding 10 mg/l of $Ca(OCl)_2$ or a bleaching powder solution to the water. The other two systems, however, do not have a provision for chlorination or another treatment for disinfecting the water before it is distributed to the households. In our study, a test on the microbial contamination of the supplied water of the three systems was not performed, since microbial groundwater contamination, for example by fecal coliform and total coliform, is rare in Bangladesh, except during conditions of flooding and heavy rains and when there are leakages in the pipeline network.

Water production capacity: Information on the water production capacity of the three systems was not available. From observation of the sites, judging from the infrastructures of the three systems, and based on discussions with staff of the NGOs and members of the community management committees, it can be concluded that the Pakundia system has highest water production capacity, followed by the Baka system, while the Khasial system has the lowest capacity. The users of the three system reported sufficient availability of water to meet their demands.

Operation and Maintenance: Since operation and maintenance of the three piped water systems is simple, the sustainability of pipeline water supply system depends on the management by the community through active participation of the users. The study shows that community efforts improve utilization rates and the functioning of project facilities. The management committees and caretakers of the three systems are actively involved in the operation of the systems. Operation and maintenance is carried out by the appointed caretaker under the supervision and monitoring of the president of the village management committee, in the case of the Baka system including the sub-committee. Caretakers were trained and are able to deal with small defects but not with major mechanical problems.

Operational safety: During the construction of the three systems, precautionary measures for occupational safety were considered. According to the caretakers, since the installation of the pumps no accident has been reported. For doing occasional repairs, the caretakers received training as well as appropriate and protective equipment.

Life expectancy: The life expectancy of the mechanical motors is always uncertain to predict. The pumping motor in Pakundia was non-functional only once, while in the other two systems such a problem did not occur during the study period. Spare parts are usually available in the local markets, so that minor electrical and mechanical problems can be solved by the caretakers with assistance of the committees. In the systems studied, the underground pipeline networks were found to be in good condition. The Pakundia system was constructed earlier than other two systems (in 2002). During the data collection in 2007 the pipeline network was found to be working well and no leakage had been reported by the users.

Environmental risk: All community-based piped water supply systems were found to be environmental friendly. The systems do not produce any iron and As-rich toxic sludge, so the issue of sludge disposal does not apply.

Sustainability of deep aquifers for long term use: The sustainability of the extraction of drinking water from deep aquifers depends on factors such as depth of the aquifer, site-specific geology, As(V) adsorption capacity of the deep aquifer sediments, and the influence of phosphate, silica, manganese and other solutes on As(V) adsorption. In addition, factors such as the overexploitation of groundwater and careless digging during the installation of deep tube wells play a role.

Aquifers deeper than 150 meters tend to contain As-safe water (BGS, 2001a), but depth is not the only criterion for As-safe drinking water. The local geology also plays a vital role. Because Pleistocene sediments provide As-free safe water irrespective of tube well depth, in some places oxidized sediments at shallower depths provide As-safe water. In Bangladesh, the geology of sediments in deep aquifers is complex. Often, deep aquifers contain high concentrations of manganese (Mn) and other trace elements, such as boron, whereas Mn concentrations may be relatively low in shallow aquifers. Therefore, it is yet to be confirmed that deep aquifers yield safe drinking water, since the consequences of exposure to high concentrations of Mn and boron for human health are still unknown (Geen et al., 2007). Deep aquifer sediment can adsorb As from potentially shallow groundwater by intrusion, but the extent to which it can do so is still unclear. Long-term viability of the deeper aquifers as a source of safe water supply depends on As(V) adsorption capacity, which is a function of the oxidation state of As.

Influences of phosphate, silica Mn and other solutes on As(V) adsorption are found in groundwater chemistry. These solutes sometimes compete for adsorption sites. Study findings indicate that oxidized sediments have a substantial but limited capacity for As removal from groundwater (Stollenwerk et al., 2007). Arsenite does not oxidize but absorbs to a much lesser extent than As (V). Phosphate (P) causes a substantial decrease in As(V) adsorption, increased pH and concentrations of silica (Si) have lesser effects on As(V) adsorption. The effect of bicarbonate (HCO_3) on As(V) adsorption is negligible.

Overextraction of the groundwater from deep aquifers leads to pumping-induced infiltration of high-As groundwater, which could cause increased As-concentrations in deep aquifers (Stollenwerk et al., 2007). Another study found an increase of As-concentrations in community deep tube wells over a five-year period to a level above the Bangladesh standard for As-in drinking water of 50 µg L^{-1} (Geen et al., 2007). This finding confirms the previous finding that As is released by oxidation of an abundance of pyrite in deep sediments because water levels are drawn down and air enters the aquifer (Chowdhury et al., 1999), but contradicts the statement by Nickson et al. (2000) that this process only negligibly raises As pollution in the groundwater (Acharyya et al., 1999). Another study cautions for overextraction of groundwater from deep aquifers because they are susceptible to contamination if As-contaminated water percolates from the upper shallow aquifers (Safiuddin and Karim, 2003). Furthermore, due to increased pumping a downward hydraulic gradient has developed between shallow and deep aquifers in some areas, which may increase the probability of contamination of the deeper aquifers through leakage between clay lenses separating the aquifers. Thus, the overextraction of groundwater remains a grave concern. Additionally, when during the installation the deep tube wells are carelessly dug and not properly grouted, there is the possibility of shunting the aquifers, which will allow contamination of the deep aquifer by the shallow aquifer.

However, the key to the sustainability of the use of deep aquifers as a source of safe drinking water is proper management. Utilization of deep aquifers should be limited to domestic water use only. As much as possible surface water should be used for irrigation. In the long run, only proper water management, taking into account geological factors and limiting water use from deep aquifers, can provide As-safe drinking water to more than 90 percent of As-affected areas in Bangladesh.

4.6.2 Economic sustainability

Although the TCC of the community-based piped water system were high initially, financial assistance from donors or the government enabled their installation. Among the three systems the Pakundia system had the highest installation cost and the Khasial system the lowest. Table 4.7 shows that contribution to the total installation cost by the village community were not same in three systems; it varied from five to 20 percent, based on the socio-economic status of the households in the community. Participation of the community in cost sharing for safe water is essential for the sustainability of the systems. However, the economic sustainability also depends on the ability to deal with emerging problems, and none of the communities have a financial reserve to cope with larger disruptions of the systems. It could be noted that in one village, people were unable to contribute money for repairs when their water motor pumps were out of order. All expenses of the reinstallation were carried by the implementing agency.

Table 4.7 Performances on economic sustainability of three systems.

Items	Baka community-based pipeline system	Khasial community-based pipeline system	Pakundia community-based pipeline system
Total installation cost (Tk)	0.82 million	0.35 million	3.2 million
Contributions to total cost of installation (Tk)	EPRC 90% Villagers 5%	DPHE 95% Villagers 5%	BRAC 93% Villagers 7%
Contributions of Beneficiaries	0.05 million Tk and land	0.04 million	0.26 million
Care taker salary (Tk)	1500- 2000	1000	2500
Water bill pay by each HH (Tk)	20-50 (no fixed rate)	80-100 (no fixed rate)	60- >200 depending on HH socio-economic status
HHs willingness to pay monthly bills	Yes	Sometimes not	Sometimes not
Electricity bill /month (Tk)	2000-2500	2000	5000-7000
Monthly O&M cost per HH (Tk)	20-50 (no fixed rate)	18	40-60 (no fixed rate)
Total O&M cost per month (Tk)	4500	5000	9600
Mechanical disturbance of the water pump (Tk)	No major cost for disturbance of water pump	Small amount for replacement of the capacitors (two times)	20,000 for repairing the water pump, paid by the villagers

Source: Field survey 2007.

The Pakundia system is the most costly in every respect. Each household is required to contribute money, ranging from 60 to 200 Tk per month for the water bill, based on the tap connection of the household. This relatively high contribution by the community is possible because this village, which is located close to Dhaka, is richer than the villages of Baka and Khashial. In addition, the BRAC micro-credit program enhanced the affordability of the Pakundia villagers. Therefore, the people of the Pakundia can afford to run the system, even though it is more expensive than the systems in the other two villages.

4.6.3 Social and gender appropriateness of the systems

Table 4.8 summarizes the access to the water supply of the three systems in terms of coverage, equity, reliability and convenience for the beneficiaries. The compatibility and appropriateness of the systems were viewed from a gender perspective, since access to safe water is an important practical gender need of women, directly related to their domestic or reproductive role (Moser, 1989). In all project sites, women play a significant role as water managers and are involved in fetching water, which follows the gender-based division of labour in the domestic sphere that assigns domestic work to women. To assess the social performance of the three programs, we conducted eight FGDs and several informal meetings with men and women, particularly those involved in fetching water from the pipeline taps. No female members were included in the village committee in any of the three projects. For sustainable management of the program female participation in the local communities is essential, since women are the main users of water. Sustainable water management can only be established with the conscientious participation of local women and the integration of a users' perspective into management practices.

Table 4.8 Performances on social and gender appropriateness of three systems.

Items	Baka community-based pipeline	Khasial community -based pipeline	Pakundia community-based pipeline
Access to water			
Total village Population (Census 2001)	1347	2566	1288
Total HH	239	492	270
Households connected to the system	150-160 HHs	45-60 HHs	190HHs
Water supply coverage of total HHs (%)	63-67	9-12	70
Water collector	Wife and other female HH members	Wife other female HH members	Wife other female HH members
Time required to fetch water	10-15 min	8-10	10-15 min
Equity			
Internal equity for access to water	Equal access once connected, flexible rates of HH contribution	Equal access once connected, flexible rates of HH contribution	Equal access once connected, flexible rates of HH contribution
External equity for access to water	Only connected HHs (63-67%) have the right to fetch water	Only connected HHs (9-12%) have the right to fetch water	Only connected HHs (61-65%) have the right to fetch water
Water supply reliability and convenience			
Adequate water supply	Yes, only disruption when power failure	Yes, only disruption when power failure	Yes , only disruption when power failure
Handling of the water tap	Easy to handle by women	Easy to handle by women	Easy to handle by women
Disruption of water supply	Sometimes	Sometimes	Frequently
Announcement of water supply disruption	No	No	Yes

Source: Field survey 2007.

Access to water: About 63-6, 9-12 and 70 percent of total households in the villages of Baka, Khasial and Pakundia, respectively, have access to the systems. During the FGDs some participants who did not yet have access to the systems showed interest for their households. They were willing to pay for the pipeline connection cost. Regarding the extension of the pipeline connection for the new households, the NGO representatives and the management committees said that existing systems were designed in accordance with the water requirements of the households who formed the systems' beneficiaries group. An additional extension might jeopardize the existing capacity of the system.

Prior to the installation of the pipeline water supply systems in the three project areas, women faced serious problems in domestic water management as they were unable to provide As-free, safe water. During the FGDs all women participants highly appreciated the pipeline water supply system. Presently, they don't have to fetch water from a distant source, which saves them a lot of time that they might use for income-generating activities. Participants in FDG 3.2 in Pakundia mentioned that before the installation of the system, during the rainy season and flooding they had to use As-contaminated tube well water for drinking and cooking, regardless of the health risk, since roads and surroundings were inundated. Participants in FGDs 1.2, 2.1 and 2.2 in Baka and Khashail reported that before they had to drink saline water and pond water, in spite of risk of bacteria in the surface water. Now they were getting non-saline and transparent water, that is iron-free as well, rather than surface water that does not look well.

Equity: In the three project areas 'internal equity' was observed in the sense that all connected households, rich and poor, and irrespective of their monthly contribution, had equal rights of fetching water from the common water taps. With regard to 'external equity', the systems created inequity in access to safe water between connected and non-connected households. For poor households contribution to the installation cost was an obstacle. It still is, if new connections can be made and the system can be extended. The latter, however, is not always possible because of the limited capacity of the systems. In the FGDs it was mentioned that sometimes poor households who are not connected to the system may use the taps, provided they have permission by the rightful beneficiary.

Water reliability and convenience: Apart from disruptions caused by power failures, the water supply is reliable. Piped water supply systems are also safe and convenient because the water can be delivered close to the houses of the consumers. This saves collection time and frees women of a physical burden. Regarding the health impacts, all participants of the FGDs meetings said that the incidence of diarrheal and other water-borne diseases has decreased after they started drinking the pipeline water. These findings support the statement that health effects by drinking As-contaminated groundwater would be reduced by approximately 70 percent, if 31 percent of As-affected shallow wells in the country are replaced by drilling deeper wells with low arsenic content (Yu et al., 2003). The piped water is also safe from external contamination of any kind, and better quality control is possible in such a system.

Social sustainability of the systems: For the social sustainability of the systems for long-term use there are some factors that need attention. Since the implementing agency handed over the systems to the community, the community is responsible for the sustainability of the systems. However, in none of the three villages the beneficiaries contribute to a community-managed emergency fund. The president of the Baka management committee raised the issue of a community fund, which would require a bank account to be maintained by the community, but this was insufficiently supported. The second issue is the lack of users' participation in the management committee meetings. The management committee members do not actively try to involve the users either. In the long run, without the conscientious participation of local communities, an accountable and sustainable water resources management will not be established (Safiuddin and Karim, 2003).

4.7 Conclusions

In this study, I have evaluated the performance of three community-based piped water supply systems in the villages of Baka, Khasial, and Pakundia. They were installed by different organizations, both governmental and non-governmental. The assessment of their appropriateness was done in technological, economic and social terms. The social assessment included a gender perspective. Field data were collected through focus group discussions, interviews with key informants, and site-specific observations during 2007-2008. Two of the three community-based pipe water systems (Baka and Pakundia) include an overhead tank and one does not (Khasial). The Pakundia water supply project has both drinking and irrigation water supply facilities.

The technical performance of the three systems in three different villages was found satisfactory in terms of efficacy, water quality, adequacy of water supply, and operations and maintenance. However, there are number of hydro-geological factors that need to be well understood in order to extract safe water from deep aquifers on a sustainable basis. Overextraction of water from deep aquifers could induce downward migration of dissolved As, permanently destroying the deep resource. Although the deep aquifers in the Pleistocene layer currently provide arsenic-free water in many parts of the As-affected areas in the country, this could be site-specific, depending on the geological conditions of the area. Groundwater chemistry is very complex and it is difficult to assess the risk of an increasing As concentration for the long term. Groundwater quality parameters of the three study areas are almost similar and within the allowable limits of the drinking water standard in Bangladesh. High concentrations of salinity, arsenic, sodium and iron were found in the groundwater of Baka village, whereas high concentrations of arsenic and iron were observed in Khasial and Pakundia. The water of the community-based water systems is noted to be safe, arsenic free and iron free. The concentrations of arsenic in the supplied water are below the Bangladesh and WHO standards, as well as within the new EPA guidelines for the drinking water (0.01 mgL^{-1}As). The users in the three project areas were favourably impressed with the good quality of the supplied water, regarding its lack of salinity and iron as well its good taste. To disinfect the probable bacterial contamination of the water, the Baka system has a chlorination facility, while the other two systems do not have such a provision. Although source water from deep aquifers is usually free from pathogenic bacteria, chlorination should be considered in all systems, as bacterial contamination in Bangladesh is a grave concern. The systems were found to be environment-friendly, requiring no disposal of contaminated sludge.

The pipe water systems are operating by village water management committees. These committees were enthusiastic and active in setting up the organization of the system and carrying out their duties, such as identification of beneficiaries, formulation of the water distribution household network, motivation and cost sharing, in which they were assisted by the project personnel. The systems appeared to operationally safe; the caretakers are well trained, sincere, and maintain the systems efficiently. So far, all three systems were found to be working well. In Pakundia, the electric water pump had broken down once in two years' time. The common cause of disruption of the systems is power failure. To overcome this problem, other sources of energy for operating the water pumps should be considered. The life expectancy of the three systems is satisfactory, provided that the systems are competently managed. However, for long-term sustainability of the systems, their management should be more participatory than it is now. The users (women) should be represented in the management committees.

The economical sustainability of three systems can be rated satisfactory, although the initial installation costs could be paid thanks to external financial assistance. The contribution of the village communities to the total installation cost varied from five to seven percent only. Participation of the community in sharing the cost for safe water is essential for the sustainability of the systems. Once the systems are installed, the ability of the users to pay the monthly bills is another factor in their economic sustainability. In all three sites, it was found that most user households were able to pay, although the rates are set according to the household's socio-economic status. In none of the villages, however, there was an emergency fund for big repairs. Installation costs are higher for rural people who live in more scattered settlements. Installation of community-based pipe water systems is most feasible economically for clustered rural settlements.

Social and gender appropriateness of the systems were found satisfactory in all respects, as users perceived the system as satisfactory and convenient. Women, who are the sole water fetchers, highly appreciated the systems because of their reliability, safety, high water quality and good taste, and the lack of any health risk. They rated the systems as convenient and comfortable, because the water is delivered close their house, which saves collection time and is physically not demanding. They also said that the monthly payments are generally within their means.

The three community-based pipeline water supply systems were found technologically efficient and socially acceptable, as well as appropriate from a gender perspective. For the long-term sustainability of these systems, some factors need to be addressed, including the availability of a community fund and the participation of the user community in the systems' management. Sustainable and efficient systems require a properly trained management group and actively participating users. It is recommended that pipeline water supply systems should be promoted in arsenic-affected areas. Further research should be done on the equity of the systems and the sustainability of the use of the deep aquifers, as well as alternative sources of electricity supply other than the local grid power supply, such as Bio-gas or wind power. Further study is needed to identify arsenic removal options in cases where safe aquifers are not found easily and community-based pipe line water supply systems are not feasible.

5

Review of the Characteristics, Weak and Strong Points of Household Technologies for Arsenic Removal

Abstract

To confront the arsenic problem in the shallow tube wells in Bangladesh, the application of arsenic removal technologies to provide safe drinking in rural areas plays a vital role. Although a number of household-level removal systems have been developed based on different technologies, so far, most of the solutions have fallen short of the technological standards set by the Government of Bangladesh, and have fallen short with regard to their social acceptability as well. This chapter presents the different available arsenic removal technologies for household level use to provide safe drinking water in rural areas of Bangladesh. Some of these technologies have been implemented full-scale in the field, but others have only been tested in laboratory.

An overview of the current available technologies for a point-of-use (POU) As-removal system at household level was carried out on the basis of literature reviewing and field observations. The technologies are evaluated in terms of their performance regarding their arsenic removal efficacy, their strong points and weak points, including their social acceptability during their use in the field. The household-level arsenic removal systems are relatively easy to operate and maintain. Consequently, millions of rural people would be able to drink safe water by using an affordable filter at household level to remove Arsenic from their own As-affected tube wells. A total of 40 removal technologies are assessed in this study.

Most of the technologies are found to have the potential to reduce arsenic concentrations from the contaminated water, to the allowable limit of the WHO (10 μgL^{-1}) and Bangladesh drinking water standards (50 μgL^{-1}). They have, however, limitations in terms of their operation and maintenance as well their social acceptability. Further development and/or modification of some of these potential technologies can turn them into a promising arsenic removal technology for household-level use. In order to select the appropriate technologies to remove As effectively, information on their process technology, groundwater chemistry, interferences of other elements with and the influence of other factors on removal efficacy, cost, the availability of filter materials and chemicals, and

social acceptance factors are essential. A multiple-criteria analysis (MCA) approach was applied to select the potential technologies amongst the identified 40 technologies, by applying interdisciplinary multi-criteria regarding both technical and social aspects, and aspects related to social acceptance as well, to address the efficacy and complexity of a technology.

Keywords: Arsenic removal technologies, weaknesses, strengths, household filter.

5.1 Introduction

Although a number of household-level removal systems have been developed based on different technologies, so far, most of them do not satisfy the technological and social feasibility standards set by the Government of Bangladesh. According to USEPA, the best performing technologies for the household level are ion exchange (95% efficiency), activated alumina (95%), reverse osmosis (>95%), modified coagulation/filtration (95%), enhanced lime softening (pH>10.5, 90%), electrodialysis (85%), and oxidation/filtration (Fe: As 20:1, 80%) (EPA, 2000; EPA, 2003). Low-cost techniques are confined to oxidation, sedimentation, coprecipitation and adsorption. In all cases, technologies should meet several basic technical as well as socio-economic criteria, such as being suitable for the poor in rural settings, being user-convenient, and being suitable from a gender perspective (Johnston and Heijnen, 2001). The materials of the appliance must be cheap, readily available, and/or reusable to reduce costs, while at same time the operation of the technology should not introduce any harmful chemicals into the drinking water or environment by the handling and disposing of As-rich spent materials (Ramaswami et al., 2001). In recent years, there has been a remarkable development in As-removal technologies, but most of these technologies were promoted without any proper observation of their performance under field conditions, and were discontinued by the users after a couple of months of installation (Hoque et al., 2006a). The main reasons are the reduction of As-removal efficacy after a short time of use, pathogenic contamination during the operation of the filters, high cost, and user-unfriendliness, particularly with regard to rural women.

In this chapter, I present an overview of the available and currently developed technologies for a point-of-use (POU) As-removal system for household-level use, a study I carried out through a literature review and field observations. A total of 40 technologies are inventoried and evaluated in terms of their performance on As-removal efficacy, their strong and weak points regarding chemical and bacteriological contamination, and their cost, and also regarding their social acceptance during household use. This was done to address the research questions 2 and 3 (see Chapter 1).

Identifying and selecting the best technologies for the As remediation at rural household level requires a careful assessment of the available technologies with regard to their technological, economical, and environmental characteristics, as well as regarding their societal acceptance, as seen from a gender perspective. Multiple-Criteria Analysis (MCA) is a holistic, interdisciplinary approach to facilitate optimal decision-making when divergent findings are involved, the main feature of which is sustainability regarding economical, social and environmental aspects (Ellis and Garelick, 2008). The MCA approach is applied in this study to select the technologies for further development amongst the identified 40 As removal technologies, in order to answer research questions 4 and 5 (see Chapter 1). The MCA was carried out through a weighted-scale screening of interdisciplinary multi-criteria regarding technical and social aspects, in order to address the efficacy and complexity of a technology, and its social acceptance as well.

5.2 Objective of this study

The objective of this study is to present an overview of the available As-removal technologies, as well as current As-removal household-level technologies which have been developed in the laboratory and/or have been implemented in the field in Bangladesh. The technologies are evaluated in terms of their arsenic removal efficacy, advantages and disadvantages, and acceptance by their users, taking into account the societal context of Bangladesh. The purpose of this study was to select the potential As-removal technologies that would be suitable to develop a promising, robust and technologically appropriate As-removal filter for rural household use, which would be socially acceptable from a gender perspective as well.

5.3 Materials and methods

This study was executed based on the review of the available relevant literature, journals, Internet websites and field observation. A screening matrix on strong and weak points of the As-removal household technologies (filters) was developed, based on several past studies on the comparison and evaluation of technologies in view of their As-removal efficiency, chemical and biological problems associated with technologies, cost, and social acceptability to the potential users for household use. The performances of three currently promoted household-level As-removal technologies, approved by the government of Bangladesh, were evaluated in the villages in the Homna sub-district, in the district of Comilla. The assessment was carried out through field observations, the testing on As of treated water samples, group discussions, and interviews with beneficiaries and representatives of the provider (a non-governmental organization). The selection of the potential technology amongst 40 currently available technologies was carried out by using a multiple-criteria analysis (MCA). Interdisciplinary and transdisciplinary approaches were considered for both technical and social issues in the MCA by a weighted-scale matrix (Seghezzo, 2004).

5.4 Arsenic removal technologies

Arsenic can be removed from contaminated water by physico-chemical techniques as well as biological techniques (Mondal, 2006). These techniques are described below.

5.4.1 Physico-chemical techniques

The physico-chemical techniques fall broadly into five major categories: precipitation or coprecipitation, adsorption, ion exchange, membrane filtration, and permeable reactive barriers (EPA, 2002). The permeable reactive barrier technology is not applicable to remove arsenic from the groundwater in Bangladesh, since in the Ganges delta basin the arsenic occurrence in the groundwater is due to geological weathering and does not come from point sources. This study mainly focuses on the physico-chemical technologies for the removal of As from contaminated water.

A wide range of conventional as well as advanced techniques has been developed based on physico-chemical processes. Appropriate technologies produce water that should meet As standards for drinking water as well as safety standards. The safety requirements include drinking water quality standards, such as residual chloride, sulfate, phosphate, nitrate, iron, manganese, and turbidity, as well as bacteriological quality. Aesthetic quality parameters, like odor, taste and color are also a concern. Technologies to remove arsenic from contaminated water depend on the As-chemistry in the groundwater.

Arsenic is one of the toxic elements naturally occurring widely in water, rocks and soils (Mandal and Suzuki 2002; Shih, 2005; Hussam and Munir, 2007). Arsenic and its compounds are mobile in the environment. As is a metalloid with the atomic number 33, atomic weight 74.9216, in Group Va of the periodic table of elements. Its occurrence, forms, distribution, and mobility in the groundwater rely on the interaction of several geochemical factors, such as reduction-oxidation reactions, pH, and the distribution of other ionic species, aquatic chemistry and microbial activity (Shih, 2005). Arsenic exists in different oxidation states as trivalent arsenite As(III) and pentavalent arsenate As(V) in the groundwater (Choonga et al., 2007). The arsenite, the reduced trivalent form As(III) is normally found in anaerobic conditions, while the arsenate, the oxidized pentavalent form As(V), is found in aerobic conditions. The fraction of As(III) to As(V) varies significantly, ranging from less than 0.1 to greater than 0.9 (Ahmed, 2001). Both As(III) and As(V) are sensitive to mobilization at the pH values usual in groundwater (pH 6.5–8.5), and under both oxidizing and reducing conditions. In an anoxic environment, As(III) exists as H_3AsO_3 and $H_2AsO_3^-$. The non-ionic form of H_3AsO_3 (arsenious acid) has pKa 9:22 (Katsoyiannis and Zouboulis, 2004). Arsenate, As(V), exists at a neutral pH as oxyanion $H_2AsO_4^-$ with pKa 2:19; and $HAsO_4^{2-}$ with pKa 6:94 (USEPA, 2003; Katsoyiannis and Zouboulis, 2004). The ionic forms of As(V) dominate at pH >2.2, while As(III) is neutral at pH <9.

The speciation of soluble Arsenic has a significant effect on the As- removal (Edwards et al., 1998). Arsenic is a redox-sensitive element, which can change its form through reduction or oxidation. The net charge of As(III) is neutral at natural pH levels (6-9) and this form is not easily removed (Kanel et al., 2005). The net molecular charge of As(V), on the other hand, is negative (-1 or -2) at natural pH levels, enabling it to be removed with greater efficiency.

The precipitation/coprecipitation process

This process involves the use of chemicals to transform dissolved contaminants into an insoluble solid or to form an insoluble solid onto which dissolved contaminants are adsorbed. The solid is removed from the liquid phase by clarification or filtration (EPA, 2000; EPA, 2002). The major steps of this technology are:

- the mixing of chemicals into the water;
- formation of the solid matrix through precipitation;
- coprecipitation, or a combination of these processes, and
- the separation of the solid matrix from the water.

The chemical process of precipitation and coprecipitation usually depends on a pH adjustment, the addition of chemical precipitants or coagulants, and/or the addition of chemical oxidants (EPA, 2000; EPA, 2002).

Arsenic is removed from the groundwater by oxidation, coagulation and flocculation. The main mechanisms are as follows:

- precipitation: the formation of the insoluble compounds, such as Al (AsO_4) or Fe (AsO_4);
- coprecipitation: the incorporation of soluble arsenic species into a growing metal hydroxide phase;

- adsorption: the electrostatic binding of soluble arsenic to the external surfaces of the insoluble metal hydroxide.

All three mechanisms can either work independently to remove contaminants from the water, or can work together as oxidation/coagulation/ flocculation processes. In most cases, pentavalent As can be removed more effectively than trivalent state As, so the oxidation of As(III) to As(V) is required as a pretreatment for efficient removal. Arsenite can be directly as well as rapidly oxidized to arsenate by atmospheric oxygen and/or by adding oxidizing agents. The passive oxidation of the water during the collection and subsequent storage in houses can be done by atmospheric oxygen, which causes a reduction of the As concentration in the stored water. The conversion of As(III) to As(V) can be done by adding a number of oxidizing chemicals, such as gaseous chlorine, hypochlorite and potassium permanganate. (Ahmed, 2001; Mondal et al., 2006). The reactions are:

Oxidation by oxygen (O_2)

$$H_3AsO_3 + \tfrac{1}{2} O_2 \rightarrow H_2AsO_4^- + H^+$$

Chlorination (Cl_2)

$$Cl_2 \text{ (Gas)} + H_2O \rightarrow HClO + HCl$$

Oxidation by Hypochlorite (HClO)

$$H_3AsO_3 + HClO \rightarrow H_2AsO_4^- + Cl^- + 2H^+$$

Oxidation by Potassium permanganate ($KMnO_4$)

$$3H_3AsO_3 + 2KMnO_4 \rightarrow 3H_2AsO_4^- + 2MnO_2 + 2K^+ + H^+ + H_2O$$

Chlorine is a cheap, rapid and effective oxidant as well as a disinfectant, but it may lead to reactions with organic matter, producing toxic tri-halomethane as a by-product. Calcium hypochlorite is a cheap and effective oxidant and disinfecting agent, and in Bangladesh it is commercially available as bleaching powder. The oxidant permanganate ($KMnO_4$) effectively oxidizes arsenite, along with Fe(II) and Mn(II). This chemical is available in Bangladesh, but comparatively, it is a poor disinfectant. Arsenic removal during the oxidation of Fe and Mn is dependent on the quantity of iron removed as $Fe(OH)_3$ form, and is relatively independent of the quantity of manganese removed as MnO_2. The permanganate residual manganese in the treated water is a grave health concern when it exceeds the limit of the drinking water standard. Hydrogen peroxide is an effective oxidant if the raw water contains high levels of dissolved iron, which often occur in conjunction with an As contamination. Furthermore, ultraviolet radiation can catalyze the oxidization of arsenite in the presence of other oxidants. Ozone is also a strong oxidizing agent with disinfectant, but it is not common in Bangladesh.

The solar oxidation and removal of arsenic (SORAS) technology is developed, based on oxidation, precipitation and coprecipitation by a solar photo-catalytic process. In this process, As is removed in two steps: firstly, As(III) is oxidized to As(V), which strongly adsorbs to iron(hydr)oxides formed from naturally present iron. Secondly, the iron(hydr)oxides are allowed to settle at the bottom of the container with the adsorbed As(V), and As-free or less clear water is decanted. In this process, reactive oxidants are produced photochemically with sunlight; the efficiency of the As removal depends on the mechanism of the formation of solid iron (hydr)oxide and the oxidation rate of As(III) (Garcia et al., 2004). Therefore, the oxidation of As(III) is followed by the precipitation or As(V) adsorbed on Fe(III) oxides, and a filtration is carried out. Oxides generated from ferrous salts are more efficient than solids formed by the hydrolysis of Fe(III). More precipitation forms in the presence of alkalinity contents (bicarbonate) in the water. The presence of silicate moderately decreases the removal of As, while the presence of phosphate removes arsenic drastically (Ayan and Malay, 2005). In fact, the underlying chemistry is unclear, and it is difficult to predict the As removal efficiency, to inform the structure of the chemical matrix and the operation conditions (Garcia et al., 2004). The arsenic removal efficiency depends on the iron concentration, which should not be smaller than $3 mgL^{-1}$and on the dissolved oxygen concentration. In the process, tartrate-citrate (equivalent to 50 μM tartrate and citrate) is used for the oxidation of As. The extract of the locally available tamarind (*Tamarindus indica*) is a natural source of tartrate-citrate (Ayan and Malay, 2005). Small amounts of citric acid (4-8 drops of lemon juice) can also be used instead of tamarind, but the large concentrations of citric acid reduce the removal efficiency. In this process, about 45-78 percent of total As was found to be removed at a field trial in Bangladesh (Hug et al., 2001). However, another study has shown a removal of arsenic of more than 99 percent by steel wool, lemon juice and solar radiation (Cornejo et al., 2008).

In Bangladesh, many technologies have been developed based on passive oxidation, oxidation, coprecipitation and adsorption, such as the Kolshi (pitcher) filter, the Two-Bucket treatment unit (BTU), the DPHE-Danida BTU, coprecipitation with naturally occurring iron, the Stevens Institute Technology system, the Ardasha filter, and others. It is noted that some of these technologies are capable of efficiently removing As from contaminated water, but that they have some limitations (Bang et al., 2005; Bruce et al., 2002; Sutherland et al., 2002). The Kolshi filter, which works through passive filtration, shows zero to 25 percent removal of the initial concentration of As. A reduction of more than 50 percent in As content was also found by the sedimentation of tube well water, which contained 380-480 mg L^{-1} of alkalinity as $CaCO_3$, and 8-12 mg L^{-1} of iron (Leupin and Hug, 2005; Milton et al., 2007). The As removal performance of the Chary filter indicates that it is effective to remove As from contaminated drinking water to some extent, but it has not been implemented in the field (Rahman et al., 2005). The Ardasha filter was found to fail consistently to reduce an As concentration below the Bangladesh standard of 50 μg L^{-1} (BAMWSP/DFID/WaterAid, 2001a; Sutherland, 2001). In the BUET-bucket sand filter, the addition of a packet of coagulants $FeCl_3$ is needed to remove As from contaminated water. The use of $FeCl_3$ was found to be more suitable than other chemicals to reduce As to less than 50 μgL^{-1} when the feed water has elevated PO_4^{3-} and Si concentrations (Ali, 2001). The naturally occurring iron filter has been developed at laboratory scale. After 24 hours of settling time, the As removal efficiency was found to be about 90 percent when the Fe/As weight ratio was ≥ 10 (Mamtaz and Bache, 2001; Mamtaz and Bache, 2002). In fact, the As reduction usually depends on the water quality, particularly with regard to the presence of iron in the water. Conventional treatment technologies that are used for As removal, such as the iron removal by aeration followed by a rapid sand filtration, rely on the oxidation, coprecipitation and adsorption of As to metal hydroxides.

The adsorption process

The process involves the concentration of solutes on the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The adsorption media is packed into a column and when As-contaminated water is passed through the column, the contaminants are adsorbed (EPA, 2002). Many sorbents, including iron and aluminum hydroxide flocs, have a strong affinity for dissolved As, and remove it effectively from the water by adsorbing it on the surface sites of sorption solids. Arsenic can reduce to less than 50 μgL^{-1}, up to 10 μgL^{-1}. The performance of the removal capacity of this technology depends on the fouling of the adsorption media, the flow rate, the pH, and the Arsenic oxidation state in the groundwater. Regeneration of the spoil media is required by backwashing or/and rinsing and neutralization.

There are several chemicals for the removal of As, based on precipitation, coagulation, flocculation and adsorption methods (Han et al., 2003; Herring et al., 1997; Saha et al., 2001; Wlckramaslnghe et al., 2004). The chemicals are aluminum sulfate, ferric salt (e.g. ferric chloride, ferric sulfate and calcium hypochlorite)), ferric hydroxide, alum (aluminum hydroxide), lime softening, limestone, calcium hydroxide, manganese sulfate, copper sulfate, sulfide (Cheng et al., 2004; Han et al., 2003; Hering et al., 1997). The most commonly used metal salts, aluminum sulfate [$Al_2(SO_4)_3.18H_2O$], ferric chloride ($FeCl_3$) and ferric sulfate [$Fe_2(SO_4)_3.7H_2O$] are effective in removing As from the water (99%) to less than 1 μgL^{-1} under optimal conditions (Cheng et al., 1994). There are other sorbents for As removal, such as activated alumina, activated carbon (Kuhlmeier and Sherwood, 1996), copper-zinc granules, granular ferric hydroxide (Driehaus et al., 1998; Wingrich and Wolf, 2002), ferric hydroxide-coated newspaper pulp, iron oxide coated sand, iron filings mixed with sand (Bang et al., 2005; Bruce et al., 2002; Manning, 2002), manganese greensand (glauconite-containing sand), surfactant–modified zeolite, etc. (Subramanian et al., 1997). Ferrous sulfate can be used, but is less effective (Hering et al., 1994; Hering et al., 1996). In most of these technologies, a pH adjustment is necessary.

In Bangladesh, a number of filters have been developed, based on adsorption, such as activated alumina and BUET activated alumina, fixed bed granular ferric hydroxide, iron oxide-coated sand, a gravel bed containing iron sludge, ferric salts, the Nelima filter, the Sono filter (zero-valent iron), the Aqua-bind TM, and Kimberlite tailings, the Alcan filter, the SOES household filter, the BCSIR unit, and the Safi filter. These are all based on effective, low-cost sorbents for As removal in a relatively short time, but most of them have performed with limited success on the field level. Some other synthetic sorbents have also recently been developed that have many advantages over other sorbents. Some conventional and low-cost technologies are being developed by using indigenous materials as sorbent to reduce arsenic, such as red soil which is rich in oxidized iron, clay minerals and processed cellulose materials. I carried out an assessment of the common sorbents in terms of their As removal efficiency, reaction time, pH advantage and disadvantage, based on literature This assessment is presented in Table 5.1. A few common sorbents are briefly discussed below.

i) Aluminum Sulfate

The reaction of a aluminum sulfate dissociation in water and the formation of aluminum hydroxide, which coprecipitates with As or adsorbs As, may be expressed as follows (Ahmed, 2001):

$Al_2(SO_4)_3.18H2O \rightarrow 2Al^{3+} + 3SO_4^{2-} + 18H_2O$ **Aluminum sulfate dissolution**

$Al^{3+} + 3H_2O \rightarrow Al(OH)_3\ (s) + 3H^+$ **Aluminum precipitation**

$H_2AsO_4^- + Al(OH)_3 \rightarrow$ **Al-As complex +Other Products Coprecipitation**

Aluminum sulfate can be used in arsenic removal technology, but the residual aluminum in the treated water is a health concern. Ferric chloride and ferric sulfate, on the other hand, are found to be more effective, since iron hydroxides formed from the ferric salts have a high adsorption capacity for the arsenate As(V). During the coagulation with ferric chloride, strong As adsorption onto hydrous ferric oxide $Fe(OH)_3$ shows that adsorption may be an important mechanism for its removal in the process (Hering et al., 1996). Experimentally, it is found that As(V) is better removed and less sensitive to a variation of source water composition than As(III). As(III) removal by an adsorption process significantly decreases in the presence of sulfate at low pH values. In the case of an As(V) removal, the efficiency slightly decreases, while the removal efficacy increases in the presence of calcium at a high pH value.

During the coagulation-flocculation, the aluminum or ferric hydroxide micro-flocs form rapidly by adding aluminum sulfate, or ferric chloride, or ferric sulfate, and As(V) is also adsorbed onto coagulated flocs. Arsenic(III), however, is not removed well. When comparing experimentally, the As removal efficiency of iron hydroxide and aluminum hydroxide during coagulation, it is found that both iron and aluminum coagulants have equal effectiveness in removing As(V) at a pH < 7.5. The iron-based coagulants are more advantageous than the aluminum-based coagulants, if in solution metal residuals are problematic, or if the pH is >7.5, or if the raw water contains As(III). Ferric salts are found to be more effective in removing As than aluminum sulfate on a weight basis, and to be effective over a wider range of pH. Best results are found when using the mixed Fe(III)–Al(III) reagent during the coprecipitation of As, rather than the individual Fe(III) and Al(III) solution used in the experiment (Edwards 1994). Elevated phosphate and silicate concentrations in the groundwater decreased the effectiveness of the As removal by ferric hydroxide in the coprecipitation treatment or adsorption process (Meng et al., 2001). When there are elevated concentrations of phosphorus and silica in the groundwater, as occurs in Bangladesh, it is noted a ratio of Fe/As greater than 40 is required to reduce As to less than 50 μgL^{-1}.

ii) Iron-based coagulants/absorbents

Groundwater with a natural iron content: generally, the dissolved Fe(II) is present significantly in most of the As-contaminated water in Bangladesh. Often, its concentration is found to be greater than 2mgL^{-1}, but in some aquifers, tube wells water are found to be unaffected by As enrichment, even at a high concentration of the dissolved Fe in the groundwater (Smedley and Kinniburgh, 2002). Dissolved ferrous hydroxide $Fe(OH)_2$ is oxidized to the insoluble ferric compounds $Fe(OH)_3$,Fe_3O_4, FeOOH and Fe_2O_3 (Sarkar et al., 2008; Sarkar et al., 2007).

$$\mathbf{4Fe^{2+} + O_2 + 10H_2O \rightarrow 4Fe(OH)_3\,(s) + 8H^+}$$
$$\mathbf{6Fe^{2+} + O_2 + 6H_2O \rightarrow 2Fe_3O_4\,(s) + 12H^+}$$
$$\mathbf{4Fe^{2+} + O_2 + 6H_2O \rightarrow 4FeOOH\,(s) + 8H^+}$$
$$\mathbf{4Fe^{2+} + O_2 + 4H_2O \rightarrow 2Fe_2O_3(s) + 8H^+}$$

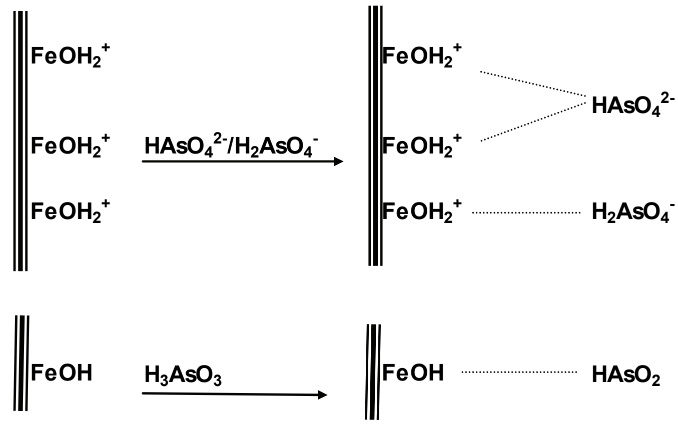
The precipitated hydrated ferric oxide ($Fe_2O_3.H_2O$) or (HFO) particle surfaces are considered to be a diprotic acid with two dissociation constants:

$$\|\!|FeOH_2^+ \longleftrightarrow H^+ + \|\!|FeOH$$

$$\|\!|FeOH \longleftrightarrow H^+ + \|\!|FeO^-$$

The lines represent the solid phase

At a circum-neutral pH, $FeOH_2^+$ and FeOH are the predominant HFO species; they can selectively bind both arsenites or As(III), and arsenates or As(V), through the formation of bi-dentate and/or mono-dentate inner-sphere complexes. In the reaction, Fe(III) serves as an electron-pair acceptor or Lewis acid.



The lines represent the solid phase

Chloride, sulfate and bicarbonate occur as relatively weak ligands and have a poor sorption affinity to HFO particles. The presence of silica and phosphorous reduces the As(III) adsorption/sorption (Kanel et al., 2005). There is a competition of the anions with As(V) for ferric hydroxide sorption sites. As(V), silicate and phosphate are adsorbed onto ferric hydroxide through the formation of the surface complexes with the surface hydroxyl groups (Meng et al., 2000; Goldberg, 1985). In Bangladesh, the concentration of phosphate in the groundwater rarely exceeds 1.2 mgL^{-1} as phosphorus, while the silica concentrations found range between 20-35 mgL^{-1} as SiO_2 (Sarkar et al., 2008). Under an anoxic environment, a reductive dissolution of Fe(hydro)oxides can take place and As may be released into the surroundings.

Granulated iron hydroxide (GFH): it is more effective in simple fixed bed reactors than activated alumina, particularly for arsenate (Wingrich and Wolf, 2002). It has a high treatment capacity of 30000-40000 bed volumes, and produces spent material in the ranges of 5-25g/m^3 of the treated water (Driehaus et al., 1998; Pal, 2001).

Iron oxide-coated sand (IOCS): this is a viable process for As-removal in Bangladesh. Both arsenite and arsenate can be removed by this adsorbent (Newcombe and Möller, 2006).

A gravel bed containing Fe-sludge is used in filters for As removal, but it has a poor removal efficiency. An unstable flow and clogging are found as well (Ali et al., 2001).

Iron filings or zero-valent iron: this is found to be most effective for removing As in the household filter (Leupin and Hug, 2005). Iron filings or zero-valent iron oxidizes to ferrous (Fe^{2+}) iron under an aerobic condition and all dissolved O_2 are consumed, while an anoxic condition develops. It is noted that As removal rates may be affected by the presence of dissolved oxygen and sulfate in the water. In this process, iron oxidation occurs due to the reduction of dissolved sulfate, and As in the water is converted to an insoluble stable arsenopyrite (FeAsS) precipitated form (Ramaswami et al., 2001).

$\mathbf{2Fe^0 + 2H_2O + O_2 \rightarrow 2Fe^{2+} + 4OH}$ – Aerobic iron oxidation
$\mathbf{Fe^0 + 2H_2O \rightarrow Fe^{2+} + H_2 + 2OH}$ – Anoxic iron oxidation
$\mathbf{H_3AsO_3 + SO_4^{-2} + 12Fe^{2+} + 11H^+ \rightarrow FeAsS + 11Fe^{3+} + 7H_2O}$ – Arsenic and sulfate reduction

In this process, zero-valent iron leads to the continues release of Fe(II) and a complete oxidation of As(III) to As(V), in parallel to the oxidation of Fe(II) to Fe(III) with dissolved O_2, without the addition of any oxidant. The HFO formed from the oxidation of Fe(II) in the water acts as an excellent adsorbent for As(V). The arsanate HFO complex retained in the sand filtration can be removed by backwashing (Leupin, and Hug, 2005; Bang et al., 2005). The experiment shows that, in oxic conditions, the arsenate As(V) removal is more than 99.8 percent by Fe^0 filings, which is faster than the arsenite As(III) removal of 82.6 percent at pH 6, after nine hours of mixing (Bang et al., 2005).

iii) Activated alumina (AA)

This is a granulated form of aluminum oxide (Al_2O_3) with a very high internal surface area, in the range of 200-300 m^2/g where sorption can occur. The As adsorption capacity varies significantly by changes of the pH and As speciation. AA is found to be a suitable adsorbent for the removal of As(III), which can reduce As(III) effectively up to 96.2 percent (Singh and Pant, 2004). The presence of chloride and sulfate in raw water may reduce the adsorption capacity of AA substantially (Rosenblum and Clifford, 1984). Other competing anions, phosphate and fluoride, also reduce the removal capacity of AA. AA can be regenerated by flushing with a solution of 4 percent NaOH, which displaces As from the alumina surface, followed by flushing with acid, to re-establish a positive charge on the grain surfaces. The disposal of the high As-concentrated regenerated spent is a concern. The naturally occurring iron degrades the performance of an alumina bed by fouling and clogging the bed, and pretreatment with an oxidation of As(III) is required for the removal of the iron.

iv) Manganese-based coagulant/absorbent

Manganese dioxide-coated sand (MDCS): instead of iron, MDCS can be used to remove arsenite as well as arsenate, but the field performance as household As removal unit has yet to be determined. Manganese dioxide-coated sand (MDCS) is prepared by reacting $KMnO_4$ with $MnCl_2$ under an alkaline condition and in the presence of sand. This filter can be used in small systems or home treatment units. No leaching of manganese has been detected (Bajpai and Chaudhuri, 1999).

Birnessite is a good adsorbent for the removal of As**.** MnO_2 oxidizes As(III), while some of the As(V) gets adsorbed to the hydroxyl group on the MnO_2 surface (Manning et al., 2002).

$\mathbf{MnO_2 + H_3AsO_3 \rightarrow Mn^{2+} + H_2AsO_4^- + 2OH}$ – Oxidation of As(III)
$\mathbf{2Mn{-}OH + H_3AsO_4 \rightarrow (MnO)_2AsOOH + 2H_2O}$ – Adsorption of As(V)

Greensand: this is a granular material comprised of glauconite-containing sand, which is prepared by treatment with KMnO4, forming a layer of manganese oxides on the sand. During filtration through a greensand bed, the $KMnO_4$ oxidizes As(III) to As(V), and As(V) adsorbs onto the greensand surface. In addition, Arsenic is removed by an ion exchange, by displacing species on the manganese oxide surface, like OH^-. The greensand media needs regeneration with a solution of excess KMnO4, or a replacement when the $KMnO_4$ is exhausted (EPA, 2002).

v) Synthetic absorbents

Aqua-bind™ is a selective sorbent to remove As, used in the Alcan filter. This synthetic sorbent is highly effective and produce non-hazardous waste, so disposal is not a concern.

ArsenX^n is more efficient than activated alumina and HFO (Sarkar et al., 2007). The ArsenX^n is a commercially available polymer of hybride anion exchanger. The regenerated ArsenX$^{n\ is}$ suitable to use for multiple cycles. This technology can be used in community-based water supply systems in villages, because it does not need any chemical addition or electricity.

Ion exchange process

Ion exchange resins are able to remove arsenic from water. The reaction mechanism of As and resin is a reversible displacement.

$$\mathbf{2R\text{-}Cl + HAsO_4^{-2} \leftrightarrow R_2HAsO_4 + 2Cl^-}$$
$$\mathbf{R\text{-}Cl + H_2AsO_4^- \leftrightarrow RH_2AsO_4 + Cl^-}$$

R= Ion exchange resin

In this process, ions held electrostatically on the surface of a solid, are exchanged with ions of similar charge in a solution. This technology can reduce As concentrations to less than 50 μgL^{-1} and in some cases even lower, to 10 μgL^{-1}. Synthetic resins and naturally occurring minerals are effective for the removal of arsenic. Resins can remove As(V) very well but As(III) is hardly removed at all (Pal, 2001). The medium used in this process is resin, made by synthetic organic and inorganic materials or natural polymeric materials, that contain ionic functional groups to which exchangeable ions are attached. Zeolites have very large surface areas with ion exchange capacities. These are naturally occurring minerals with a crystalline structure, characterized by large internal pore spaces. Natural zeolite minerals, such as clinoptilolite and chabazite, have a strong affinity for both arsenite and arsenate. These sorbent surfaces are positively charged and have anion–exchange properties. The arsenate removal is relatively independent of the pH and influent concentration.

Removing As from contaminated groundwater in Bangladesh is challenging, due to high concentrations of As(III), sulfate, phosphate and silicate (Leupin and Hug 2005). A high iron concentration leads to a ferric hydroxide coating on the resin surface. In addition, high anion concentrations will reduce the capacity of the media for As removal. The competing anions, such as nitrate and sulfate, strongly reduce the arsenic removal potential. For this reason, it is not practical to use it in groundwater where anions such as nitrate and sulfate are present in high concentrations. In low-sulfate waters, ion exchange resin can easily remove over 95 percent of the arsenate, and treat from several hundreds to over a thousand bed volumes before an As breakthrough occurs. Generally, ion exchange resin needs to be regenerated periodically to remove the adsorbed contaminates and replenish the exchanged ions, by backwashing with a solution of ions and rinsing to remove the regenerating solution. The main concern is the generation of the large volume of sludge, while the disposal of highly concentrated spent regenerating solution and corrosive spent resin is a serious problem.

The Read-F filter has been developed in Bangladesh, based on ion exchange resin. The Read-F consists of an Ethylenevinyl alcohol copolymer (EVOH)-borne hydrous cerium oxide, in which hydrous cerium oxide ($CeO_2 \cdot n\ H_2O$), is an adsorbent. This filter has received provisional verification for promotion in Bangladesh. The filter can produce 40000 liters of treated water that contains Arsenic ≤ 500 μgL^{-1}, iron ≤ 10 mgL^{-1}, phosphate ≤ 4 $mgL^{-1}$and pH ≤ 7.5, and at flow rate of 60 l/h (BCSIR, 2003; BETV-SAM-DPHE, 2007).

The membrane filtration process

This process separates the As contaminant from the water by passing it through a semi-permeable barrier or membrane. The membrane allows some constituents to pass, while blocking others (EPA, 2002). Membrane filtration is a pressure-driven process. It is categorized by the size of the particles that pass through the membranes, or the molecular weight cut off, or the pore size of the membrane:

- Low-pressure membranes, such as Microfiltration and Ultrafiltration; these types of membranes have larger nominal pore sizes, and operate at pressures of 10-30 psi.

- High-pressure membranes such as Nanofiltration (NF) and Reverse Osmosis (RO); these types typically operate at pressures from 75 to 250 psi, or even higher (Johnston and Heijnen 2001; Letterman, 1999).

Most of these applications have proven to be reliable in removing arsenic from water (Shih, 2005). They depend on source water parameters, membrane material, membrane types, et cetera. The oxidation state of As, the pH and temperatures have an influence on the performance of this process. As(V) removal is more effective than that of As(III), so prior oxidation of the feed influent to convert As(III) to As(V) increases the removal efficiency. Synthetic membranes are selectively permeable to certain dissolved compounds but exclude others; in this way, membranes can act as a molecular filter to remove dissolved arsenic, along with many other dissolved and particulate compounds. The pH in the water affects the adsorption of arsenic by creating an electrostatic charge on the membrane.

In Bangladesh, As-removal filters based on RO and NF technologies have been developed in a laboratory setting. The removal efficacy is satisfactory but the water rejection is very high, and the discharge of rejected water is also a concern (Pal, 2001). An alternative reverse osmosis system, named Reid System Limited, was promoted in Bangladesh, but the capital and operational costs of this system are too high. In the NF process, the removal of As and arsenite found lower rejection than arsenate in ionized forms, while arsenite requires pre-oxidation for the reduction of total As. Low-pressure NF with pre-oxidation, or reverse osmosis with a bicycle pump could be used for the treatment of As- contaminated groundwater in rural areas (Oh et al., 2000). The presence of Fe and Mn in the groundwater makes the membrane techniques inefficient for As-removal, due to Fe and Mn, which promote fouling of the small pores of the membranes by coprecipitations (Mondal et al., 2006). In Bangladesh, the Tetrahedron membrane filter has been developed based on this process, and the factor affecting performance of the filter is membrane foiling by suspended solids, dissolved solids, organic compounds and colloidal matter in the raw water, particularly organic matter. High concentrations of iron and manganese in Bangladesh tube wells affect the removal efficiency by membrane technology. In water, ferrous iron oxidized to ferric hydroxide, which leads to scaling and membrane fouling or blockage of the pores of the membrane. The membrane technique is not cost–effective in the context of Bangladesh.

Table 5.1 Arsenic removal efficiency, reaction time, pH, advantages and disadvantages of the common sorbents in Bangladesh.

Sorbent	Sorbent Used	Range of As Tested		Removal efficiency	Reaction Time	pH	Advantage	Disadvantage	Ref:
		Ranges	As Species						
$FeCl_3$	100 mg/L $FeCl_3$ and 1.4 mg/L $KMnO_4$	375-640 μgL^{-1}	Both As(III) As(V)	>90% - 95% or more	15 L/ min	Wide range	LC; SP; CC; Effective at pH wide range; As correlates best with Fe	PO needed; water should not have high SiO4 or PO_4 conc.	(Ahmed, 2001; Vu et al., 2003)
Al-alum	20 mg L^{-1}	0.1 mg L^{-1}	As(V) As(III) less	96%	6 h	6.6	LC, SP, CC ,	PO needs for high removal efficiency; less soluble than $FeCl_3$; TSW	(Ahmed, 2001, Khan et al., 2001)
Read-F	Resin	-	Both	>95	Brief	Wide range	HS; HC; NTW	Adsorbent not as effective at high Fe conc. CPM	(Ahmed, 2001; BETV-SAM, 2007)
Iron filings/ zero-valent iron	1g 2000 mg L^{-1}	200-2000 $\mu g L^{-1}$	As(III) or Both	95 99%	30 min 4 days	7	LC; SP; NT	Not effective in presence of PO_4. Effective in presence of SO_4	(Ramaswami et al., 2001; Su and Puls, 2001)
Mn coated sand	4L of coated sand	500 μgL^{-1}	Both	Good	6L/h, column	Wide range	LC; NO	Complicated. Breakthrough at 740 L in first cycle	(Bajpai and Chaudhuri, 1999)
Al-Mn oxide	1 g	50 mg L^{-1}	As (III)	94%	24h	5.5-8	"Self protecting" from Mg and Ca; remove other toxic metals	Long CT; Most effective at pH 7	(Kepner et al., 1998)

Table 5.1 Arsenic removal efficiency, reaction time, pH, advantages and disadvantages of the common sorbents in Bangladesh. Cont.

Sorbent	Sorbent Used	Range of As Tested		Removal efficiency	Reaction Time	pH	Advantage	Disadvantage	Ref:
		Ranges	As Species						
Aqua-Bind TM	Aqua-Bind TM	152-3500 $\mu g\ L^{-1}$	Both	Almost 100%	15 sec	Wide range	LC; NPT; HS for both As(III and V)	Expensive, HS	(Senapati and Alam, 2001; Vu et al., 2003)
	20 $g\ L^{-1}$	1 $mg\ L^{-1}$	As(III)	90-94%	8-12 h	5-7	LC; NO needs	Slightly less effective at pH >7	(Dikshit et al., 2000)
Lanthanum Hydroxide	0.10 g	0.25 mM	As(V)	reach safe limit	Rapid at pH 3-7, >1day	3-8 INA	LC SP	Long contact time at high pH >8.75	(Tokunaga et al., 1997)
Activated alumina	Fixed bed	170-240 $\mu g\ L^{-1}$	As(V)	~98%	INA	6-7	HAsR for As(V)	LAsR for As (III) Cl^- and SO_4 in raw water reduce adsorption capacity, PO requires and CPM.	(Jalil and Ahmed, 2001)
Granular ferric hydroxide	Fixed bed	Large	As(V) As(III) less	>95%	INA	5.5-9	ST, NTW SP, LM	Fe- Pre-treatment needs to avoid clogging of filter	(Ahmed, 2001; Pal, 2001)
Anion exchangers	100 ml of resin	600 $\mu g\ L^{-1}$	Only As(V)	99%	removal 20 bed vol/h	Tap water pH	Very high As(V) removal	SO_4 and NOx exchange before arsenic; TDS, Se and F- can also decrease life of resin	(Ahmed, 2001; Kepner, 1998; Korngold et al., 2001;
Illite clay minerals	1:40 rock: water ratio	.4 µM As(III) and .4 µM As(V)	Both As(V) and As(III)	80% As (III), 90-100 % As (V)	16 h	6-9.5	LC; pH 6-8.5 for As (III); 7.5-9.5 for As(V)	LCT; low As (III) removal	(Manning and Goldberg, 1997)
Soyatal	1:2, 1:10, or	Half of	As(V)	94% for	24 h	7.1	LC, SP	Long contact time	(Ongley K.L et al.,

Table 5.1 Arsenic removal efficiency, reaction time, pH, advantages and disadvantages of the common sorbents in Bangladesh. Cont.

Sorbent	Sorbent Used	Range of As Tested		Removal efficiency	Reaction Time	pH	Advantage	Disadvantage	Ref:
		Ranges	As Species						
formation	1:20 solid: water wt. ratio	samples ~500 μgL^{-1}	mostly	crushed rock	frequent shaking	INA	HAsR		2001)
Manganese Green sand	.005 m3 greensand + 10g $KMnO_4$ in 972 mL	100 □gL^{-1}	As(III) and oxidizing agent	81%	Flow rate of 1.5 L/min/m2	pH not adjusted	HAsR for As(V)	PO requires, CPM and expensive	(Viraraghavan et al., 1999)
Gravel bed containing iron-coated sand	80 mL of 2 M $FeNO_3$ per 200 cm^2 sand	226 $\mu g\ L^{-1}$	Both	200-225 bed Vol. 15 μgL^{-1}	Several minutes	6-7	As(III) and As(V) remove; Sand can regenerate	TWS, complicated process to make sand; Need temperature control. Quick clogging, regular washing sand	(Ali et al., 2001)
Gravel bed containing iron sludge		300 $\mu g\ L^{-1}$	Both	50%	INA	wide	LAs R, CPM	Not adhere well to gravels, sensitive to flow rate, difficult to install	(Ali, 2001).
Calcium oxide	0.1% lime/ water by wt.	INA	INA	99.9%	16 h	INA	HAsR	Long CT	(Hussain et al., 2001)
Wood charcoal	600-757	INA	INA	97-99%	12-45 mL/ min	INA	HAsR, but not all studies suggested so	Complicated	(Hussain, 2001)
Laterite	5g		Both	50-90%	10 min	INA	Short CT	Long CT	(Sharmin, 2001)

Notes: LC= Low cost, HC=High cost, SP= Simple operation, HS= High selectivity, CC= Common chemical, NTW= Non toxic waste, TSW= Toxic sludge waste, LM= Little maintenance, NP= Non pretreatment, NO= Non Oxidation, PO= Pre-oxidation, HAsR= High As removal, LAsR=Low As removal, NAAS= Not affected by anion competition for adsorbent site; NE=Non effective; CT=Contact time, CPM=Clogging problem of filter media, regeneration is required, and INA- = Information not available

5.4.2 Biological techniques

Biological techniques for As removal include phyto-remediation and biological treatment with living microbes/biofiltration.

The phyto-remediation process

The Phyto-remediation process involves the use of plants to degrade, extract, contain, or immobilize contaminants in groundwater. Arsenic hyper-accumulating ferns, *Pteris vittata* and *Pitylogramma calomelanos*, have been tested for their efficiency in removing arsenic from water and soil. In Thailand, local people have rejected the use of *Pitylogramma calomelanos* for arsenic removal, as they could not find any economic benefit to gain from this fern (Visoottiviseth and Ahmed, 2008). The Polyethylenimine modified fungal biomass (*Penicillium chryosogenum*) is favorable for the removal of anionic arsenic species in water (Deng and Ting, 2007). Limited studies are done on these techniques.

The microbiological process

This process involves the use of living microbes/biofiltration; the microorganisms act directly on contaminant species or create ambient conditions that cause the contaminant to leach from the soil or precipitate/coprecipitate from the water (EPA 2002). Biological oxidation is a common As removal treatment. Certain bacteria in the groundwater are cultured to oxidize iron and manganese, which are often present in high concentrations. Arsenic can be removed through adsorption to the iron and manganese solids. One advantage of this technology is that all three contaminants, Fe, Mn, and As, are removed simultaneously. Biological oxidation is an alternative technology for both As(III) and As(V) species removal, based on the established biological iron oxidation of the groundwater (Katsoyiannis and Zouboulis, 2004). The As(III) oxidation by iron-oxidizing bacteria leads to an improvement of the overall removal efficiency, because As in the form of arsenite cannot be efficiently sorbed onto iron oxides. Indigenous microorganisms in the groundwater, such as *Gallionella ferruginea* and *Leptothrix ochracea*, can catalyze iron oxidation. The main product of the biological oxidation of iron is usually a mixture of amorphous iron oxides. The intermixing of iron oxides, organic material and a bacterial presence produces complex, multiple sorbing solids, which have unique metal retention properties. The As can then be removed by direct adsorption or coprecipitation on the preformed biogenic iron oxides. This technology can be applied with high concentrations of Fe and As in the groundwater, but so far, only a limited treatment by living microbes/bio-filtration has been developed to remove As from drinking water in Bangladesh.

5.5 Strong and weak points of household filters for arsenic removal

Several technologies for As removal filters at household level have been developed in Bangladesh in a laboratory setting, in field trials and/or on a promotion basis in the country. An inventory of the available technologies for the arsenic removal household filters in Bangladesh, including their strengths, weaknesses, costs and users' opinions, is presented in Table 5.2. The screening was done based on previous studies on the evaluation of the existing arsenic removal technologies and other relevant reports (BAMWSP/DFID/WaterAid, 2001a; BAMWSP/DFID/WaterAid, 2001b; BCSIR, 2003; BCSIR, 2008; Mohan and Pittman, 2007; Sutherland et al., 2002; Visoottiviseth and Ahmed, 2008).

5.5.1 Currently implemented As-removal technologies at household level in Bangladesh

In 2001, the Bangladesh government conducted a rapid assessment of nine at that time available removal technologies for household-level use, through the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), and in collaboration with WS Atkins, commissioned by the DFID (the Department for International Development, UK). The technologies were based on adsorption, coprecipitation (usually with iron), ion exchange resins and coagulation. The selection criteria were considered to assess the best potential technology in terms of the groundwater treatment, use of chemicals, biological contamination and social acceptability by the potential users. The evaluation of the performance of five As removal technologies, the Sono, Alcan, Read-F, SIDKO and Tetrahedron, were carried out in 2003 by the Bangladesh Council of Scientific and Industrial Research (BCSIR) of the government of Bangladesh. They did so in association with the Ontario Center for Environmental Technology Advancement (OCETA), funded by the Canadian International Development Agency (CIDA). This project was carried out by the government of Bangladesh under the aegis of the Environmental Technology Verification-Arsenic Mitigation (ETV-AM) Program. The government approved the promotion of the four arsenic removal options that were found socially and technologically acceptable by the evaluation body of the BCSIR. These approved technologies are the Sono, Alcan, and Read-F filters for household use.

The BCSIR has carried out the second-round performance evaluation of seven arsenic removal technologies under the Bangladesh Environmental Technology Verification Support to Arsenic Mitigation Program (BETV-SAM, DPHE et al., 2008). Seven technologies were assessed for water treatment through a set of criteria under realistic conditions in different areas of Bangladesh. Amongst them were four household filters technologies: Earth Identity Project-Star Stevens, the CIWPL, the Shapla Arsenic Removal Filter, and the Nelima. The other three were community-based technologies: Wholly Water, MAGC/Alcan, and Apyron-Aqua bind. Based on the performance evaluation, none of the seven technologies received verification certificates, as the performances claimed by their proponents were not verified and the water produced by the technologies was not safe to drink.

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Simple Aeration filter	* Simple process. * Low cost technology. * No chemical addition.	* 0-50 % As removal.	* *Capital cost*: 20L mud pitcher Tk 100-150. * *Operational cost*: less.	*NIA	Ahmed et al., 2000; BAMWSP/ DFID/ WaterAid, 2000).
SORAS (Solar Oxidation) Removal of As	* Local materials. * Lime locally available.	* Light is required for oxidation. * As removal one third. * Constituents silicate, natural DOC, phosphate etc., have a significant influence on As(III) oxidation and on subsequent removal by adsorption and precipitation. * Not to easy process, if chemical addition is added. * Only 45-78% removal in lab but field tests show lower removal than the one observed in the laboratory <10 % removal observed by researcher.	**Capital cost*: Tk 200-300. **Operational cost*: less.	*NIA	(Hug et al., 2001; Visoottiviseth and Ahmed, 2008).
Passive sedimentation filter	* Simple process. * Low cost technology.	* 0-5% As removal. * Rapid assessment of technologies test shows this technology failed to reduce As to the desired level * Mostly As reduction of 0- 25% of the initial. concentration of As in groundwater possible * Dependent on water quality particularly presence of Fe. * Not reliable for reduce As to desired level. * 50% reduction of As was possible when tubewells water containing 380-480 mgL^{-1} of alkalinity as $CaCO_3$ and 8-12 mgL^{-1} of Fe.	* *Capital cost:* 20 L Aluminum pitcher approx. Tk. 200-250. **Operational cost*: less.	NAF	(BAMWSP/ DFID/ WaterAid, 2000; Ahmed et al., 2000).
GARNET homemade filter	* 50- 60% As removal. * Low cost technology. * No chemical addition. * Simple process to O & M. * Water is taste and iron free. * Locally available of the filter material & spare parts.	* Regular checking is required to detect As breakpoint. * Slow flow rate of the filter. * Bacterial contamination possibility in sand bed. * Method can work in excess Fe content water. * Flow rate 1.8/h.	**Capital cost*: Tk 250-600 based on quality of materials **Operational cost*: less	*Not accepted	(BAMWSP/DFID/Water Aid, 2001; Sutherland et al., 2001; Sutherland et al., 2002; Hoque et al., 2000; Visoottiviseth and Ahmed, 2008).

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Sono 3-Kolshi filter	* >99% As removal * No create problem on water chemistry. * No addition of chemicals. * locally available materials. * Water is clear, taste ,free from metallic taste of high Fe & Ca in water. * Produce 20–30 L/hour.	* Unit is sometimes rapidly clogged if water contains high iron. * Over time, the iron filings bond with solid mass, rendering cleaning and replacement , to overcome this problem CIM is used in two bucket. * Field observation found filter clogging very frequent in the Homna sub district. * Regeneration for original efficiency can only be achieved by changing sand. * Flow rate decreases very quickly. * Control of the flow rate needs further research. *	* *Capital cost*: Tk 2700. * *Operational cost*: less.	* Well accepted. * Simple process to operate. * Simple to maintenance. * Water is taste and iron free.	(BAMWSP/DFID/ WaterAid, 2001; Hussam and Munir, 2007; Visoottiviseth and Ahmed, 2008).
Naturally occurring Fe/Mn	* 90% of As could be removed after 3 days' settlement. * Simple operation by simple shaking the water. * Simple method. * No chemical addition is required.	* Fe levels should be sufficiently high >1.2 mg L^{-1}. * Fe/As ratio and pH need to be favorable. The necessary iron (as Fe3+) to attain the standard as Fe=66 As $^{1.75}$, where Fe and As are in mgL^{-1}. * Removal rate sensitive to form of iron. * Adsorption dominate trapping mechanism when Fe/As weight ratio ≥10. * Fe removal is not easy without a filtration step, as Fe can remain suspended as colloidal matter, even after oxidation. * Sometimes Fe is slow to oxidize, or may be complexes with organic material that hinders oxidation * Precipitation may not occur if alkalinity is low. * Arsenite As removal is less efficient. * High risk of bacteria contamination.	**Capital cost*: NIA. **Operational cost*: less.	NIA	(Mamtaz and Bache, 2000; Mamtaz and Bache, 2001).
Iron coated sand	* >90% of As removal * Well defined * System does not need daily supply of chemicals. * Both As(III) and As(V) can be removed from contaminated water * Low rick of sludge leaching	* Requires pre-treatment for excess iron removal. * Clogging of the sand filter occurs * Requires upper sand bed washing, once in a month * Regular monitoring for As breakpoint of filter * Regeneration of media by passing concentrated 0.2N NaOH or replacement is required * Unit preparation is time consuming and difficult to produce mass production of iron-coated sand * High oven temp up to 550^{0}C, long preparation time:	* *Capital cost*: unit preparation is high cost. * *Operational cost*: Tk 600 for chemical to prepare iron coated sand for 7	* Controlled condition performed in field * Needs oven/ brick kiln to prepare iron coated sand so villagers were	(Ahmed, 2001; Ali et al., 2001 Murcott, 1999; Visoottiviseth and Ahmed, 2008)..

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
		2 days. * Dangerous chemicals handling NaOH & HCl.	L water	not interested. * Flow rate decrease within very short time. * Handling not safe.	
UNESCO-IHE family filter	* Effective removal of As * effective removal of iron * capacity of 100 L/day * Easy to operate	* A byproduct of iron removal plant. * Locally available chemical and equipment. * Mn removal only when groundwater contains low ammonia. * Regular draining of the filter is needed with occasional flushing for maintaining the filter's capacity.	* *Capital cost*: NIA * *Operational cost*: NIA	Well acceptance by users.	(Petrusevski et al., 2008)
Shapla As Removal Filter	* Effective As removal in some water sample * Exhausted spent media is not toxic * Can easily be disposed	* Not received verification certificates from BETV-SAM testing of GoB, failed to meet proponents' performance claims. * Every three months media should be changed. * Fe dissolved in groundwater is not or not adequately removed before reaching the As removal media. Fe not removed rather accumulates in the cracks and crevices and fills the empty bed space of the media and either washes-out into the effluent and carries As/ or reduces media contact time, and creates short circuiting. * Silts and sands are not removed properly resulting in reduced media contact time and/or short circuiting. * As-toxicity of the spent material is unknown, as TCLP and TALP test was not carried out.	* *Capital cost*: US $7 and media cost $2.8 Media should be replaced every three months. * *Operational cost* Normally Tk 350 for 20 kg filter material but can produce Tk 100 at a retail price.	* Replicate units tested on the same well did not perform comparably. * Quality and workmanship of technologies was less than satisfactory.	(BCSIR, 2008; Visoottiviseth and Ahmed, 2008)
Nilima As removal unit (NARU)	* Effective As removal in some water sample * Easy to operate	* Not received verification certificates from BETV-SAM testing of GoB, failed to meet proponents' performance claims on most wells. * Quality and workmanship of technologies was less than satisfactory.	* *Capital cost*: NIA * *Operational cost*: NIA	* Replicate units tested on the same well did not perform comparably.	(BCSIR, 2008)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Filter using gravel bed containing iron sludge	* Some extend As removal * Simple process to operate	* As removal efficiency of the gravel beds is relatively low * Prepared iron sludge does not adhere strongly to the gravel bed. * Iron sludge accumulates on top of the gravel bed and found to be very sensitive to the flow rate. * Higher flow rates or abrupt increase of flow rate destabilized the accumulated iron sludge	* *Capital cost*: NIA *.*Operational* cost: NIA	* NAF	(Ali et al., 2001)
Rajshahi University /New Zealand Iron Hydroxide slurry filter	* Can be installed with locally available materials	* No easy process, three units. * Needs to make iron hydroxide, which is difficult to get.	*.*Capital cost*: NIA * *Operational* cost: NIA	* NIA/ NAF	(Jones, 2000)
STAR Household	* >90% As removal * Tech has no problem with major water chemistry * Little bacterial contamination Good flow rate 18L per hour (mean 14L per hour	* Sand bed used for filtration is quickly clogged by flocks and requires washing at least twice a week. * Chemicals form visible large flocks on mixing by stirring with stick.	*.*Capital cost*: 500 *.*Operational cost*: NIA	* Fairly accepted by users *.Frequently cleaning of unit is needs * Need to add reagent	(BAMWSP/DFID/Water Aid, 2001; Sutherland et al., 2001; Visoottiviseth and Ahmed, 2008)
Earth Identity Project-Star Stevens	* .>90% As removal *.Easy to operate * TCLP and TALP test shows that iron sludge and filter media are non hazardous.	* Not received verification certificates from GoB. * Failed to meet proponents' performance claims on most wells. *.Only deployed on wells with conc. of As arsenic ≤ 650 µg/L, Fe ≤ 11.0 mg/L and $PO4^{3-}$ ≤ 8 mg/L. * No guarantee for producing arsenic-safe water if O & M manual is not followed strictly by the end-users.	* *Capital cost*: NIA * *Operational cost*: NIA	* Replicate units tested on the same well did not perform well.	(BCSIR, 2008)
CIWPL (Canadian International Water purification for HH use)	* Easy to operate * TCLP and TALP test shows that iron sludge and filter media are non hazardous.	* Not received verification certificates from GoB. * Only deployed to wells with conc. of As≤ 622 µg/L, conc. of Fe ≤o 11.3 mg/L and PO_4^{3-} ≤ 4mg/L. * Treated water contained high levels of Cl_2 and 2, 2-dichloropropane and conc. of Cl_2 in some treated water above GoB/WHO drinking water limits.	* *Capital cost*: NIA * *Operational cost*: NIA	* Replicate units tested on the same well did not perform comparably	(BCSIR, 2008)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Iron filings in jerry can	* Simple process to operate. * Simple to maintenance.	* Needs iron filling packing. * Iron filings not easily found. * No reduction of As found at 242μgL^{-1}.	* *Capital cost:* Tk 50 for jar for 10 L. * *Operational cost*: NIA.	* NAF	Massachusetts Institute of U.S.A email: murcott@it.edu
DPHE/ Danida Bucket Treatment Unit	* As removal performance to some extent good. * Low cost. * Locally available materials * Alum and potassium permanganate are cheap. * Can be promoted in community on large scale.	* Fails to remove arsenic to 0.05 mg/L in some waters. * Poor performances with poor mixing and variable water characteristic & pH. * Residual concentrations of Al and Mn in treated above the recommended levels set by WHO. Al conc. > 300 ppb, Mn conc. exceeded WHO standard. * Excess Mn-Fe ion imparts undesirable taste to beverages. * Possibility of bacterial contamination. * Low flow rate 3.6/h.	* *Capital cost*: Tk 350 filter * *Operational cost*: Chemical for 20 L water Tk 1.5	* Fairly accepted * Sand filter and unit needs regular washing is boring, * Treated water is taste and color less	(BAMWSP/DFID /WaterAid, 2001; Mudgal, 2005; Sutherland et al., 2001; Sutherland et al., 2002)
BUET two bucket treatment unit	* 80-90% As removal * Use of $FeCl_3/Fe(SO_4)^3$ is more efficient than alum. * Locally available materials	* Colour formation due to addition of $KMnO_4$ * Limited removal of Mn by the bucket system. *Possibility for presence of excess concentration. of Al and Mn in treated water. * Fe/As greater than 40mg/l is required. * Elevated Si and P decrease adsorption of As by ferric hydroxide. * Bacteriological problem.	* *Capital cost*: NIA * *Operational cost:* $ 4 for 50 liter water	* Studied people well accepted	(Ahmed, 2001)
Two bucket treatment, unit tea bag method	* >80% As removal * Bleaching powder Ferric chloride and fly ash locally available.	* Need vigorous stirring after adding the chemical packet and after 1 hr again to vigorous stirring. * Need to be careful not to disturb As sludge at bottom As sludge problem.	* *Capital cost*: NIA * *Operational cost:* Tk 35/ (0.05$) /packet to treat 10 liter water	NIA	(Murcott, 1999)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
BUET Activated Alumina Filter	*> 80% As removal * Water tasts o.k. and is iron free * Both total and ferrous iron are removed from the water during the treatment * Manganese can be removed but not as efficiently as Fe (II) because oxidation of Mn (II) is a slower process. * Process is very efficient in removing As(V) from water, while As(III) is poorly removed. * In the filed residual chlorine found within limit * Flow rate 8 L per hour	* Not accepted in rapid assessment. * Potentially prone to clogging by FeOH. * Problems on design of filter such as filter frame, liable to fall over and too height. * Adjusting flow rate to designated mark needs to find water flowing from the tube. * Connection tubes easily contaminated by bacteria through external and unhygienic practices of the users. * Periodically regenerated with 175 L of 4% NaOH and 150 L of 1% HCl (*2*) and replace after a certain lifetime. * Regular monitoring needs at outlet, and trained people to properly conduct O & M. * 10% of Fe seems to pass the AA unit while the household sand filters remove ≥99%. * Pre-treatment must for oxidation of As (III) to As (V) and removal of Fe. * Tubes and column if not well sealed and prone to leakage. *Bacteriological contamination. * Flow rate easily decreases.	* *Capital cost*: Tk 1000 * *Operational cost*: NIA	* Not simple to O & M * Design needs modification for women's use in raising water for gravity flow through the subunit * Needs long time wash * Connection tubes are hard to wash and fit * Difficult to dosage chemicals (reagent on hand). * Sands needs wash twice a week, because of clogged sand filter * Water iron free * Pipette and bottle of reagent are hard to dispense.	(BAMWSP/DFID/Water Aid, 2001; Sutherland et al., 2001; Ahmed, 2001; Berg et al., 2007; Visoottiviseth and Ahmed, 2008)
Granular Activate Carbon (GAC) filter	* As removal some extent	* Removal depends on pH of water * Re-generation problem exist * No economically viable	* *Capital cost*: Expensive * *Operational cost:* Expensive	NIA/ NAF	(Visoottiviseth and Ahmed, 2008; Mohan and Pittman, 2007)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
AMAL Household Filter with AA	* >90% As removal * Simple to operate. * Technically very effective	* AA gets exhausted after a certain time and will need to be regenerated periodically. * Replacement is expensive. * Depends on chemical composition of raw water. * Regeneration is needed by dipping exhausted AA in 4% NaOH followed by dipping in 0.5N HCl and rinsing in water till pH value of (7-8). * High Fe bearing water can cause clogging of filter requiring frequent washing of media. * Poor quality AA can adversely affect the performance and increase the risk of unacceptable level of residual Al in treated water.	* *Capital cost*: Indian Rs 700 to Rs. 1,500 depending upon the material of construction * *Operation cost:* Chemical * AA costs Rs. 100 (US$ 2.25) per kg	* Very attractive to users	(Mudgal, 2005)
Fixed bed Granular Ferric Hydroxide (AdsorpAs®)	* 100% As removal *High As removal, both As forms As(III) & As(V) on different adsorbents * GFH with high specific surface 5 to 10 times higher efficiency for adsorption of As than other adsorbents * Simple, safest & effective for small water facilities * Spent GFH is nontoxic solid * Easy to operation * Arsenate adsorption on GFH was maxima when the initial As(V) < 500 mg/L at sorbent concentration of 10 g/L.	* Very costly. * Can not be prepared with locally available materials. * Large As-Fe sludge waste generate. * Difficult to disposal of waste. * AdsorpAs® no needs chemical regeneration. * Capacity of GFH depends on the PO_4 , pH and raw water Arsenic content. * Adsorption is deceases with increases of pH and PO_4 content. * Complexation of arsenate to GFH depends. on both pH and amount of loading of the oxyanion. * Arsenate has a strong affinity for GFH and with monodentate complexation being highly favored at acidic pH while bidentate binuclear complexation dominates at neutral pH.	* *Capital cost*: Expensive * *Operational cost*: Expensive	* Sometime difficult to install * Waste disposal problem	(Driehaus et al., 1998) (Guana et al., 2008)
SOES Household Filter and Tablet system	* 93-100% As Removal * One tablet is sufficient for 20 liters of contaminated water *of 1000 µg/l.* *	* Difficult to prepare tablet contains iron salt, oxidizing agent and activated charcoal by rural HH women. * Sludge is rich arsenic. * Easy disposal sludge is to be done on soil with cow-dung, As can eliminate from the sludge as volatile As species through the microbes in the cow-dung.	* *Capital cost*: NIA * *Operational cost*: U.S $ 10 for per year for	* Removal efficiency was found in the range of 93-100% at field level in West	(Das et al., 2001)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
			20 liter water	Bengal, India .	
Bijoypur Clay Filter	* Aluminum rich –Bijoypur clay * No chemical unit	* Difficult to get appropriate soil. * Commercially no unit is constructed to utilize these cellulose material for As removal.	* *Capital cost*: NIA * *Operational cost*: NIA	NAF	(Visoottiviseth and Ahmed, 2008; Sharmin, 2001)
BCSIR Filter Unit	* Simple * May be installed with local materials	NIA	* *Capital cost*: NIA * *Operational cost:* NIA	NIA/ NAF	(Ahmed, 2001)
Adarsha Filter	* Simple process * Low cost technology	* Rapid assessment of technologies test shows this technology failed to reduce As to the desired level * <5% As removal. * Low flow rate, 0.9 liter per hour. * Chemical control unknown. * Rapid assessment of technologies test shows this technology failed to reduce As to the desired level.	* *Capital cost*: Tk 550 * *Operational cost:* NIA	* NAF	(BAMWSP/DFID/Water Aid, 2001; Sutherland et al., 2001; Sutherland et al., 2002; Visoottiviseth and Ahmed, 2008)
Safi Filter	* 86-100% As removal * Simple, no odor * No physical problem * 40L water /day enough for a HH * No leaching up to candle pH 11	* As removal good initially but decreases very soon * Media became clogged and suffered rapid erosion from mechanical cleaning. * Filter candle leaked at the joints and disintegrated due to inadequate strength. * Terribly low filtration rate is a major hindrance to the efficiency of the techniques. * Need regular washing and washing more or less frequently than the recommended intervals may hamper the efficiency of the filters. * Need to wash as recommended fifteen days. * Disposal of As-laden candle of the S*afi filter* is a concern * Reduction of As removal capacity after usage for two months. * Bacterial contamination found at all operation.	* *Capital cost*: Candle cost Tk 200-600, which has to replace every two months. * *Operational cost:* Tk 900 for 40 L per day	* Taste of the filtered water was different from the un-filtered water according to 80% of the users. Odour was not un-pleasant. * Users were ignorant about the adsorbing candle materials * Most of users didn't follow washing	(Mudgal, 2005; Rahman et al., 2005; Visoottiviseth and Ahmed, 2008)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
				schedule of 15 days	
Indigenous Raw Materials - Coconut Shells, Coir, Husks Filter	* Local materials, so easy to build filter	* Effectiveness of Removal efficiency is not known. * Commercially no unit is constructed to utilize these cellulose material for As removal.	* *Capital cost*: NIA * *Operational cost*: NIA	NIA/ NAF	(Ahmed, 2001)
Kanchan ™ As /Biosand filter	* 87-95 % As removal * Simple and easy O&M *High flow rate 15-20L /hr * All material available in Market	* Needs boil-layer for removing pathogens. It takes 30 days to establish depending on water quality. * Flow rate problem, which is controlled by sand grains, sieve and proper wash. * Risk for bacterial contamination, only 58% TC and 64% E. Coli removal.	* *Capital cost*: Tk 14000 * *Operational cost*: Tk 350 /yr HH	*Controlled condition accepted by users	(Murcott, 1999)
Biological filtration for As removal	* As could be removed below 5 mg/L in a biological sand * Iron in the effluent was < 0.1 mg/L at all times.	* Filtration column provided the ratio of iron to arsenic was 40:1. * Depth of filter was found to influence As removal more. Possibility of filter clogging. * Optimum backwashing schedule are also needed. * Exterminated only lab scale.	* *Capital cost*: NIA * *Operational cost*: NIA	NIA/ NAF	(Pokhrel and Viraraghavan, 2009)
Alcan enhanced activated alumina	* 100% As removal * Easy to handle * Simple to operate * No problem to water chemistry * High flow-rate > 300/h	* Relatively high cost. * Clog by FeOH. * Bacteriological problem sometimes.	* *Capital cost*: Tk 3500 * *Operational cost*: Initially no requires	* Well accepted by users * Simple to O&M	(BAMWSP/DFID/Water Aid, 2001a; Sutherland et al., 2002; BCSIR, 2003; Visoottiviseth and Ahmed, 2008)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Ion exchange with chloride-form strong-base resins	* Strong basic resin can remove negatively charged species and As when it pretreated with chloride * Ion –exchange can easily be regenerated by NaCl solution	* Depends on sulfate and nitrate of the raw water, but less dependent on pH of water. * As is uncharged so pre-oxidation of As (III) to As (V) is required. * Oxidants must be removed from ion –exchange media to avoid damage the resign. * High tech O&M. * Regeneration creates sludge problem.	* *Capital cost*: NIA * *Operational cost*: NIA	NIA/ NAF	(Visoottiviseth and Ahmed, 2008)
Read F Filter	* 100% As removal * Very high flow rate * Easy to handle * Material contains no organic solvent or other volatile substance and is not hazardous material	* Received provisional verification for development in Bangladesh. With new media ART can produce 40000 liters of treated water with conc. that contain arsenic ≤ 500 µg/L, iron ≤ 10 mg/L, phosphate ≤ 4 mg/L and pH ≤ 7.5. Flow rate 60 l/h. * Locally not easily availability of this medium.	* *Capital cost*: Tk 5500 * *Operational cost*: Initially no requires	* Water is taste and iron free * Easy process to operate * Simple to O&M	(Ahmed, 2001; BCSIR, 2003; Visoottiviseth and Ahmed, 2008)
Tetrahedron ion exchange resin filter	* >80 % removal As from initial conc. of 100-1700ppb. * Filter bed can regenerate by NaCl solution * Easy to operate * Residual chlorine kill bacteria growth in the media * High flow rate (mean 52 l/h	* Unit is Costly. * Potentially prone to clogging by FeOH. * Needs regenerate the resign. * Materials locally not available. * Locally not repairable. * Concern on toxicity of spent media and its leachate.	* *Capital cost*: Expensive **Operational cost*: Expensive	Fairly/ well accepted by users Water is taste and iron free * Easy to process and operate * Simple to O&M	(BAMWSP/DFID/Water Aid, 2001a; BCSIR, 2003; Sutherland et al., 2001;, Sutherland et al., 2002; Visoottiviseth and Ahmed, 2008) ()
Apyron Arsenic Treatment Unit Aqua-Bind™	* 100% As removal * simple to use, easy to maintain, * Highly selective to remove only As(III) and As(V). * Nontoxic and resistant to bacterial growth * Health or disposal concerns	* Backwash requires every couple of weeks. * Replaced after six months. * Locally not easily availability of this medium.	* *Capital cost*: Expensive * *Operational cost*: Expensive	NIA/ NAF	(Senapati and Alam, 2001; Vu et al., 2003)

Table 5.2 Strengths, weaknesses, costs and users' opinions regarding the common technologies for household filters in Bangladesh. Cont.

Name of Tech	Strengths	Weakness	Cost	/User Opinion	References
Low-pressure Nanofiltration and Reverse Osmosis	* NF can remove > 90% of As removal * RO can remove >95% * Easy operation * High As removal performance * No solid waste * Low space require	* Due to lower rejection of arsenite water needs pre-oxidation. * Not easy to build with locally available materials. * As removal is independent of pH and presence of other solutes but affected by presence of colloids. * If once fouled by impurities the membrane can not withstand, needs to be replaced/ pretreatment. * Membrane does not withstand oxidizing agent. * Fe and Mn can lead to scaling and membrane fouling.	* *Capital cost*: Expensive * *Operational cost*: Expensive	NIA/ NAF	(Ahmed, 2001; Visoottiviseth and Ahmed, 2008)
MRT-10000 and Reid system , Ltd	* Effectively reduce As * 80 % As removal * Easy system * Removes impurities	* Capital cost high. * Operational cost high.	* *Capital cost*: Expensive * *Operational cost*: Expensive	Tested in BUET Lab scale/ NAF	(Visoottiviseth and Ahmed, 2008)
	* 95% of As removal *Water taste is good * Used beads can be used as fish food. * Filter is economic * Produces no toxic waste.	* Light is required for photosynthesis. * As removal efficiency depends on number of beads and duration of exposure. * Alginate beads of filter must be changes every three months.	*:Capital cost*: NIA * *Operational cost*: NIA	NIA/ NAF	(Visoottiviseth and Ahmed, 2008)
Techno-food water technology	* 95-98% As removal * Impurities and bacteria * Membranes do not utilize chemicals and do not accumulate * Disposal of membranes is no threat to environment	* Removal is depended on pH. * O & M requires wiping to clean the membranes. * Safest As removal system. * Not cost effective for single household.	* *Capital cost*: NIA * *Operational cost*: NIA	NIA	(Visoottiviseth and Ahmed, 2008)

Note: NIA stands for= No information available, NAF=Not applied at field level, TCLP= Toxicity Characteristic Leaching Protocol and TALP= Total Available Leaching Procedure

5.5.2 The field performance of currently implemented household As-removal technologies and users' opinions

In this study, conducted in 2008, the performance of the three currently implemented As-removal technologies at household level was assessed. A field visit was made to villages in the sub-district of Homna, in the district of Comilla, the southeastern part of the country, where an NGO (DART) had promoted the Sono, the Alcan and the Read–F filters, after approval by the government. Information on the number of operating filters in the villages, their operation and maintenance, cost, method of sludge disposal and frequency, was collected through conducting group discussions, and interviews with users and representatives of the implementing NGO. Until the moment this study was conducted, DART had distributed a total of 327 Sono filters, 11 Alcan filters, and one Read–F filter to the villagers in nine wards. In Bangladesh ward is an area which constitutes seven to ten villages to facilitate local self government activities. All filter units were found to be comparable and sufficient in their As-removal capabilities (≥ 95%), although with some limitation.

The Sono filter: since one year, DART has provided Sono filters to seventeen interested households in Huzurkandi village, in Hommna. Nine workers of DART are working in nine wards in the Garmora union. The DART workers have been testing the water quality of the Sono filters quarterly, through the UNICEF Wagtech As field kit. The price of the filter is Tk 2,700[2]. The provider set two price ranges according to the socio-economic condition of the villagers. The very poor had to pay 10 percent of the total price, i.e. Tk 270, and the poor and middle class had to pay 20 percent of the total price, i.e. Tk 540. Now, many people in the same village and adjacent villages are interested to get the Sono filter. The representative of DART suggested to the users to pour hot water into the filter, to kill bacteria, after each 15-days interval. Yet, only a few users are following this procedure. During interviews, one user informed us that his filter very often gets a slow flow rate; it sometimes takes 12 hours to treat five liters of water. To solve this problem, he has to clean the filter device and sands frequently. All users told us that they had yet to start with the sludge disposal. Some of the villagers preferred to use the Sono filter over other filters, because the two buckets of the filter have some resale value. When the filter does not work well, they can always sell their buckets for at least Tk 300-400. When asked about any bacteriological contamination of the treated water, the users said that they do not know whether their drinking water is contaminated or not. The NGO did not execute any bacteriological test of the treated water until the survey.

The Alcan filter: DART distributed Alcan filters to 11 households in the villages. The flow rate of the treated water is faster than that of the Sono filter. The filter device is small, so it does not need much space to keep it in a room. Chemicals are needed for treating As-contaminated water (two packets). The filter has a life span of three to four years. It is suggested to pour hot water through the filter after each 15-days interval, to disinfect the treated water. The original price of the filter is Tk. 3,500. The NGO's set price of the filter was 10 and 20 percent of the total price as the contribution of very poor and others villagers, respectively. Most of the villagers are interested to buy this filter, as the flow rate is high. A disadvantage is that the filter appliance is small in size, with less water capacity, so filtering the water takes relatively much time.

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[2] At the time of study Euro 1 was Tk 93

The Read-F filter: the flow rate of this filter is very high. The price of the filter is Tk 5,500, with 10 and 20 percent of the total price subsidized for the very poor and others, respectively. Because of the relatively high price, only one household in the village took this filter. In the beginning, the treated water had some smell, but after the installation had been working for several days, the smell disappeared.

User's perception on the filters' operation: users of the three types of filters are satisfied to drink the treated, As-free water of their filters. A comparison of the different types of As treatment units is presented in Table 5.3, based on the users' opinion.

Table 5.3 Field performances and users' opinions of three promoted household filters.

User Opinion	Arsenic removal filters		
	Read-F	**Alcan**	**Sono filter**
Taste	- Good taste. Untreated water contains a lot of iron	- Good taste. Untreated water contains a lot of iron.	- Good taste. Untreated water contains a lot of iron.
	- At the beginning of filtration	- At the beginning of filtration.	- At the beginning of filtration.
Filter appliance	- Very small.	- Smaller compared to Read-F filter.	- Larger (big buckets, stands) than Alcan and Read-F filters.
Flow rate	- Very fast.	- Medium.	- Slower compared to Alcan and Read-F filters.
As (tested by field kit)	- 0 µg L^{-1} As.	- 0 µg L^{-1} As.	- 15-20 µg L^{-1}As.
Operation and handling	- Easy operation but requires more time to feed water, so user feels bored and disturbed. - Handy appliance; can be moved easily from one place to another.	- Easy; takes less time compared to Read-F filter but more time than the Sono filter. - Not a handy appliance to move easily from one place to another.	- Moderately easy operation. Less time required for feeding water. - Heavy appliance; needs to be fixed in one place in the room. - Design needs improvement, stand and buckets can be broken anytime, not strong enough to last for 2-3 years.
Maintenance	- Requires no attention.	- Requires attention to use chemicals.	- Requires regular cleaning of the appliance and sand bed, otherwise water flow rate becomes very slow. Clogging problems frequently occur.
	- No need of hot water use to kill the bacteria.	- Requires hot water use to kill the bacteria.	- Requires hot water use to kill the bacteria.
Capacity of production	- 41000 L	- 8100 L	- 8100 L
Chemical	- Requires no chemical addition. So user is happy.	- Requires two packets of 3 kg of chemical addition.	- Requires no chemical addition.
Cost (Tk)	- 5,500	- 3,500	- 2,700
Life span	4-5 years	3-4 years	3-4 years. Within 3 months As removal efficiency decreased to some extent, so users are confused.
Interested in filter	- Not interested due to high cost, no resale value & time-consuming use.	- Moderately interested due to relatively high cost and no resale value.	- Most are interested in this filter because its cost is low and two buckets have resale value.

Source: Field visit, 2008.

Information on the disposal practices of the users was not collected, because users had not yet started to dispose of their sludge. The arsenic leaching from the sludge or waste generated from the three treatment processes is dependent on the type of removal mechanism and the ultimate sludge disposal methods. Most of the other villagers are observing the performances of the three types of filters, in order to select the best one for their own use.

5.6 Selection of technology for optimization

To select the technology for optimization, a MCA was used, to conduct an integrated assessment of the 37 technologies out of 40 inventoried As-removal technologies. Because three technologies; Read-F, Alcan and Sono filters are approved by the government and promoted in the villages. An integrated assessment includes an analysis of technological, economical and environmental factors as well as social aspects through an interdisciplinary approach (Seghezzo, 2004; Wenzel, 2001). Using a set of criteria, the MCA produced a ranking of all identified technologies, which was used to support the selection of the potential technology for future optimization (cf. Ellis and Garelick, 2008).

For the integrated assessment two types of criteria were defined: (i) technical, (ii) social. Per criterion, the MCA procedure utilized a performance matrix, in which the As-removal technologies are presented in columns, while their performance values are presented in rows. Each criterion was further divided and a total of 21 indicators included a variety of parameters to be assessed (see Table 5.4). A screening matrix on strengths, weaknesses, cost, acceptability and development status of the technologies in Bangladesh was developed. The matrix was set up, based on the available information on technical and societal factors (see Appendix 3). The operational indicators were intended to select the technology for the optimization, in terms of technical appropriateness and suitability for the users. The social indicators were based on the five slots in the adapted model of Spaargaren and Vliet (2000). The technical indicators include the As-removal efficiency, investment costs, chemical uses, the availability of chemicals and materials, operation and maintenance, environmental risk, the handling and disposal of As sludge. The social indicators include the users' acceptance and participation in a rural context, and the operation, maintenance and cost of the appliance. Health and environmental indicators are included as well, because of their potentially long-term effects, like in the handling of spent As-rich filter materials. Except for the three technologies currently promoted in the field, all inventoried As-removal technologies, were evaluated according to the two sets of criteria, comprising 21 operational indicators.

5.6.1 The calculation procedure for the selection of a potential technology

Selection of the technologies was done through calculation by a weighted-scale checklist (Seghezzo, 2004). The weighted-scale checklist distinguishes the relative differences between the importance of technological, economical and social issues. It also permitted a quantitative comparison between the different technological alternatives according to their technological appropriateness and suitability of users, based on the assessments of different technologies (Tables 5.1 and 5.2, and Appendix 3). The selected indicators were weighted according to their relative contribution (Importance) to the whole of the technological, social aspects and economic in the context of rural Bangladesh. A relative score was assigned to each technology in relation to these particular indicators (Performance) after the categories were weighted. The individual potentiality for each indicator was calculated as the Importance of the indicator multiplied by the Performance given to the technology for this particular indicator. The Potentiality Index (PI) of the technology for the optimization was obtained by individual scores, summed by rows.

Table 5.4 Criteria and indicators for selecting an As removal-technology for optimization.

Criteria	Indicators(*)	Description
Technical aspects	Efficacy	Arsenic reduced < 50µgL-^{1} As (Bangladesh Standard).
	Chemical use	Requirement of multiple chemicals.
	Pre-treatment needs	Pre-treatment like pre-oxidation, readjustment of pH, etc.
	Chemical problems created by the technology.	Water chemistry is changed due to the addition of chemicals.
	Bacteriological problems.	Collection, transportation and/or operation make any contamination possible, such as growth of FC and TC.
	Adequate production of As-free water.	High flow rate. Production of an adequate volume of treated water for a household members.
	Management requirements of the system.	System is complicated; it needs addition of chemicals, pre-treatment, monitoring of breakthrough and clogging, regeneration of filter bed material or media change, requires electricity, et cetera.
	Reliability.	Robustness: vulnerability and risk associated with errors in its operation.
	Installation cost / equipment cost.	High cost depending on imported chemicals and equipment.
	Lifetime of installation.	Lifetime of the equipment/filter.
	Local availability of required chemicals.	Local availability of the chemicals for treatment of the water.
	Local availability of filter materials.	Locally available spare parts of the filter.
	Generation of As-toxic waste/sludge.	Production of large toxic As waste, which creates a problem of disposal.
Social aspects	Acceptability by users.	Compatible to the rural lifestyle (slot1).
	Operation and maintenance time.	Suitable for household time allocation, HHs women can operate and maintain within their household allocated time (slot 2a).
	Size of the appliance.	Space structure and portable filter (slot 2a).
	Installation cost.	Low cost of the filter, affordability for the poor house-holds based on their recourses allocation (slot 2b).
	Operation and maintenance cost.	Low cost for operation and maintenance of the filter. Chemicals and equipment spare parts are locally available and affordable for households (slot 2b).
	Simplicity of operation and maintenance.	Comfort and convenience of operation and maintenance by rural HHs women (slot 3).
	Disposal of As sludge	Clean handling of As toxic waste water and sludge with regard to health and safety (slot 3).
	Required training and discipline	Easy operational and no extensive training and prolonged motivation by the provider (slot 4).

(*) A definition of the indictors is presented in Chapter 3.

The first step of the assessment was the screening of all 37 technologies by a relative weighted scale of Performance (Table 5.5) and the second step was to calculate a Potentiality Index (PI) of the 14 technologies selected the first round (Table 5.6) for the optimization. The details of the calculation are as follows:

Importance of criteria and indicators

The maximum importance assigned to a criterion was 100 and relative importance values were assigned as proportional importance. In the analysis, more than one criterion had the maximum importance. When all criteria were equally important, then all were assigned the maximum importance. So, the criterion with the highest relative importance was considered 100 and the rest of the values were given proportional importance (Ratio in Table 5.6) and calculated as criterion (weightage), divided by the criterion with maximum relative importance (weightage) and multiplied by 100. Ratio represents the proportionate value to maximum weightage. A similar procedure was done on the indicators and, subsequently, all categories were expressed as a percentage. The maximum possible Importance Value for the criteria (MIVc) of technical and social aspects was calculated, as the individual ratio (R) of a criterion, divided by the total ratio (TR) of the criteria and multiplied by 100.

$$R = (\text{Weightage}/\text{Maximum weightage}) \times 100$$
$$RT = \sum R$$
$$MIVc = R / RT \times 100$$

The Maximum possible Importance Value for the indicator (MIVi) of technical and social criteria, on the other hand, was calculated as the ratio (R) of the indicator, divided by the total ratio (RT) of all indicators and multiplied by MIVc (50) of each criterion.

$$R = (\text{Weightage}/\text{Maximum weightage}) \times 100$$
$$RT = \sum R$$
$$MIVi = R / RT \times 50$$

Performances of technology (PT)

Different technologies were compared by assigning certain performances from 0 to 100 to each technology in relation with each indicator, based on the performance evaluation (Tables 5.1 and 5.2, and Appendix 3). The performance of a technology (PT) indicates the goodness of the technology related to the indicator, according to the perceived potentiality of each technology for each particular indicator. The assignment was made simple by reducing the possible relative performance values to only 100, 75, 50, 25 and 0, and by rejecting the technologies that had a relative performance value of 0. The higher the performance, the more a particular indicator will contribute to the overall score of the technology potentiality. For example, if a technology was able to reduce an As concentration less than $50 \mu g L^{-1}$, the indicator of the As removal *efficiency* for this technology was assigned a performance=100. Certain indicators, such as high installation/equipment costs, local unavailability of materials, or the technology having failed in the evaluation by the government, scored zero performance. The technology concerned was then dropped altogether from the assessment, even if it had a high As-removal efficiency and high rankings on other indicators in the screening matrix.

Potentiality Performances of technology (PPT)

A potentiality performance of technology (PPT) was calculated for each indicator for each technology, as the Maximum possible Importance Value (MIVi) of indicator multiplied by the Performance of Technology (PT) of the same indicator, divided by the maximum possible performance (100).

$$PPT = PT \times MIVi / 100$$

The assignment of PPT was only done with indicators, not with criteria. The potentiality of a criterion is the sum of the potentiality of the indicators within this criterion. Potentiality depended on the performance of the technology, assigned independently on the indicators, and the importance previously assigned to those indicators.

Potentiality Index of the technology (PI)
The potentiality Index of a technology is the sum of all scores of potentiality performances for both technical and social criteria of each technology. The potentiality performance of technology in terms of the technical aspect (PPTt) and in terms of the social aspect (PPTs) was calculated by summation performances scores of the indicators in lines of rows for individual technology.

$$PI = \sum PPTt + \sum PPTs$$

The maximum PI was 100.

The Potentiality Index of a technology is the sum of all performance scores for both the technical and social indicators. The potentiality performance of technology in terms of the technical aspects (PPTt) and the social aspect (PPTs) were calculated by adding up the performance scores of the indicators per individual technology.

Table 5.5 Relative weightage screening of the As removal Technologies.

Arsenic removal technologies/filter	Weightage of Performance				Potential for optimization
	Technical Aspects			Social aspects	
	As removal efficiency	Installation /equipment cost	Locally availability chemicals/ materials	Field application and performance	
Simple aeration	25	100	100	0	Not potential
SORAS As-removal	25	100	100	25	Potential
Passive sedimentation	0	75	100	0	Failed by GoB
GARNET homemade	50	100	100	50	Potential
Naturally-occurring Fe/ Mn	75	75	50	0	Not potential
Iron coated sand	50	25	75	25	Potential
UNESCO-IHE family filter.	100	0	0	50	Not potential
Shapla As-removal	0	100	75	75	Failed by GoB
Nilima As-removal	0	75	50	25	Failed by GoB
Gravel bed -iron sludge	25	25	100	25	Potential
Rajshahi Uni /New Zealand Iron Hydroxide slurry	75	100	100	0	Not potential
STAR household	75	50	75	25	Potential
Earth Identity Project (EIP)-Star Stevens	0	25	50	25	Failed by GoB
CIWP HH filter	0	100	10	50	Failed by GoB
Iron Filings in Jerry Can	0	100	100	25	Not poential
DPHE/Danida two-bucket	50	75	50	50	Potential
BUET two bucket	75	75	50	25	Potential

Table 5.5 Relative weightage screening of the As removal Technologies. Cont.

Arsenic removal technologies/filter	Weightage of performance				Potential for optimization
	Technical aspects			Social aspects	
	As removal efficiency	Installation /equipment cost	Local availability of chemicals/ materials	Field application and performance	
Two bucket unit-tea bag	75	75	50	25	Potential
BUET- AA	100	75	50	25	Potential
Granular Activate Carbon	50	25	25	0	Not potential
AMAL Household AA	75	75	50	25	Potential
Fixed bed GFH (AdsorpAs®)	100	25	25	100	Potential
SOES household	75	75	50	75	Potential
Bijoypur clay	25	75	75	*[1]	Not Protential
BCSIR	100	100	0	100	Not Protential
Adarsha	50	100	75	100	Failed by GoB
Safi filter	0	100	75	75	Failed by GoB
Indigenous raw materials (Coconut Shells, Coir etc.)	75	100	100	0	Not potential
Kanchan ™ As /Biosand	75	100	100	50	Potential
Biological filtration unit	75	100	100	0	Not potential
Ion exchange with chloride-form strong-base resins	100	25	25	25	Potential
Tetrahedron ion exchange	100	75	0	50	Failed in field application

Table 5.5 Relative weightage screening of the As removal technologies cont.

Arsenic removal technologies/filter	Weightage of Performance				Potential for optimization
	Technical Aspects			Social aspects	
	As removal efficiency	Installation /equipment cost	Locally availability chemicals/ materials	Field application and performance	
Apyron - Aqua-Bind™	100	25	0	50	Not potential
Low-pressure Nanofiltration and Reverse Osmosis	100	25	0	0	Not Potential
MRT-1000 and Reid	75	50	0	25	Not potential
Bioremediation by algae	75	25	25	0	Not potential
Technofood water technology	75	*[1]	*[1]	0	Not potential

Table 5.6 Potentiality matrix of the technologies

Analysis Parameters		Importance				Performance of technology (PT)							Potentiality performancs of technology (PPT)						
Criteria	Indicators	Weightage (W)	Ratio ®	Ratio total (RT)	MIV	Two bucket tea bag	BUET AA	AMAL AA	Fixed-bed GFH	SOES	Kanchan biosand	Ion exchange	Two bucket tea bag	BUET AA	AMAL-AA	Fixed-bed GFH	SOES	Kanchan biosand	Ion exchange
Technical aspects		50	100.0		50														
Social aspects		50	100.0		50														
				200															
Technical aspects	As removal efficiency	99	100.0		5.0	50	75	75	100	75	75	50	2.5	3.7	3.7	5.0	3.7	3.7	2.5
	Chemical use	80	80.8		4.0	50	75	50	25	50	50	75	2.0	3.0	2.0	1.0	2.0	2.0	3.0
	Pre treatment needs	75	75.8		3.8	50	75	25	75	25	75	25	1.9	2.8	0.9	2.8	0.9	2.8	0.9
	Technology create problems water chemistry parameters	65	65.7		3.3	25	25	25	100	75	25	75	0.8	0.8	0.8	3.3	2.4	0.8	2.4
	Bacteriological problems associated with the process	75	75.8		3.8	25	75	25	100	25	50	50	0.9	2.8	0.9	3.8	0.9	1.9	1.9
	System manageable	80	80.8		4.0	50	75	50	50	50	50	25	2.0	3.0	2.0	2.0	2.0	2.0	1.0
	Reliability	75	75.8		3.8	50	75	50	100	50	50	25	1.9	2.8		3.8	1.9	1.9	0.9
	Addequate production of water	75	75.8		3.8	25	25	25	100	75	75	50	0.9	0.9	0.9	3.8	2.8	2.8	1.9
	Installation / equipment cost	90	90.9		4.5	75	75	25	75	50	25	75	3.4	3.4	1.1	3.4	2.3	1.1	3.4
	Life time of installation items	75	75.8		3.8	50	75	50	75	50	50	50	1.9	2.8	1.9	2.8	1.9	1.9	1.9
	Locally availability of Chemicals	75	75.8		3.8	75	75	25	25	75	75	75	2.8	2.8	0.9	0.9	2.8	2.8	2.8
	Locally available of filter equipment materials, spars	75	75.8		3.8	75	50	50	25	75	75	75	2.8	1.9	1.9	0.9	2.8	2.8	2.8
	Generation of large toxic sludge	60	60.6	**1009**	3.0	25	50	50	75	75	50	25	0.8	1.5	1.5	2.3	2.3	1.5	0.8
	Potentiality performances of the technology in terms of technical aspects (PPTt)												**25**	**32**	**19**	**36**	**29**	**28**	**26**
Social aspects	Well acceptable by the users at field level	97	100.0		8.2	25	25	25	25	75	25	25	2.0	2.0	2.0	2.0	6.1	2.0	2.0
	Minimum operation time	70	72.2		5.9	50	50	25	75	50	50	50	3.0	3.0	1.5	4.4	3.0	3.0	3.0
	Less structure of the filter devise	60	61.9		5.1	75	50	25	25	75	25	25	3.8	2.5	1.3	1.3	3.8	1.3	1.3
	Easy operation	80	82.5		6.8	50	25	25	75	75	25	25	3.4	1.7	1.7	5.1	5.1	1.7	1.7
	Health safety during handling of the arsenic toxic waste	75	77.3		6.3	50	25	50	75	50	50	50	3.2	1.6	3.2	4.8	3.2	3.2	3.2
	Operation requires training and discipline	50	51.5		4.2	50	25	25	50	50	50	50	2.1	1.1	1.1	2.1	2.1	2.1	2.1
	Capita or installation cost	80	82.5		6.8	75	50	50	25	50	25	75	5.1	3.4	3.4	1.7	3.4	1.7	5.1
	Operation and maintenance cost	80	82.5	**610**	6.8	75	50	25	25	25	75	75	5.1	3.4	1.7	1.7	1.7	5.1	5.1
	Potentiality performances of the technology in terms of social aspects (PPTs)												**28**	**19**	**16**	**23**	**28**	**20**	**23**
Potentiality Index of the technology (PI) =PPTt+PPTs													**52**	**51**	**34**	**59**	**57**	**48**	**50**

Table 5.6 Potentiality matrix of the technologies (continued)

Analysis Parameters		Importance				Performanceof of technology (PT)							Potentiality of technogy (PT)						
Criteria	Indicators	Weightage (W)	Ratio (R)	Ratio total (RT)	MIV	SORAS	Garnet	Iron coated sand	Gravel bed-ron sludge	Star HH	DPHE-DNIDA	BUET two bucket	SORAS	Garnet	Iron coated sand	Gravel bed-iron sludge	Star HH	DPHE-DNIDA	BUET two bucket
Technical aspects		100	100.0		50														
Social aspects		100	100.0		50														
				200															
Technical aspects	As removal efficiency	99	100.0		5.0	25	50	75	50	75	50	50	1.2	2.5	3.7	2.5	3.7	2.5	2.5
	Chemical use	80	80.8		4.0	50	75	50	50	50	50	75	2.0	3.0	2.0	2.0	2.0	2.0	3.0
	Pre treatment needs	75	75.8		3.8	75	75	25	75	75	75	25	2.8	2.8	0.9	2.8	2.8	2.8	0.9
	Technology create problems water chemistry parameters	65	65.7		3.3	50	100	25	50	75	25	75	1.6	3.3	0.8	1.6	2.4	0.8	2.4
	Bacteriological problems associated with the process	75	75.8		3.8	75	50	75	75	100	25	50	2.8	1.9	2.8	2.8	3.8	0.9	1.9
	System manageable	80	80.8		4.0	50	75	50	50	50	50	25	2.0	3.0	2.0	2.0	2.0	2.0	1.0
	Reliability	75	75.8		3.8	50	75	50	50	50	50	25	1.9	2.8		1.9	1.9	1.9	0.9
	Addequate production of water	75	75.8		3.8	25	25	25	25	75	50	50	0.9	0.9	0.9	0.9	2.8	1.9	1.9
	Installation / equipment cost	90	90.9		4.5	75	100	50	50	50	75	75	3.4	4.5	2.3	2.3	2.3	3.4	3.4
	Life time of installation items	75	75.8		3.8	50	75	50	50	50	50	50	1.9	2.8	1.9	1.9	1.9	1.9	1.9
	Locally availability of Chemicals	75	75.8		3.8	75	100	75	50	50	75	75	2.8	3.8	2.8	1.9	1.9	2.8	2.8
	Locally available of filter equipment materials, spars	75	75.8		3.8	75	100	50	75	50	75	75	2.8	3.8	1.9	2.8	1.9	2.8	2.8
	Generation of large toxic sludge	60	60.6	**1009**	3.0	75	75	75	50	50	50	25	2.3	2.3	2.3	1.5	1.5	1.5	0.8
	Potentiality performances of the technology in terms of technical aspects (PPTt)												**28**	**37**	**24**	**27**	**31**	**27**	**26**
Social aspects	Well acceptable by the users at field level	97	100.0		8.2	25	25	25	25	25	25	25	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Minimum operation time	70	72.2		5.9	75	75	25	50	25	50	50	4.4	4.4	1.5	3.0	1.5	3.0	3.0
	Less structure of the filter devise	60	61.9		5.1	75	75	25	50	25	25	25	3.8	3.8	1.3	2.5	1.3	1.3	1.3
	Easy operation	80	82.5		6.8	75	100	25	75	50	50	25	5.1	6.8	1.7	5.1	3.4	3.4	1.7
	Health safety during handling of the arsenic toxic waste	75	77.3		6.3	50	25	50	50	50	50	50	3.2	1.6	3.2	3.2	3.2	3.2	3.2
	Operation requires training and discipline	50	51.5		4.2	75	100	50	50	50	50	50	3.2	4.2	2.1	2.1	2.1	2.1	2.1
	Capita or installation cost	80	82.5		6.8	100	100	50	50	50	75	75	6.8	6.8	3.4	3.4	3.4	5.1	5.1
	Operation and maintenance cost	80	82.5	**610**	6.8	75	75	25	25	50	75	75	5.1	5.1	1.7	1.7	3.4	5.1	5.1
	Potentiality performances of the technology in terms of social aspects (PPTs)												**34**	**35**	**17**	**23**	**20**	**25**	**23**
Potentiality Index of the technology (PI) =PPTt+PPTs													**62**	**72**	**41**	**50**	**51**	**52**	**50**

5.6.2 Potentiality of the technologies for the optimization

During the first step of the screening, ten out of 37 technologies failed in the evaluation carried out by the governmental organizations, while 11 technologies were not yet applied at field level and two technologies had been rejected due to their high cost and were not being applied in the field at all. The remaining 14 technologies were selected for the second step of the screening. These were the two-buckets tea bag, the BUET- AA and AMAL household filters, the Fixed bed GFH, the SOES, the Kanchan biosand and Iron exchange system, the SORAS, the Garnet, the Iron-coated sand filter, the Gravel bed iron sludge filter, the Star HH, the DPHE-Danida, and the BUET two-buckets filter. In this assessment, more emphasis was given to locally available materials and water chemistry, as well as to a lesser use of chemicals and a minimum complexity of the system. In Graph 5.1, the PI systematically expressed the comparison of the technologies and provided the decision to consider the high performances as the potentiality of the technology for further development. As the MCA shows, the GARNET technology, followed by the SORAS technology, were ranked highest with a PI score of 72 percent and 63 percent, respectively, according to the performance indicators.

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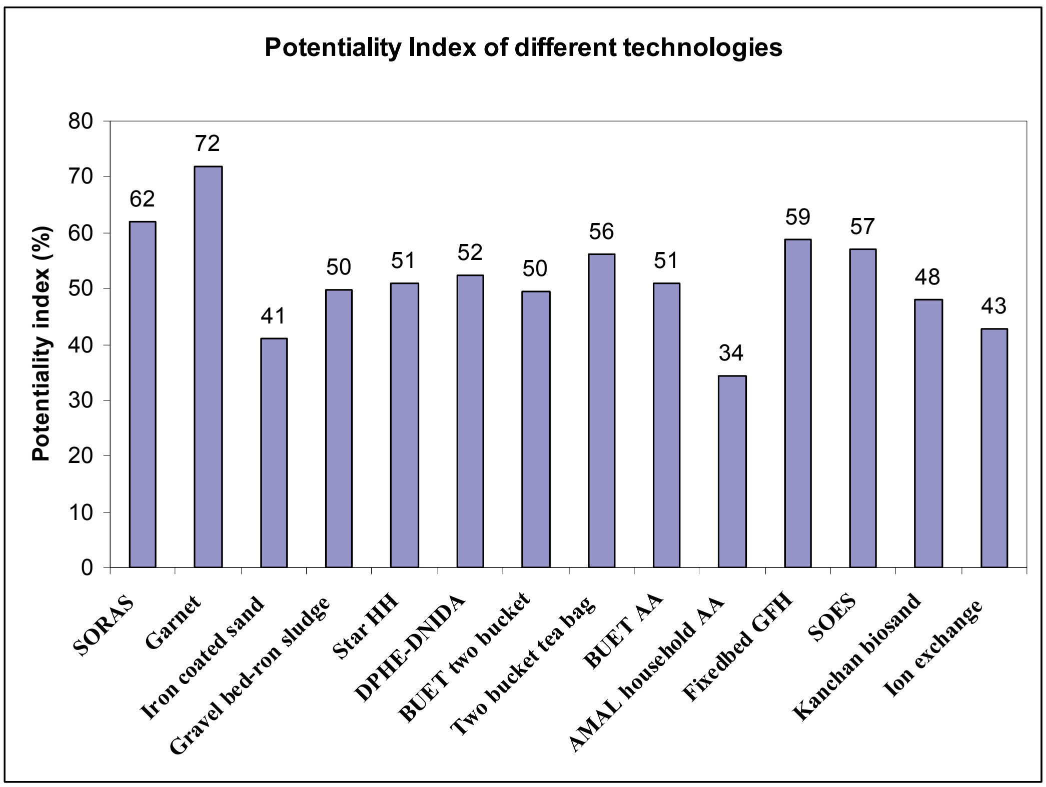

Figure 5.7 Potentiality Index of the technologies for the optimization.

Among the 14 technologies. the GARNET was selected as priority technology, since the filter has been developed based on local materials, with a minimum use of chemicals for disinfecting bacteria. The 'Rapid Assessment of the household level As-removal technologies' (BAMWSP/DFID/WaterAid, 2001a) shows that the GARNET performed better when removing As from contaminated water in this particular condition, such as the presence of a high Fe content in the source water (Sutherlands et al., 2001). This technology earned its ranking in the list according to a performance to remove As of 60 percent of the contaminated water under controlled conditions (BAMWSP/DFID/WaterAid, 2001b). The As removal efficiency of the SORAS filter was reported to be effective when treated with zero-valent iron (steel wool) and a few drops of lemon juice and solar radiation (Cornejo et al., 2008). The rest of the technologies all have some technical constraints.

5.7 Conclusions

This review of the currently available technologies shows that application at the field level was not as successful for most of the technologies as the laboratory scale tests were, because besides As removal efficacy, many other variables related to the suitability, appropriateness and social acceptance of the technology had to be considered. In this study, an overview with the strong and weak points of the 40 currently available As removal technologies in Bangladesh indicates that there are some limitations in terms of technological validation as well as social acceptance. The information on the strengths and weaknesses of the available technologies will contribute to overcoming or off-setting the drawbacks of the technologies by optimization and to the development of a new, promising technology. In full-scale operation, many filters were not capable of providing an acceptable service under the circumstances that applied, in terms of location-specific quality-of-water characteristics and socio-economic conditions. In addition, the operation and maintenance of the systems, user-friendliness from a gender perspective, the capital costs, the availability of the filter materials and chemicals, and the safety of the sludge disposal and management are also of concern. Filed observations of the currently implemented filters indicate that there are significant problems yet to be solved. Innovative improvements are needed to develop an effective As-removal technology for household-level use.

An integrated assessment of the available technologies was carried out to determine the potential of the technologies for optimization, in order to develop a promising As-removal technology for household use. A multiple-criteria analysis approach was applied regarding technical and social aspects, to address the efficacy and complexity of each technology, and its social acceptance as well, to arrive at the selection of a priority technology for optimization. The assessment showed that the GARNET technology has the most potentiality for optimization, because of its low costs and simple technology. Therefore, based on the MCA, the GARNET filter, followed by the SORAS technology, was found to be most promising for optimization into a technically and socially appropriate filter for household use.

6

Developing an Arsenic Removal Filter for Household Use

Abstract
This chapter presents the development of a household filter, which has been named the MGH filter and is based on the passive oxidation/adsorption/filtration technology. We adopted this technology from the GARNET filter, which was found to be one of the technologies with the highest potential for optimization into a promising filter amongst the currently available As-removal technologies. The structural, operational and maintenance characteristics of the filter were developed based on the findings of the research executed at the Sub-department of Environmental Technology at Wageningen University, the Netherlands, and on the findings of the field experiments conducted in the Narail and Munshiganj districts in Bangladesh. The design of the MGH filter includes i) four buckets: two large buckets that contain a filtration unit and two small buckets for water collection from the tube well and for storage of the treated water; ii) the filter bed, consisting of three layers with sand, brick chips and sand, respectively, of the same thickness, and each contained by a polyester cloth pillow. The As removal efficiency of the MGH filter was studied, including research on the effect of different filter bed thicknesses, on size and types of different filter media, the water flow rate, and the breakthrough point under controlled conditions. We tested the arsenic concentration of the tube well (feed water) and filtered (treated) water samples in the field, through field testing kits and through AAS in the laboratory. Thus, we also tested non-arsenic water quality parameters, such as its pH, Fe, Mn, and the turbidity as well as the bacteriological quality, such as the total coliform and fecal coliform of the feed and treated water samples. Chlorination was done during the filtration process to kill pathogenic bacteria and to enhance the As removal efficiency of the filter through addition of $Ca(ClO)_2$) solution. After standardization of the MGH filter by a technical validation based on the laboratory experiments, a field trail of MGH filters was performed at eight households in Kumarbhog village in the Munshiganj district during March 2008.

The results show that the MGH filter met the Bangladesh standard for the allowable limit of arsenic in drinking water (50µgL^{-1}). The filter reduced the arsenic concentrations of the shallow tube well water from 160- 959µgL^{-1} to 0-50µgL^{-1}. The bacteriological contamination of total coliform and fecal coliform was reduced from >500 cfu/100 mL^{-1} to 0 cfu/100 mL^{-1}. The arsenic removal efficacy was best at a 14 centimeter thickness of each layer of filter beds with first class brick chips of 1.3 centimeter size. The Sylhet coarse

sands removed As more efficiently than fine, normal sand. We observed also a significant reduction of the iron concentration and turbidity. The breakthrough point of the filter was reached after filtration of 350-450 liters of As-contaminated water, depending on the groundwater quality. The field trial indicates a high arsenic removal by the MGH filter at the rural household level. The users accepted this simple, low-cost, robust technology to remove As from their contaminated tube well water.

Keywords: *Bangladesh; drinking water; tube wells; Arsenic; pathogen; As removal filter, household level*

6.1 Introduction

6.1.1 General

A wide range of sound, science-based, appropriate technologies needs to be developed in Bangladesh for an effective realization of the Millennium Development Goal for safe water (Hoque et al., 2006). In the previous chapter, an inventory was carried out of the available and currently developed arsenic removal technologies for household use in Bangladesh. Most of the As removal technologies that have been documented are dealing with large-scale applications, which are costly and use non-local materials. They have not been developed from a gender perspective. The development of a simple technique, that is cost-efficient and user-friendly from a gender perspective, is essential for the benefit of common rural people (Mondal et al., 2006). In this endeavor, a technologically appropriate and socially acceptable arsenic removal technology was developed, based on an passive oxidation/adsorption/filtration process.

The objective of this study is to develop an environmentally appropriate, low-cost, simple, socially acceptable and gender-friendly safe-water technology for use by As-affected households in rural Bangladesh.

The GARNET filter is one of the As removal technologies based on passive oxidation/adsorption/filtration technology that can be made from local materials. In this research, based on the multiple criteria analysis, this technology was selected for optimization as the best feasible methodology among the potential low-cost and simple technologies (see Chapter 5). The major problems of the GARNET technology (BAMWSP/DFID/WaterAid, 2001a and 2001b; Hoque et al., 2000) are:

i) The As removal efficiency of the filter is relatively low; only 54-66 percent of As removal from low As-contaminated water ≈100µg L^{-1}.

ii) The flow rate of the filter is slow; the mean flow rate is found to be 1.2 L per hour (BAMWSP/DFID/WaterAid, 2001c). The flow rate valve of the filter does not work well due to blockage of the outlet stopper, which needs continuous care to control the flow rate.

iii) Contamination of the treated water takes place by the dropdown of feed water into the storage container due to improper packing of the filter material.

iv) A high level of bacteriological contamination of the treated water.

v) It is necessary to remix the brick chips and sands (upside down) about once in every two or three days.

vi) The efficiency of the filter is low if a high fraction of the arsenic is As(III).

Various components influence the performance of the filter:

- The As removal relies on passive coagulation with Fe and adsorption to the sand matrix.
- The removal selectivity for anions is: $PO_4^{3-} > SO_4^{2-} >> SiO_4^{2-} > F^-$.

- A high HCO_3^- concentration has a negative impact.
- A high Ca^{2+} and Mg^{2+} content has a positive impact.

Preliminary, the experiments on the further development and improvement of this technology were carried out in the laboratory of the Sub-department of Environmental Technology of Wageningen University in the Netherlands between December 2005 and February 2006. Synthetic As(III)- and As(V)-contaminated water and the iron content ($FeCl_3$) of water samples were prepared by adding the chemicals into the dematerialized water. These were used for the development of a filter, with one bucket adopting the same design as the GARNET filter. In Bangladesh, the experiment on the further development of the filter was initiated in the laboratory of the Environment Population Research Centre (EPRC) in Dhaka during March and April 2006. The experiments were done on both the one-bucket and two-buckets filter systems, using the natural As-contaminated shallow tube well waters, which was brought from villages in the Kalia sub-district.

The original design of the newly adapted GARNET filter was modified and tested under different conditions (brick chips, filter bed, flow rate, use of pillows, et cetera) to determine the optimum construction and operational parameters for an almost 100 percent removal of As from the contaminated water samples from shallow tube wells. The $Ca(ClO)_2$ (bleaching powder*)* solution was added for disinfecting the treated water and the filter bed. Leachate toxicity of the spent As-rich filter material and its possible disposal were studied. We selected the combination of the conditions of the variables that gave the highest As removal efficiency (0-<50μL^{-1}As) and lowest microbiological contamination ('nil' count /100 mL) to develop an improved filter for the following field trial.

In the field experiment, only the two-buckets system was investigated, as the one-bucket system showed poor performance. Field experiments were carried out on two locations where groundwater is severely As-contaminated. One field laboratory was set up in Kalia and was operative from May 2006 to March 2007. Another laboratory was set up in the Kumarbhog village in the Lohajang sub-district, which falls under the Munshiganj district; this laboratory continued the experiment from April 2007 to July 2008.

A field trial was performed during March 2008 to monitor the practical application and social acceptance of the newly developed filter, now named the Modified Garnet Homemade (MGH) filter. In the trial phase, the As concentration of the tube well water was measured as well as the As concentration in the treated water, after filtration was done, in order to be able to calculate the As removal efficacy of the filter.

6.1.2 The mechanism behind the removal of arsenic by the MGH filter

The MGH filter is developed on the basis of the hypothesis that "naturally occurring iron reduces the As concentration of the water" (Nickson et al., 1998). The filter removes the As concentration from the feed water, which has a high Fe content. So dissolved iron, primarily present in the groundwater as Fe(II), plays a very decisive role in removing As and other trace cations and anions (Khan et al., 2000; Sutherlands et al., 2001). The inorganic As(V) species present in the groundwater exist as oxyanions $H_2AsO_4^-$ and $HAsO_4^{2-}$ at a neutral pH, whereas As(III) species exist in protonated form as H_3AsO_3 at a pH value below 9.2 (Manning et al., 2002). An association between iron hydroxide and As compounds was found. It is noted that simple aeration of the anoxic groundwater in Bangladesh, followed by settling, would remove a considerable amount of As from the groundwater (Nickson et.al., 1998).

In this MGH filter technology, aeration occurs by atmospheric air during the whole process, from the extraction of groundwater through the pumping of the tube wells, to the slow feeding of water from the water collection container to the top bucket, as well as from the top to the bottom buckets. The top bucket and bottom bucket are 12 centimeters apart from each other and the flow rate of the water to the filter is 300lm/min, which gives a sufficient aeration of the water samples during the process of filtration. As a consequence, the As(III) in the feed water is oxidized to the more stable As(V), and removed through immobilization from both species by adsorption or coprecipitation and sand filtration (Su and Puls, 2001).

It may be noted that the MGH filter removes As from the contaminated water by a surface complexation reaction like in the Sono filter technology (Hussam and Munir, 2007). The basic difference between the two filters is that, in the Sono filter, the chemo-sorption reaction occurs on a composite iron matrix (CIM), while in the MGH filter, the iron content Fe(II) of the source water is converted from a hydrous ferric oxide form (Fe(III) as HFO or FeOH) by aeration, which reacts with As(V) species. In this case, the concentration of the dissolved iron in the groundwater is a decisive factor for the removal of arsenic. The probable reactions are:

$$\| \mathbf{FeOH + H_2AsO_4^- \leftrightarrow \| FeHAsO_4^- + H_2O} \qquad \mathbf{K=10^{24}}$$

$$\| \mathbf{FeOH + HAsO_4^{2-} \leftrightarrow \| FeAsO_4^{2-} + H_2O} \qquad \mathbf{K=10^{29}}$$

‖ *The lines illustrate the surface solid phase*

The hydrous ferric oxide (HFO) with adsorbed As(V) can be removed by settling or by filtration through a sand filter (Hug et al., 2008). Efficient As removal requires the oxidation of As(III) to the strongly sorbing As(V). Finally, As(III) and As(V) adsorption complexes are formed, which are attributed to inner–sphere bidentate as an As(III) and As(V) complex (Manning, 2002). A competition sorption of arsenite and arsenate on iron(III) hydroxide (FeOH) or (HFO) occurs according to the following scheme:

$Fe(II), H_3As(III)O_3, HPO_4^{2-}$ (in groundwater during tube well pumping)
O_2(Air)

↓ **Oxidation of Fe (II)**
Partial oxidation of As(III)

$Fe(III)(OH)_3, HAs(V)O_4^{2-}, H_3As(III)O_4, HPO_4^{2-}$

↓

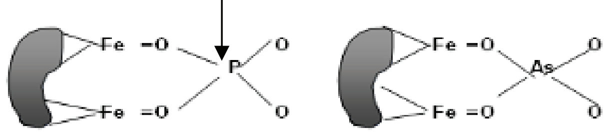

Figure 6.1 Surface complexes of As(III) and As(V) on iron (III) hydroxide (FeOH) or HFO.

In Bangladesh, at reducing conditions, the dissolved iron is a natural component of the groundwater and is found to be present at a maximum concentration of up to 61 mgL^{-1} Fe. The concentrations of Fe in the source water samples from Kumarbhog village were found to range from 5.4 to 10 mgL^{-1}. In contact with oxygen from the atmospheric air, Fe(II) oxidizes to Fe(III) and precipitates as $Fe(OH)_3$, hydrous ferric oxide (HFO:Fe_2O_3, 2-3H_2O), and $Fe(HCO_3)_2$ (Khan et al., 2000). A previous study has demonstrated that a close association exists between iron oxide (HFO) and As, where both As(III) and As(V) are adsorbed on iron oxide, forming inner-sphere surface complexes (Sarkar et al., 2008). The HFO acts as an effective adsorption agent for the arsenic removal in the MGH filter (Manning et al., 2002: Zhuang et al., 2008). During the aeration and filtration process, part of the Fe(III) precipitate adheres to or nucleates on the surface of the sand grains. The filter sand is transformed into grains covered with a voluminous reactive layer with a high specific surface area at which Fe(III)-dominated precipitation takes place. In neutral water, As(V) sorbs more efficiently to the iron compound than the As(III), and the presence of Mn in the groundwater may enhance the oxidation of the As(III) that has been pre-adsorbed onto iron oxides. The concentrations of the Mn in the study areas were found to be 0.45 mL^{-1} in Kalia and 0.10 mgL^{-1} in Kumarbhog, which may enhance the oxidation of As(III) to As(V) for the adsorption onto iron oxides (BGS, 2001b; Jessen et al., 2005).

With regard to drinking water, bacterial or pathogenic contamination is a big concern. Pathogenic bacteria can be present in the source water (feed water); in addition, there are also risks of microbiological contamination of the water during its handling (Hoque et al., 2006a). The potentiality of bacterial growth on the filter beds of most As removal technologies has indeed been observed (BAMWSP/DFID/WaterAid, 2001c). Therefore, chemical treatment is a primary requirement during the filtration process, to prevent bacterial contamination. In Bangladesh, like in other developing countries, the most common and comparatively low-cost chemical method of disinfection is chlorination with a $Ca(ClO)_2$ solution or bleaching powder (BP) solution, which is locally available throughout the country. Chemically, BP is a mixture of calcium hypochlorite ($Ca(ClO)_2$), calcium chloride ($CaCl_2$), calcium hydroxide or slaked lime ($Ca(OH)_2$), and water with slaked lime.

In this study, chlorination was done for two purposes: one was to disinfect the microbial contamination of the treated water, while the second one was to enhance the oxidation of feed water containing Fe(II) to Fe(III) by the hypochlorite in the bleaching solution. The removal of As in the presence of a BP solution (chlorination) was also enhanced by the oxidation of As(III) to As(V). Furthermore, washing the filter media with a solution of bleaching powder helps to regenerate the spoiled sand and brick chips to some extent, which enhances the As removal capacity of the filter. Therefore, chlorination facilitates the arsenic removal efficacy as well as the functional and maintenance performance of the filter.

6.1.3 Interference of other non-arsenic parameters in groundwater

Low concentrations of NO_3^- and SO_4^{2-} and high concentrations of DOC, HCO_3^- and PO_4^{3-} in the groundwater in Bangladesh indicate reducing conditions in those subsurface aquifers, where sediments are deposited with abundant organic matter. A distinct weak correlation is observed in the concentration of total As with the concentration of total Fe and Mn, and a strong correlation with the concentration of DOC in the groundwater. This result suggests that the biodegradation of organic matter occurs along with a reductive dissolution of Fe–Mn oxyhydroxides, which is considered the dominant process involved in the release of As in the aquifers in Munshiganj and other parts of the country (Halim et al., 2008). The concentration of phosphate in the study area was 1.6 mgL^{-1} in Kumarbhog and 0.3 mgL^{-1} in Kalia, respectively (BGS, 2001b). The dissolved phosphate in the feed water sample of this experiment might not be influencing the removal efficiency of the filter. It is noted that it sometimes slightly affects the coprecipitation by competing with As oxy-anionic for the adsorption site, only if the phosphate concentration is above 2.5 mgL^{-1} (Berg et al., 2006; Meng et al., 2000). A low concentration of phosphate has none to a moderated effect on the As(V) removal performance in water containing 6.7mgL^{-1} Fe and 300 μgL^{-1} As (Meng et al., 2002). However, As removal can be difficult if the groundwater has a high As(III) concentration, a high phosphate and silicate concentration, and low natural iron concentrations (Leupin et al., 2005). In this experiment, brick chips were used as the source of additional iron, as well as the adsorption medium for As(V) in the contaminated water.(Hug et al., 2008).

6.1.4 The disposal of As-rich spoils

When the breakthrough point is reached in the filtration process, the filter bed materials are saturated with As, and the produced As-rich spoil (spent filter bed materials) have to be removed. Improper handling and disposal methods of this waste, such as uncontrolled dumping in the reducing conditions of landfills, may release arsenic back into the environment. During the filtration process with the MGH filter, apparently, naturally dissolved Fe(II) in the groundwater is oxidized and precipitates as iron oxyhydroxides (FHO), which scavenges As from the water. The aerated HFO-As-loaded wastes, such as bricks and sand of the filter, predominately contain Fe(III) and As(V), of which Fe(III) is insoluble. The relatively high solubility of Fe(II) and low sorption affinity of As(III) of Fe(II) will always turn iron-loaded filter waste more susceptible to rapid leaching in the anoxic or O_2-limited environment of the landfill or underground waste site. In an oxic environment, As and Fe leaching occurs less, while arsenic removed as a solid on aerated sand filters has minimal potential for arsenic release (Sarkar et al., 2008).

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6.2 Materials and methodology

6.2.1 The filter set up in the laboratory

Two pilot designs of the MGH filter were set up in the laboratory of the Sub-Department of Environmental Technology (ETE) at Wageningen University in the Netherlands and in the laboratory of the Environment Population Research Centre (EPRC) in Dhaka, Bangladesh. Two different filters were designed, based on the passive oxidation/adsorption/filtration process, and the As removal efficiency of both filters was investigated. The designs of the filters were as follows.

The one-bucket filter

This filter consists of one plastic bucket (Figure 6.2). The bucket was filled with three layers of the same thickness: the first consisted of sand, the second of brick chips and the third again of sand. The thicknesses of each layer of sand, brick chips and sand was 8 centimeters. A polyester cloth separated each layer. A plastic lid with small holes was used on top of the bucket. One steel bench was placed over the outlet at the bottom of the bucket, keeping filter bed materials from disrupting the water flow pipe pressure through a blockage of the outlet. Arsenic-contaminated water samples (feed water/influent) were poured onto the perforated lid of the bucket and passed through the holes into the bucket. After the bucket was filled with water, the outlet of the connected narrow pipe at the bottom of the bucket was opened and effluent passed to a storage pot or container. A valve was installed at the outlet of the connected pipe of the bucket, making it possible to control the flow rate of the filtered water.

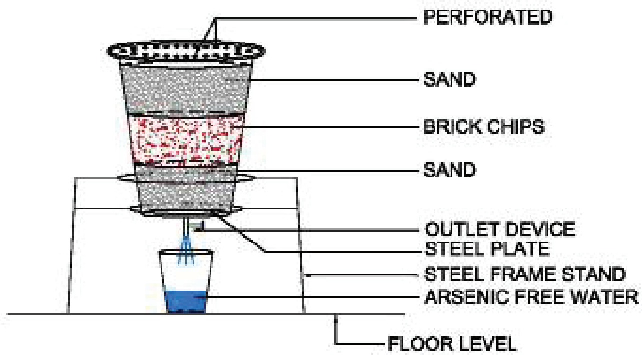

Figure 6.2 One-bucket filter.

The two-buckets filter

This filter system consists of two plastic buckets of the same size (Figure 6.3). The two buckets were placed on a two-staged, rod-made stand. There were two lids with several small holes, placed on top of both the top and bottom buckets. Both buckets were filled with three filter bed layers of sand, brick chips and again sand. The filter bed materials were placed inside three polyester cloth bags, and placed in the order of sand, brick and sand inside each bucket. One small steel bench was placed over the outlet hole of each bucket, so that bricks and sands layers could not disrupt the water flow pipe pressure through a blockage of the outlet. Two narrow pipes were attached at the bottom of each bucket and two valves were installed in the pipes to control the flow rate of the filtered water. The feed water was poured into the top bucket through the holes in the lid. After it had been filled with water, the valve was opened and the effluent from the top bucket passed to the bottom bucket, and finally to the drinking water storage container/ bucket.

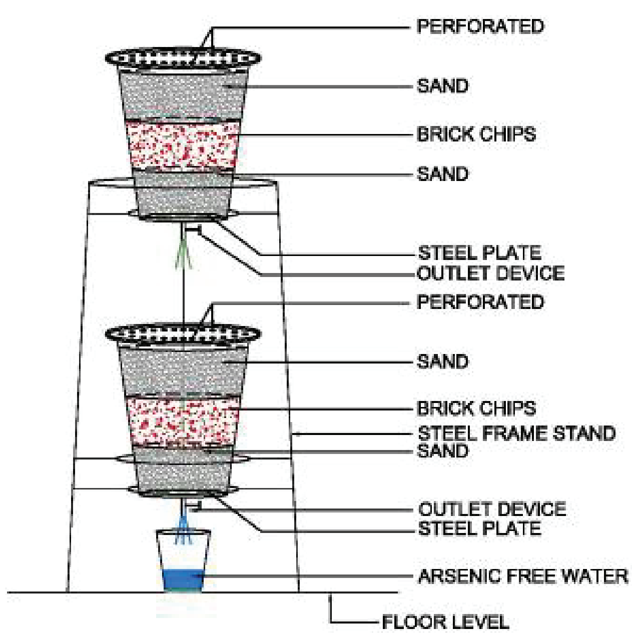

Figure 6.3 Two-buckets filter.

6.2.2 Water

The synthetic As-contaminated water used in Wageningen

Experiments in the laboratory of ETE, at Wageningen University in the Netherlands, were executed with synthetic As-contaminated water. Three types of synthetic, As-contaminated water were prepared, using demineralized water, demineralized water mixed with a $FeCl_3$ solution (10mgL $^{-1}$), and laboratory tap water. The $FeCl_3$ solution was used to add to the synthetic As-contaminated water, in order to simulate with this water the groundwater in Bangladesh, where As and naturally occurring Fe are co-existing.

The preparation of synthetic As-contaminated water: An arsenic stock solution, 1000mg As L^{-1}, was prepared by dissolving dehydrated sodium arsenite ($NaAsO_2$) and sodium arsenate $Na_2HAsO_4.7H_2O$ in the de-ionized water. The dissolution of $NaAsO_2$ was promoted by the addition of HCl. The blank filtration tests were conducted to confirm that no As was lost through adsorption onto the glassware. Different concentrations of the synthetic As water samples were freshly prepared from the stock solution. The compositions of the stock solutions were:

> **Standard arsenite solution:** 0.1734g $NaAsO_2$ dissolved in demineralized water and diluted to 1000mL.
>
> **Standard arsenate solution:** 416mg $Na_2HAsO_4.7H_2O$ dissolved in demineralized water and diluted to 1000mL.

As-contaminated tube well water in Dhaka

Arsenic-contaminated water samples were used in the laboratory of EPRC in Dhaka to execute the experiment. The water samples were transported by bus, in a jar, from the As-contaminated tube wells in Kalia to Dhaka. The total As concentration of the collected water samples was 200-250 μgL^{-1} As.

As-contaminated water in Kalia

In the field laboratory experiments, As-contaminated tube well water was directly used in the filter. Water samples were collected from the tube wells of 12 households located closely to the field laboratory in Kali, after which the concentrations of As were tested. The As concentrations of these tube wells ranged from 60 to 500 μgL^{-1} As. Of them, two tube wells were selected as the source of the As-contaminated feed waters for the experiments. The As concentrations of these tube well water samples were 200 μgL^{-1} As and 500 μgL^{-1} As, respectively.

As-contaminated water in Kumarbhog

Twenty-five arsenic-contaminated shallow tube wells were tested in Kumarbhog village in the Louhaganj sub-district, which falls under the Munshiganj district. For the experiments, the water samples were collected from three tube wells with different As(total) concentrations, with a range of 428-959 μgL^{-1} As(total). In the trial phase of the filter, the concentrations of total As in eight tube wells ranged between 285-500 μgL^{-1}.

6.2.3 Analysis of the arsenic

ICP-AES (Inductive Coupled Plasma Atomic Spectrophotometer)

In the laboratory of the Sub-Department of Environmental Technology at Wageningen University, in the Netherlands, the Inductive Coupled Plasma Atomic Spectrophotometer, Varian VISTA-MPX (CCD Simultaneous ICP-OES) method was used for an analysis of the arsenic removal efficiency of the one-bucket filter. The concentrations were measured of As(III) and As(V) in influent and effluent samples of the filter. In this method, all chemicals used were analytical grade. Water samples were acidified according to the *Standard Methods for examination of water and waste water* (APHA, 1998). An yttrium solution was used as an internal standard.

Field test kits

The HACH EZ arsenic Test Kit, Cat no. 2817800, was used to determine concentrations of As(total) content in the influent and effluent samples of the one-bucket and two-buckets As removal filters in the Dhaka, Kalia, and Kumarvogh laboratories. This kit has a color scale for visual reference. The color chart has two scales for As; 0-500 ppb (0, 10, 25, 50, 100, 250 and 500) and 0-4000 ppb (0, 35, 75, 175, 1500, and 4000). For the reported results, we relied on a visual assessment, while replicate testing was carried out for each experiment, and the average results were considered for reporting.

AAS (Atomic Absorption Spectrophotometer)

The analysis of the As(total) concentration in the influent and effluent samples of the two-buckets filter were conducted by AAS, Model–SAS 7500 with a Flameless Atomizer Model–PS-200, Sieko Instrument Inc., Japan, in the Laboratory of the International Centre for Diarrhoeal Disease Research, in Bangladesh (ICDDR,B). In addition, water samples were tested with the use of AAS in the laboratories of the Bangladesh University of Engineering and Technology (BUET), the NGO-Forum, and the Department of Public Health Engineering (DPHE). About 5-10% of the total testing of water samples was repeated by the AAS in the Dhaka laboratories.

Field test kits for non-arsenic parameters

Other physico-chemical parameters, such as turbidity, pH, temperature, conductivity, iron, manganese, sulfate and phosphate concentrations in the feed and filtered water samples of the two-buckets filter were tested by a portable HACH field kit, in the field as well as in the environmental laboratory of the EPRC in Dhaka.

6.2.4 Bacteriological test

The influent and effluent samples of the two-buckets As removal filter were directly and aseptically collected from each tube well, using sterile Nalgene plastic bottles in a transport box filled with ice packs, and transported immediately to the analytical laboratory in Dhaka. A water sample of 100mL was filtered through a 0.22µm membrane filter paper (Millipore Corp., Bedford, MA USA). Then, the filter papers were placed for 18-24 hours on membrane fecal coliform (MFC) agar plates for incubation at 37^0 C, in order to measure total coliform (TC), and at 44 ^{0}C to measure fecal coliform (FC) according to the APHA

(APHA, 1998). All water samples were tested for FC and TC in the EPRC Laboratory, and some tests were repeated in the laboratory of ICDDR,B as well. The results of the microbiological test are expressed as colony formation units (cfu)/100mL.

6.2.5 Spent filter material (mixed sand and brick) test

The toxicity characteristic leachate procedure (TCLP) test of spent filter materials was carried out according to Environmental Protection Agency (EPA) test method 1311, to determine the leachate toxicity of spent materials.

6.2.6 Laboratory filtration test methodology

Laboratory filtration tests in the Netherlands

With the filter set up in the laboratory of the Sub-Department of Environmental Technology at Wageningen University in 2005, we executed several filtration experiments. The arsenic removal efficiency of the filter was determined by passing different concentrations of As(III)- and As(V)-containing water samples through the one-bucket filter. Four different concentrations of synthetic As(III)- and As(V)-contaminated water samples were analyzed. The concentrations of As in the influent (feed) and effluent (treated) water samples were analyzed to determine the removal efficiency of the filter.

Laboratory filtration tests in Dhaka

Two types of filters were set up and investigated in the laboratory of the EPRC in Dhaka. The effect of several variables on the filters' performance were investigated.

A. Types of filters that were investigated

- The one-bucket system
- The two-buckets system

The set-up of the one-bucket filter in the Dhaka laboratory was the same as the one used in the experiments in Wageningen. In this case, real As-contaminated water was used in the experiments, whereas laboratory-prepared, synthetic arsenic-contaminated water was used in the executed experiments in Wageningen.

B. Filter bed materials' thickness

Two different thicknesses of filter bed materials were considered in the experiment with both types of filters, in order to determine the best removal efficiency of the two filters. The thicknesses of the filtration layers in both filters were:

- For the one-bucket system: sand 5.1 cm + brick chips 5.1 cm + sand 5.1 cm;
- For the two-buckets system: sand 15.2 cm + brick chips 15.2 cm + sand 15.2 cm.

C. Flow rate through the filter

Different flow rates of the contaminated water through the filter system were considered: 5 ml/min, 6.3 ml/min, 7 ml/min, 10 ml /min, 50 ml/min, 75 ml/min, 100 ml/min, and 300ml/min (fully opened control valve). The flow rate was controlled by adjusting the valve in the outlet pipe.

D. Breakthrough point of the filter
The breakthrough points (the moment when the allowable limit of As concentration in the water leaving the bottom of the filter is exceeded) of the two types of filters were also determined. The 'breakthrough point' was noted when the As concentration of the filtrate water reached 50µgL^{-1}, which is the allowable limit of As for drinking water in Bangladesh.

E. Calcium hypochlorite, $Ca(ClO)_2$, or the bleaching solution treatment
Chlorination was done by adding different doses of a Calcium hypochlorite solution to the feed water. To develop the optimum dose of the chlorination, several steps of jar tests were conducted as trial and error, without any pH adjustments, to disinfect the treated water by maintaining the residual chlorine (RCL) in drinking water within 0.2mg L^{-1} limit.

F. The arsenic removal efficiency of the two filters
As-contaminated water samples from the same tube well were tested by both one-bucket and two-buckets filters to determine their As removal efficiency. The As removal performance was poor in the one-bucket filter, and further work on this filter was abandoned.

G. Accuracy of the test results
In Bangladesh, India and other Asian countries, most of the As field kits applied are chemistry-based. Common and widely used kits are Merck, HACH, Arsenator, ANN, or locally made kits (such as the NIPSOM kit, made in Bangladesh) (Kiniburgh and Kosmus, 2002). It is noted, that these field kits have, in fact, a very low reproducibility and accuracy when measuring As concentrations between 10 µg/L and 100 µg L^{-1}, compared to analyses performed by flow injection in hydride generation atomic absorption spectrometry (FI-HG-AAS) or IPC methods (Rahman et al., 2002; Trang et al., 2005). In this research, therefore, to get realistic and acceptable results, a comparison was carried out between the results obtained by the HACH field kit and the results obtained by the AAS testing at different laboratories in Dhaka.

6.2.7 Field test methodology

The Kalia field

Based on laboratory experiments in Wageningen and Dhaka, the two-buckets As removal MGH filters were set up in the field laboratory in Kalia. Two tube wells of different concentrations, 200 µmL^{-1} and 500 µmL^{-1}, were selected for conducting experiments. Water samples from these two tube wells were used in two identically designed two-buckets filters for the laboratory experiments. The following variables were then considered.

A. The thickness of the filter bed materials
Two different thicknesses of filter material beds were considered for the two identical two-buckets filters using the water of two different tube wells, which contained different As concentrations.

Design 1: sand 5.1 cm + brick chips 5.1 cm + sand 5.1 cm
Design 2: sand 15.2 cm + brick chips 15.2 cm + sand 15.2 cm

B. The flow rate of the filter
We tested the arsenic removal efficiencies of the two two-buckets filters at different flow

rates by adjusting the valve of the connected pipe with which the flow rate could be controlled.

C. The breakthrough point of the filter

We determined the 'breakthrough point' of two two-buckets filters, the design of which was identical, with different As concentrations in the water from the tube wells. The volumes of the As-contaminated water passing through the filters were recorded in units of 10 liters. The 10-liter capacity container or bucket was used for the collection of the feed water. The 'breakthrough point' of both filters was noted when the As concentration of the filtrate water samples reached $50\mu gL^{-1}$ As.

D. The dosing of calcium hypochlorite $Ca(ClO)_2$

A Calcium hypochlorite $Ca(ClO)_2$ solution was prepared by adding one teaspoon $Ca(ClO)_2$ to 10 liters of water and mixing it thoroughly. The concentrated solution was poured into the filter and kept the media soaked overnight. The following morning, the solution was drained out and the media was washed with As-free tube well water until the residual chlorine (RCL) in the filtrate water became less than $0.2mg\ L^{-1}$.

The Kumarbhog field

Arsenic-contaminated water samples from the tube wells in Kumarbhog village were treated with identically designed two-buckets filters and with the same variables as had been applied in Kalia, in order to assess the performances of the filters at two different locations. In addition, the following design variables were considered.

A. Filter bed material types and filter bed thicknesses

Two filters were constructed with different types of filter media, which had different thicknesses. They were operative at the same time.

Types of sands

In Bangladesh, broadly two types of sands are available, such as coarse sand, also called *Sylhet* sand, and fine or normal sand.

Types of brick chips

The different types of brick chips: first-class, second-class, or third-class bricks, overburnt bricks and stone chips. The particle sizes were all close to 1.3 cm.

The chips come from bricks that are commonly used as construction material in Bangladesh. These are of three grades, depending upon the quality of the raw materials used, the evenness of their burning process, and damage, like cracks or breaks. Holocene and Pleistocene clays are used for manufacturing good quality bricks or first class, grade-I bricks suitable for the construction of buildings, roads, or bridges. Grade-II bricks have less compressive strength, and grade-III bricks are used for temporary construction. While Jama brick chips are bricks burnt for a prolonged time, stone chips are crushed rock gravel.

Thicknesses of the filter bed

- Filter beds thicknesses; 5.0 cm, 10.0 cm, and 14.0 cm were considered for different types of filter bed materials.

B. As removal efficiency of the filter for different As concentrations in the water

Water samples were collected from the three tube wells with different As concentrations and filtered with three identically designed two-buckets filters. The feed and treated water samples from the top and bottom buckets were analyzed by means of a field kit in the field laboratory and by AAS in the laboratory.

C. Bacteriological contamination
Bacteriological contamination of the water samples was determined by analyzing the water samples before and after filtration. The water samples were collected and transported to the EPRC laboratory for testing within 6-8 hours.

D. Toxicity of the filter's spent material and its disposal
The spent material (sand) of the filter was tested for the Toxicity Characteristic Leaching Procedure (TCPL) in the BUET laboratory. The sample was collected after the concentration in the effluent has reached the breakthrough point.

D. Reuse of the arsenic-rich filter bed materials
To investigate the possibility of reducing the disposal of the spent As-rich residual after the breakthrough of the filter, two experiments were carried out.

- The first experiment focused on the reuse/regeneration of the filter's spoiled sand and brick chips after reaching the 'breakthrough point' through treatment with a $Ca(ClO)_2$ solution.

- The second experiment focused on re-use of bucket materials. The spoiled sand and brick chips of the first bucket were discarded and a second bucket with old used materials was placed at the top, as the first bucket, and new materials were used in the second bucket of the filter. This was done because, after reaching the breakthrough point of the filter, the spent material of the second bucket was less contaminated at the breakthrough moment than that of the first bucket, and therefore had some residual absorption capacity. In this process, the half-spent materials of the filter's first bucket (bricks and sand) were disposed of, while the half-spent material in the second bucket of the old filter was re-used in a new filter operation.

6.2.8 The trial phase of the MGH filter

Study area

In the trial phase, the performance of the MGH filter was assessed during its household use in the study area. The study village, named Kumarbhog, is located in the Louhaganj upazila, which falls under the Munshiganj district in Bangladesh. The village is situated about 33 km southwest of Dhaka city. It is located on the bank of the great Padma river and is mainly covered by the recent alluvial and flood plain sediments deposited by the river. About 90 percent of the tube wells in the study area were As-contaminated above the permissible limit of the drinking water standard in Bangladesh.

Filter operation

In March 2008, after executing a technical validation of the newly developed filter in the laboratory, eight filters were distributed to eight households in the study village. A one-day training was provided to eight women living in the selected households (Id1-Id8) on the application, operation and maintenance of the filter. They were told to discard the first 5-10 liters of treated water until the filtered water appeared to be transparent. The number of family members of the households Id2, Id3, Id5, Id6, Id7 and Id8 ranged from four to seven, whereas the households Id1 and Id4 counted 12 members. There was more drinking water consumption in the larger-sized households than in the smaller-sized ones. The concentrations of As in the feed (source tube wells) and treated water samples of eight filters were measured to assess the As removal efficacy of the filters; the bacteriological quality of the source and treated water samples were also analyzed.

6.3 Results

The experiments were executed during the development of both the one-bucket and the two-buckets As removal filter. In the ETE laboratory in the Netherlands, the synthetic, As-contaminated water was prepared and used for the analysis of the As removal efficiency of the one–bucket filter. In Bangladesh, both types of filters were analyzed in the laboratory by using the As-contaminated tube well water. In the field, however, only the two-bucket filter was experimented with, because the one-bucket system had shown an unsatisfactory arsenic removal efficiency. The results of the removal efficiency of the two-buckets filter are described below, in order to analyze the effect of different filter bed thicknesses, sizes and types of filter media, water flow rates, breakthrough points, $Ca(OCl)_2$ chlorination and toxicity of the filter's spent material.

6.3.1 Synthetic As-contaminated water

Table 6.1 shows that the filter reduces the As concentration in the synthetic As(V)-contaminated tap water with about 80-90 percent, whereas the As-removal from the As-contaminated demineralized water (demi-water) sample was 50-80 percent, and from demineralized water mixed with $FeCl_3$ was 42-81 percent. The highest As removal was found in tap water and As concentrations of all treated tap water samples were below 50 µg L^{-1} As (the drinking water standard in Bangladesh), except when the As concentration of feed water samples was as high as 658 µg L^{-1}As. Arsenic removal was found to be relatively high in the presence of a $FeCl_3$ solution in the demineralized water. This may be the effect of iron, as formation hydroxide (FeOH) had enhanced the removal of arsenic, but the results were not consistent in different concentrations of As-contaminated, demineralized water.

Table 6.1 As-removal efficiency of the one-bucket filter, using synthetic As(V) water samples.

Synthetic As(V) demi-water			Synthetic As(V) demi-water with $FeCl_3$ (10mgL^{-1})			Synthetic As(V) tap water		
Feed water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)	Feed water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)	Feed water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)
48	23	51	48	28	42	56	11	80
147	61	59	65	22	66	150	15	90
282	59	79	242	44	82	315	40	87
553	196	64	455	169	63	658	95	86

Table 6.2 shows that the filter reduced the As level with 32-55 percent, and with 11-33 percent in the synthetic As(III)-contaminated, demineralized water and the synthetic As(III)-contaminated tap feed water samples, respectively. The reduction of As in the synthetic As(III)-contaminated, demineralized water mixed with $FeCl_3$ ranged wide (13-56%). The results indicate that the As concentrations of all the treated water samples were above 50 µg L^{-1} As, except when the As concentration of the feed water was lower than 73 µg L^{-1}As. The As removal efficiency of the demi-water samples with a $FeCl_3$ mixture was found to be higher than the demi-water samples when the As concentration of the feed water was higher than 196 µg L^{-1}As, whereas in the tap water, the removal efficiency was less, probably because no oxidation of As(III) to As(V), and no formation of ferric hydroxide had occurred.

Table 6.2 As-removal efficiency of the one-bucket filter, using synthetic As(III) water samples.

Synthetic As(III) demi-water			Synthetic As(III) demi-water with $FeCl_3$ (10mgL^{-1})			Synthetic As(III) tap water		
Feed water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)	Feed water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)	Feed Water As (µgL^{-1})	Treated water As (µgL^{-1})	% Removal (mean)
73	34	53	56	49	13	146	130	11
196	94	52	141	73	49	301	203	33
352	224	36	289	128	56	350	284	19
643	438	32	615	338	45	688	484	30

6.3.2 As-contaminated tube well water in Dhaka

As-removal efficiency of one-bucket and two-buckets filters: Table 6.3 shows the As removal efficiencies of the two different designed filters, using the same As-contaminated tube well water. About 40-50 percent As(total) removal efficiency was found after filtration of contaminated water by the one-bucket filter, whereas higher removal efficiencies (60-75 %) were obtained from the two-buckets system. The highest removal efficiency (90%) was obtained after the addition of a $Ca(ClO)_2$ (bleaching powder) solution to the inlet water of the two-buckets filter. These results indicate that the addition of the bleaching liquid enhances the oxidation of As(III) to As(V), and as a consequence, it improves the removal efficiency of the two-buckets filter even more.

Table 6.3 As-removal efficiencies of with a different filter bed thickness.

Tube well water As (µg L^{-1})	Filter design	Filter bed thickness of each layer (cm)	Treated water As (µg L^{-1})	Removal efficiency (%)
200	One Bucket	5.1	120	40
		15.2	100	50
	Two Bucket	5.1	80	60
		15.2	50	75
		15.2 $Ca(ClO)_2$ solution addition	20	90

Filter bed thickness: both types of filters show that a higher As-removal efficiency is obtained with a filter bed (sand-brick-chips) in which each layer has a thickness of 15.2 cm, than with one in which the thickness of each layer is 5.1 cm.

Flow rates and breakthrough point of the filter: no significant differences of the As-removal efficiency were observed when the filtration was carried out at different flow rates, varying from 5 ml/min, 7 ml/min, 50ml/min, and 100 ml/min, to 300 ml/min. Therefore, 300 ml/min, which can be obtained at a fully opened valve, was found to be the best flow rate for the process. The breakthrough point was found after the filtration of 220 liters of raw water at a 300ml/min flow rate of the two-buckets filter.

Accuracy of the kit test results: comparison analysis of As testing shows that the result obtained by the HACH field kit and the AAS were more or less the same. The result of the same water samples tested by the HACH field kit was 200 μmL^{-1}As, whereas 270 μmL^{-1} and 172 μmL^{-1} As concentrations were obtained from analyzing samples by the AAS in the NGO Forum Laboratory and the BUET Environmental Laboratory, respectively.

6.3.3 As contaminated tube well water in Kalia

Table 6.4 shows the water quality parameters of the water sample collected from the tube wells in Kalia. Arsenic (total) concentrations of the tube wells were found to be within the ranges of 100-500 μgL^{-1}, while a high bacterial contamination TC (20->500) and FC (0-400) counts were found per 100 ml water. These results indicate that the groundwater in the study area has a high content of As, Fe, chloride, and bacteria.

Table 6.4 Water quality parameters of the tube well water in Kalia.

Parameters	Unit	Results
pH	-	7.4
Fe	(mgL^{-1})	8
As	(μgL^{-1})	100-500
Chloride	(mgL^{-1})	220
DO	(mgL^{-1})	4
NO_3^-	(mgL^{-1})	0
Alkalinity	(mgL^{-1})	600
Hardness (dissolved Ca and Mg_2CO_3)	(mgL^{-1})	660
Mg	(mgL^{-1})	46.6
Ca	(mgL^{-1})	177
Na	(mgL^{-1})	149
NH3	(mgL^{-1})	<3
Conductivity	MS	0.58
Turbidity	F.T.U	88
TC	c.f.u/100 mL	20->500
FC	c.f.u/100 mL	0-400

Table 6.5 shows the As removal efficiencies of the two identically designed two-buckets filters, at different flow rates and different concentrations of As in the contaminated water. The color chart of the field test kit has a scale of 0, 10, 25, 50, 100, 250 and 500 μgL^{-1} As concentrations. The obtained results indicated that, visually, a very small amount of color formed on the testing strips in between the 0-10 colour scale, which means that it was almost colorless and close to the detecting scale. No significant difference in removal

efficacy was found during the filtration of contaminated water at different flow rates with different concentrations of As-contaminated tube well water. The results indicate that the concentrations of As in the effluent from the second bucket of the filter and the storage bucket were the same. The concentration of As in the water sample from the storage bucket is the average concentration during the collection period of the water stored.

Table 6.5 The effect of flow rates at different As concentrations on As-removal efficiency.

Flow rate ml/min	Sample collection	Tube well water (200 μgL^{-1} As)		Treated water (μgL^{-1} As)	Tube well water (500 μgL^{-1} As)		Treated water (μgL^{-1} As)	As-free water (L) after 5 hrs
		pH	Temp (°C)		pH	Temp (°C)		
5	2nd bucket effluent	7.0	31	0-10 (near to 0)	7.1	30	0-10 (near to 0)	1.5
		7.0	30	0-10 (near to 0)	7.0	29	0-10 (near to 0)	
	Storage bucket	6.5	30	0-10 (near to 0)	7.0	29	0-10 (near to 0)	
6.3	2nd bucket effluent	7.0	30	0-5 (near to 0)	7.0	30	0-5 (middle)	1.9
		6.9	29	0-10 (near to 0)	6.9	29	0-10 (middle)	
	Storage bucket	7.0	30	0-10 (near to 5)	7.0	29	Near to 0-10	
7	2nd bucket effluent	6.9	31	0-10 (near to 0)	7.0	30	0-10 (near to 0)	2.1
		7.0	30	0-10 (near to 0)	7.2	29	0-10 (near to 10)	
	Storage bucket	7.0	30	0-10 (near to 6)	7.0	29	0-10 (near to 0)	
10	2nd bucket effluent	7.0	30	0-10 (near to 0)	7.0	30	0-10 (middle)	3
		7.0	29	0-10 (near to 0)	7.6	29	0-10 (middle)	
	Storage bucket	6.6	30	0-10 (near to 0)	7.5	29	0-10 (middle)	
50	2nd bucket effluent	7.0	31	10-25 (middle)	6.9	30	10-25 (near to10)	15
		7.2	30	No water flow	7.2	29	10-25 (near to 10)	
	Storage bucket	7.1	30	10-25 (near to 25	7.0	29	0-10 (middle)	
75	2nd bucket effluent	7.0	31	0-10(near to 0)	7.0	30	0-10 (near to 0)	22.5
		6.8	30	10-25 (middle)	6.9	29	0-10 (near to 0)	
	Storage bucket	7.0	30	0-10 (near to 0)	7.0	29	0-10 (middle)	
100	2nd bucket effluent	7.0	31	10-25 (middle)	7.0	30	0-10 (near to 0)	30
		7.0	30	0-10 (near to 0)	6.9	31	0-10 (near to 0)	
	Storage bucket	6.7	30	0-10 (middle)	7.0	29	0-10 (near to 0)	
300	2nd bucket effluent	6,8	31	0-10 (near to 0)	6.8	30	0-10 (near to 0)	90
		7.0	30	0-10 (near to 0)	7.2	29	0-10 (near to 10)	
	Storage bucket	7.1	30	0-10 (middle)	6.9	29	0-10(near to 10)	

Table 6.6 shows the concentrations of As(total) of four samples collected from the feed water, the effluent from the first and second buckets of a two-buckets filter, and from the drinking water storage bucket. As concentrations of the treated water were reduced to below the allowable limit of the Bangladesh drinking water standard of 50μgL^{-1}As after

filtration through the second bucket. Both testing methods (field test kit and AAS) show the same results (60% removal) regarding the effluent from the first bucket, after filtration. The field kit test result indicates an As(total) removal efficiency of 90 percent after filtration by the second bucket, whereas the AAS result shows an 83 percent removal, and the concentrations of As(total) were 27.21 μgL^{-1} and 26.85 μgL^{-1}, respectively, for the treated water and the storage water, which met the drinking water standard of Bangladesh.

Table 6.6 As removal at different stages during the filtration of tube well water by filter in Kalia.

Water samples	Tested by field kit (μgL^{-1}As)	Tested by AAS in ICDDRB, (μgL^{-1}As)
Influent or feed water before filtration	200	156.2
Effluent from the first bucket after filtration	80	62.8
Effluent from the second bucket after filtration	20	27.2
Storage container	15	26.9

6.3.4 As contaminated tube well water in Kumarbhog

Table 6.7 shows the water quality of the samples collected from the 11 arsenic-contaminated tube wells in Kumarbhog village. The concentrations of As were found to be within a range of 76-959 μgL^{-1} As. A high concentration of iron content, 3.3-10 mgL^{-1}, and high turbidity of the tube well water samples were found as well. In addition, almost all samples were bacterially TC- and FC-contaminated.

Table 6.7 Water quality parameters of the tube well water in Kumarbhog village.

Parameter	Unit	Result
pH		6-5 7.7
Fe	(mgL^{-1})	3.3-10
As	(μgL^{-1})	76-959
Sulfate	(mgL^{-1})	50
Mn	(mgL^{-1})	0.2-0.3
Turbidity	F.T.U	2.79-73
TC	c.f.u/100 mL	4-290
FC	c.f.u/100 mL	4-78

Figure 6.4 shows the turbidity and concentrations of Fe and Mn in water samples collected before and after filtration by the two-buckets filter. Results indicate that the iron content of the treated water samples was lower than that of the feed water sample. Yet, at the beginning, the turbidity of the treated water was more than that of the feed water when 30L water had passed into the filter equipment, but after passing more water through the filter, the turbidity and concentration of Fe were reduced.

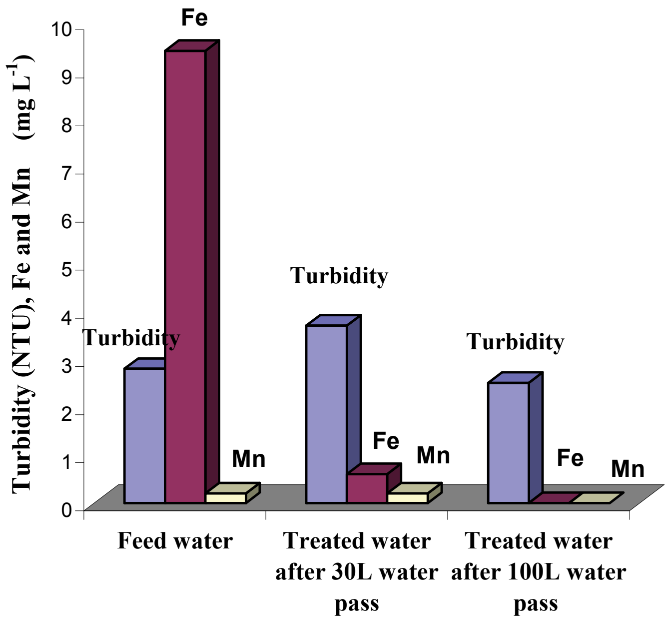

Figure 6.4 Turbidity, Fe and Mn concentrations of feed water and treated water after 30L and 100 L water passed through the filter.

The results show a comparatively better removal of As when the filter bed thickness was 10.16 cm, but they did not meet the drinking water standard. The highest removal was found in the testing procedure at a 14 cm thickness of the filter bed, consisting of first class brick chips and Sylhet sand. Most of the results show that the filter bed with Sylhet sand removed As more effectively than that with normal sand, but these results were not always consistent. Similarly, inconsistent results were also found in using different types of brick chips, but first-class brick chips showed comparatively the highest As removal, except in the case of a 10.16 cm thickness. The lowest removal efficiency was found while using stone chips at all thicknesses of the filter bed material.

Table 6.8 shows the result of the removal efficiencies of the two two-buckets filters constructed with different filter bed thicknesses and different types of materials. The water samples were analyzed with the field kits, and some of them were tested through the AAS in order to compare the results. The removal of As was found lowest when the water had been treated by a filter constructed with a filter bed thickness of 5.1 cm.

Table 6.8 Removal of As, dependent on types of sand, brick chips, and thickness of the filter beds.

Feed water As concentration (μgL^{-1})	Filter bed thickness of each layer (cm)	Brick chips type	Effluent of filter As concentration (μgL^{-1})		Method of analysis
			Sylhet sand	Normal sand	
959	5.0	Overburnt brick	196	183	Test kit
		1st class	175	125	Test kit
			345.30	261.60	AAS
		2nd class	225	250	Test kit
			268.00	313.80	AAS
		3rd class	325	350	Test kit
			335.80	376.80	AAS
		Stone chips	400	450	Test kit
	10.0	Overburnt brick	58	66.6	Test kit
		1st class	141.6	125	Test kit
		2nd class	83.3	100	Test kit
		3rd class	180	180	Test kit
		Stone chips	200	250	Test kit
	14.0	Overburnt brick	50	75	Test kit
		1st class	0	0	Test kit
			0	0	AAS
		2nd class	20	25	Test kit
		3rd class	25	30	Test kit
		Stone chips	75	100	Test kit

Table 6.9 shows the As removal efficiencies of three similarly designed two-buckets filters with a bed thickness of 14 cm, treating the contaminated water from three different tube wells. Both the results obtained with the field kit and the AAS analysis indicate that the As concentration of the effluent from the second bucket of the three filters were below the permissible limit ($50\mu gL^{-1}$As) and the removal efficiencies of the three filters were between 97-99 percent.

Table 6.9 As removal efficiency of the two-buckets filter, using three different samples of As-contaminated tube well water in Kumarbhog.

Influent water As (μgL^{-1})		Flow rate ml/min	Effluent from 2nd bucket As (μgL^{-1})	
Field kit	AAS in lab		Field kit	AAS in lab
>500	959	300	10	26,8
>250	428,3	300	0-10	<5
>500	818	300	0-5	<5

Table 6.10 shows that high bacterial count (TC and FC) in the feed water samples collected from two tube wells. After treatment of the filter with a $Ca(ClO)_2$ solution, this count of both types of bacteria became nil, which met the WHO guideline value for bacterial-free, safe drinking water. In this process, chlorination was done by adding a calcium hypochlorite solution (one teaspoon per 10 liters of water) to the filter, which was

then kept overnight. This disinfected the bacterial contamination of the feed water as well as prohibited the bacterial growth on the sand beds of the filter.

Table 6.10 Bacterial count of the water samples before and after filtration.

Feed water from tubewell			Treated water after Bleaching treatment		
As Conc. (μgL^{-1})	Bacteriological count c.u.f /100ml		As Conc. (μgL^{-1})	Bacterilogical count c.u.f /100ml	
	Feacal coliform	Total coliform		Feacal coliform	Total coliform
490	16	290	0	0	0
475	4	8	0	0	0

Re-use of the filter's spent media: Figure 6.4 shows the As removal efficiency of a filter when the filter's spent material is re-used. In this case, after reaching breakthrough, the filter bed materials of the second bucket was re-used and kept as the bucket at top position, while the first bucket was re-filled with new materials and kept at bottom position of the filter. The results indicate that the filter reduced the As concentration of an additional 160 liters of contaminated water before reaching again the breakthrough point.

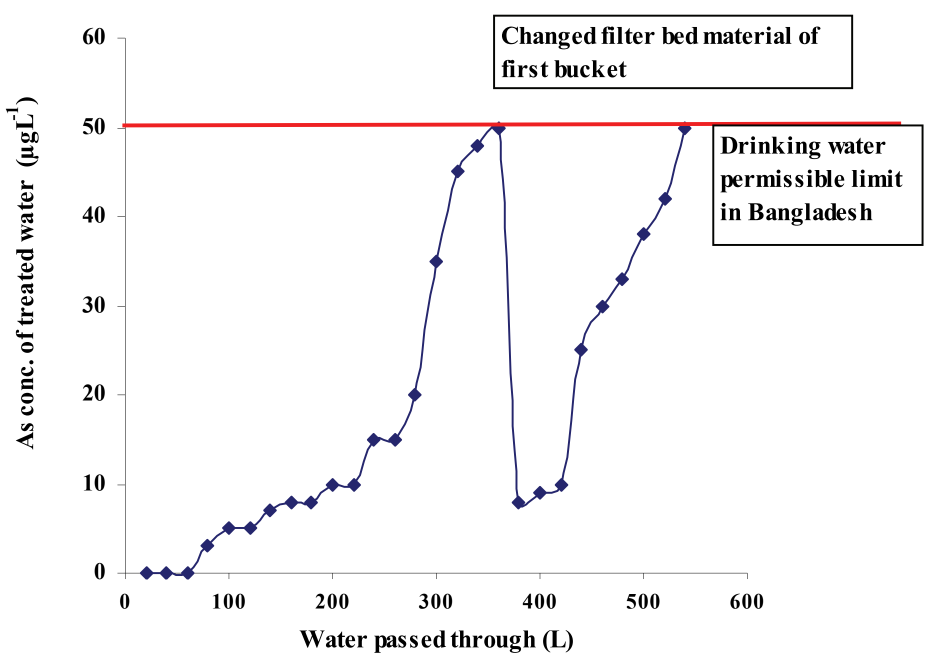

Figure 6.5. Re-use of filter bed materials.

Another investigation shows that the As removal capacity of a filter increases through the regeneration of filter bed materials after the breakthrough point, by washing the spoiled sand and brick chips with a $Ca(OCl)_2$ solution. The use of these regenerated filter bed materials reduces the As contamination of additional 50-80 liters of contaminated water to a level lower than the permissible limit for drinking water ($50 \mu g L^{-1}$), before reaching breakthrough point again.

Toxicity of spent media: the result of the TCLP shows that the spoiled sand with brick chips had a content of 0.406 mg/kg As, which was within the permissible level of the EPA regulatory limit of 5 mgL^{-1}. The result ensures that the As toxicity is at its minimum in the filter spent, which may not be a grave concern if the waste gets thrown on the lands or in water bodies.

6.3.5 Comparison of the MGH filter at two different geological locations

As removal efficiencies of the MGH filters at two different geological locations in Kalia and Kumarbhog were compared with respect to the effect of the flow rate and breakthrough points. Table 6.11 shows a more or less complete removal of As from the contaminated water in two study areas when treated by filters. On both locations, the dependency of the As removal by the filters was found to be insignificant on the flow rate, in the same experimental set-up, with a 14.0 cm bed thickness of the individual sand and brick chips layers.

Table 6.11 As removal efficiency at different flow rates during filtration.

Water sample	Feed water As concentration ($\mu g L^{-1}$)	Treated water As concentration ($\mu g L^{-1}$) at different flow rates							
		5 ml /min	6.3 ml /min	7 ml /min	10 ml /min	50 ml /min	75 ml /min	100 ml /min	300 ml /min
Kalia	156	2	0	0	0	1	1	1	1
	172	0	4	0	0	1	2	2	2
	500	0	1	0	0	3	1	2	3
Kumarbhog	959	0	2	0	2	1	2	2	2
	428	0	2	2	3	1	2	2	3
	818	0	3	3	0	1	1	0	1

Figure 6.5 shows the breakthrough curves of two identically designed filters operated in Kumarbhog and Kalia. The concentration of the feed water in Kumarbhog was 959 $\mu g L^{-1}$, while it was 250 $\mu g L^{-1}$ in Kalia. After filtration, the breakthrough points were 430-450 liters and 280-350 liters of water in Kumarbhog and Kalia, respectively. The breakthrough points in Kumarbhog village were reached later than in Kalia, after treating more As-contaminated water. The high Fe content (Table 6.7) in the tube well water may be the reason for the higher amount of As removal in Kumarbhog, compared to that in Kalia.

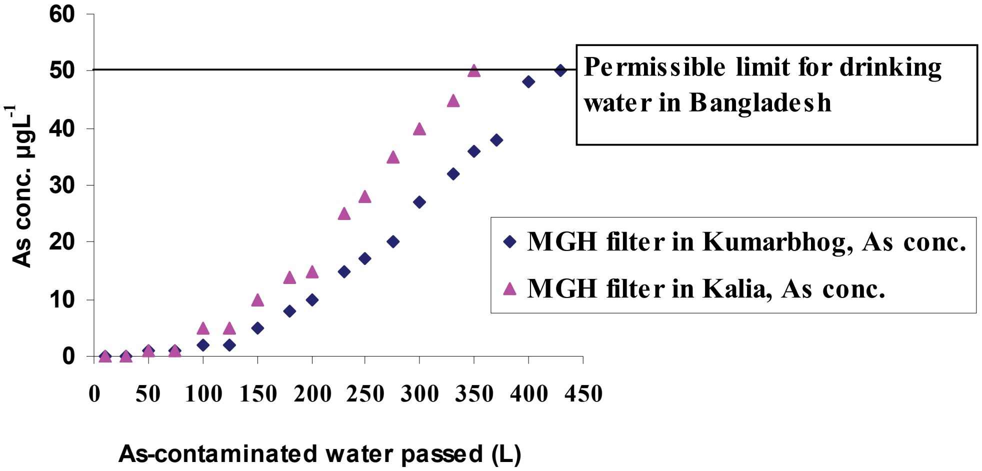

Figure 6.6 Breakthrough curves for MGH filters.

6.3.6 Performance of the MGH filter during the trial phase in household use

The experimental condition of the filter applied in the field trial on its household use was as follows.

Experimental conditions applied in the field experiments of the filter during the field trial

Flow rate	300ml/min
Thickness of the filter beds	Sand 14.0 cm+ Brick chips 14.0 cm+ Sand 14.0 cm
Sand type	Sylhet sand
Brick chips	First-class brick, size 1.3 cm
Breakthrough point	400-450 L
$Ca(ClO)_2$ dose	One spoon of $Ca(OCl)_2$ powder into 10L of water. With a fifteen-days interval, pour this mixture into the filter and keep overnight.

Table 6.12 shows the results of chemical and bacteriological tests of the source water samples from the eight tube wells. The results indicate that the pH, temperature and sulfate values of the water samples were within the allowable limit of the Bangladesh drinking water standards (ECR, 1997). The turbidity of some water samples was above the allowable limit and ranged between 17-73 NTU. The concentration of Mn in one sample was higher than the allowable limit. The concentrations of Fe ranged between 5.3-10.0 mg/L, and the concentrations of As ranged from 285 to 500 μgL^{-1}. Both Fe and As concentrations of all samples of the source water samples exceeded the allowable limits.

Table 6.12 Chemical and bacteriological parameters of the source water samples.

Filter Id	Temp (°C)	pH	Turbidity (NTU)	Chemical parameters (mgL^{-1})				Bacteriological parameters (C.F.U /100mL)	
				Fe	Mn	SO_4^{2-}	As	TC	FC
1	25	7.0	17	3.3	0.0	50	490	116	78
2	25	6.7	42	6.4	0.0	50	475	4	8
3	26	6.6	47	7.6	0.3	50	450	22	50
4	26	6.7	56	9.0	0.0	50	285	26	32
5	25	6.8	73	10	0.2	58	450	18	8
6	25	6.7	39	5.3	0.0	50	500	16	18
7	26	7.0	42	6.2	0.0	50	500	24	44
8		7.0	46	7.2	0.0	50	480	40	14
Bangladesh standard for drinking water		**6.5 - 8.5**	**10**	**0.3-1**	**0.001**	**400**	**50**	**0**	**0**

i) *As removal efficiency of the filters:* Figure 6.7 shows that the As concentration of the effluent samples of most of the filters (Id2, Id3, Id5, Id6, Id7 and Id8) were less than $50\mu gL^{-1}$ within four weeks. The MGH filter reached the breakthrough point after treatment of 400-450 liters of arsenic-contaminated feed water. The As concentration of the treated water samples was zero during the first week, after which the concentration level gradually increased up to the end of the 4th week, to a level below the $50\mu gL^{-1}$. Only two filters (Id1 and Id4) reached the breakthrough point before the end of one month, because these two households filtrated more contaminated water every day than the other households did.

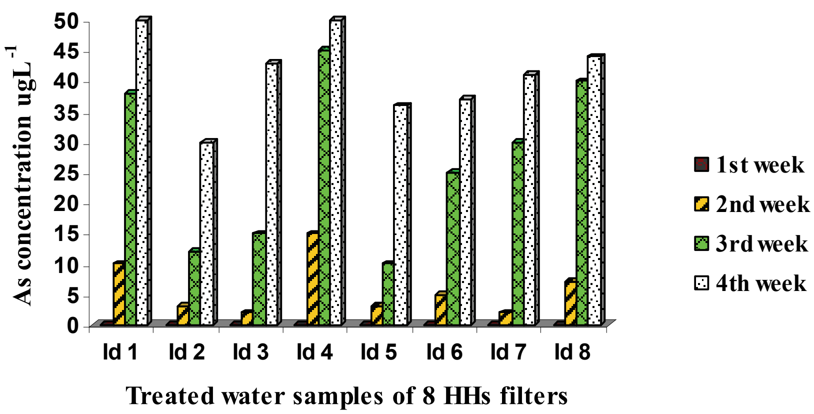

Figure 6.7 As concentration in the effluent of the MGH filter during a one-month treatment. As concentrations in the first week were close to zero.

***ii) Bacteriological quality of the water samples*:** Figure 6.8 shows the bacterial contamination of the treated water samples collected once a week from eight different tube wells. After filtration through the MHG-filter, with chlorination, most of the treated water samples became bacteria-free. Results show that the water samples of three filters (Id2, Id4, and Id8) were bacteria-free, whereas the other water samples were contaminated.

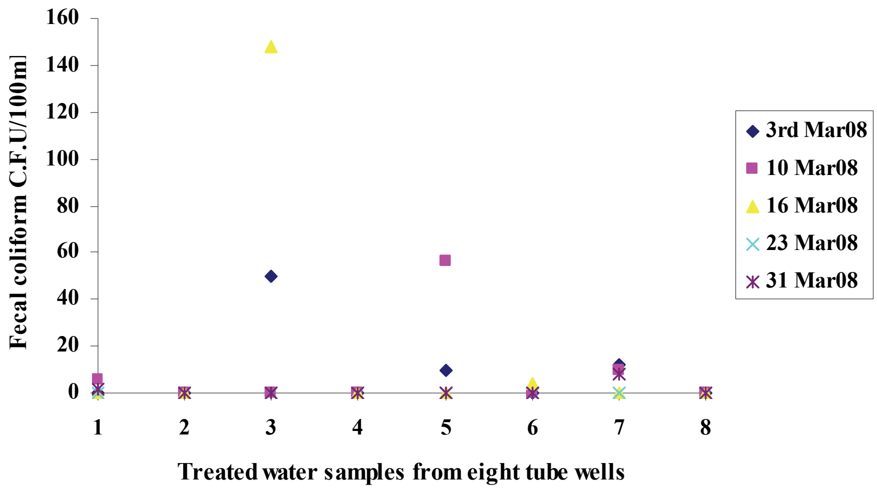

Figure 6.8 Bacteriological counts of the treated water tested in four weeks during the trial phase.

Figure 6.9 shows the bacterial counts of feed and treated water, both with $Ca(ClO)_2$ and without $Ca(ClO)_2$ treatments. The bacterial counts of the treated water were higher than those of the feed water if no bleaching has been applied. The bacterial counts were found to be zero, however, in all water samples when a bleaching treatment was carried out during the filtration process, because this technology is sensitive to the growth of bacteria, (Hoque et al., 2000).

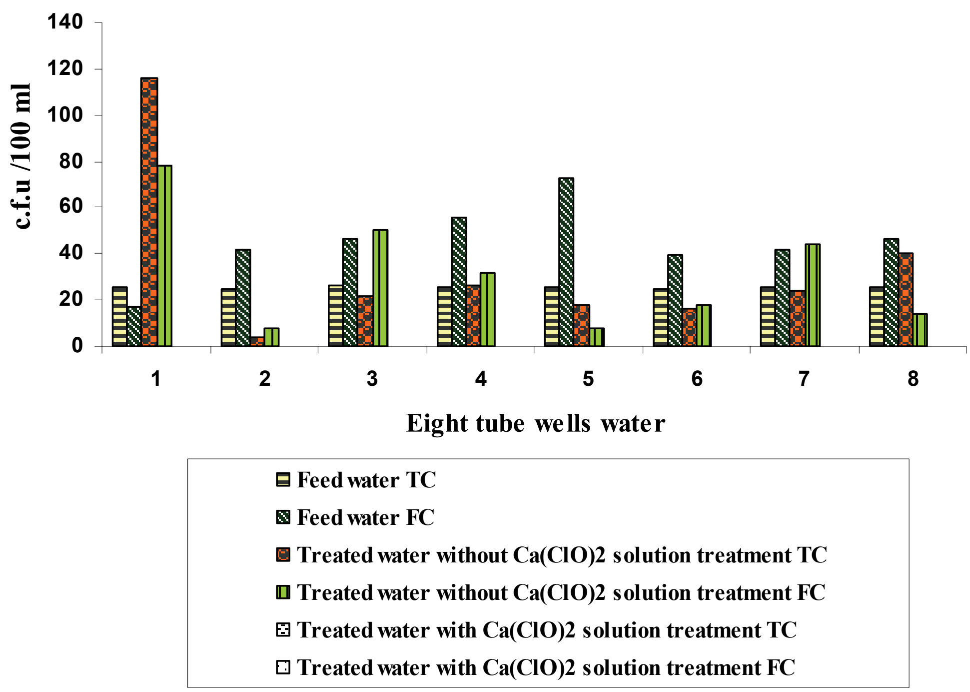

Figure 6.9. TC and FC contamination in CFU/100 ml of water samples with and without $Ca(ClO)_2$ treatment.

iii) The toxicity of spent media

The TCLP test showed the arsenic concentration of the TCLP-sand to be 0.406 mg/kg, which was below the EPA regulations for the maximum permitted As concentration of 5.0 mgL^{-1}.

6.4 Discussion

As-contaminated water. Experiments with synthetic As-contaminated water indicate that the As removal efficiency of the MGH filter in the cases of As(V) was more than that of the As(III) cases (Tables 6.1 and 6.2). This observation confirmed that As in the form of arsenite is more mobile than that in the form of arsenate. According to Ramaswami et al., (2001), it can be concluded that the As(V) removal is more efficient than the As(III) removal, due to the formation of precipitates and adsorption on brick chips and sand. To assess the influences of the Fe on the removal of As, a $FeCl_3$ ($10 mgL^{-1}$) solution was added to the synthetic As(III)- and As(V)-contaminated waters. Results indicated that the As removal efficiency from the synthetic feed water increased in the presence of Fe. This finding supported the hypothesis that the presence of Fe in the groundwater facilitates the oxidation of naturally occurring As (III) to As(V) in water, and thereby also facilitates the removal of more As (Baker et al., 2005; Hug et al., 2008). Therefore, the laboratory analysis in Wageningen reconfirmed that the As(III) removal is more difficult than the As(V) removal. In the field study, we did not consider the influence of the As speciation (As(III) and As(V)) on the arsenic removal efficacy of the filter.

The indicative results from the Wageningen experiments guided the experimental work in Bangladesh with real As-contaminated tube well water under laboratory conditions, followed by a field trial. Arsenic testing of a number of shallow tube well waters indicated a spatially heterogeneous distribution of the arsenic concentration in the shallow groundwater in the study area. In Kumarbhog village, the concentrations of As in the collected water from the tube wells, which had been installed within a distance of 200 m from each other, were found to vary significantly between 285 and 959 μgL^{-1}, similar to other parts of the country (Trang et.al., 2004; Smedley, 2002). In both study areas, high concentrations of As and Fe were found in the tube well water. In Kumarbhog village, due to the high concentration of iron, the turbidity of the water samples was high (Table. 6.12). A high salinity was observed in tube well water in Kalia as well.

Design of the filter: experiments were executed on two As removal filter designs, the one-bucket and the two-buckets design. The removal performances of the two-buckets filter were found to be effective. This design was considered for the field experiments, since the removal efficacy of the one-bucket filter was only 50-60 percent.

Flow rate of the filter: The MGH filter was tested with water from different study areas, with concentrations ranging from 100 to 959 $\mu g\ L^{-1}$ on the two different locations. No significant difference in As removal efficacy was found at different flow rates of the filter. The MGH filters produced safe and As-free drinking water at a rate of 18 liters per hour. The GARNET filter, on the other hand, showed lower flow rates at a higher turbidity of the feed water, such as 0.7 liters per hour at a turbidity of 1.9 NTU and 0.4 liters per hour at a turbidity of 9.6 NTU of the feed water (BAMWSP/DFID/WaterAid, 2001a). In this experiment, no significant variation of the As removal efficacy was found for the different turbidities of the raw water samples at different flow rates. The MGH filter produced sufficient safe drinking water per day in one hour of operation for a household of 5-6 members.

Filter bed materials and thickness: Two types of filter materials were used in this study: brick chips and sand. Usually, in Bangladesh, bricks are made from clay soils containing iron, calcium, magnesium and other ingredients. The Holocene clay is slightly enriched with silica (61-63%), lime (1.1-1.4%), and magnesia (2-9%), while the Pleistocene (Madhupur) clay is rich in alumina (20-21%) and iron oxide (8-10%). The soluble salts, organic matter and considerable amounts of iron concretions are present in the other clay soil from the Pleistocene (Banglapedia). In the MGH filter, brick chips were used as the source of Fe needed to enhance the As removal, since it is evident that a low natural iron content and high concentration of phosphorous in the As-contaminated water requires the addition of iron to As-removal (Berg et al., 2006; Hug et al., 2008). The different types of chips have shown different removal efficiencies, based on the composition of the soil, specially its content of iron. Amongst five types of chips in the filter bed, the first-class brick chips were found to be more efficient to remove As from the concentrated water than the other types of chips were (Table 6.8).

The filter made with the Sylhet sand was found to remove As better than that with a normal sand filter, although both filters had reached the breakthrough point at almost the same time. Sylhet sand consists of Bengal basin coarse grain sands, deposited as generally more quartzes and less lithic than the sands from the western Himalayan foreland basins. This sand is a more effective filter bed material to adsorb the As floc, and IS, therefore, usually used in most filters and water works as filtration material (Uddin et al., 2007).

The highest As removal was obtained at a thickness of 14 cm of the sand and brick chips layers. No difference in removal efficiency was observed between the thicknesses of 14 cm and 15.2 cm. A thickness of 14 cm of each layer was found to be the optimized thickness for the MGH filter, comprised by 47 cm tall 50 L buckets.

Bacteriological quality and disinfection: the application of the calcium hypochlorite solution in the filter resulted in an FC and TC count in the treated water samples of zero (Table 6.10). The feed water samples were bacterially contaminated, maybe due to growth of the bacteria in the filter bed sands or the source water. The use of the calcium hypochlorite for disinfection usually results in the formation of toxic chlorinated by-products. However, these health risks are small in comparison to the risks associated with drinking microbially contaminated water. During the preparation of the bleaching solution precautions are needed, so it is preferable to use the hydrated form of $Ca(ClO)_2$ rather than the dry form.

In the trial phase, all feed water samples of the eight households' filters were found to be bacterially contaminated (Table 6.12). The bacterial counts of treated water without any $Ca(ClO)_2$ treatment were found to be higher than that of the feed water samples, whereas the bacterial counts were found to be zero in all water samples when a $Ca(ClO)_2$ solution was added to the filter and kept overnight (Table 6.13, figure 6.8). This result confirms the conclusion that bacterial growth in sand filters can be effectively prevented by chlorination (Ali et al., 2001). Tested results show that ten out of 40 samples collected from filter-treated water were bacterially contaminated. The main causes of the bacterial contamination might be the fact that the tube wells were not surrounded by concrete platforms, contamination during the transportation of feed water from the tube wells to the filter, or mishandling of the filters. The filter outlet can be easily contaminated if kids or other members of the household touch it with dirty hands, or if the storage containers are not kept in a clean and hygienic condition. The treated water samples may have high bacteria counts even though the filter itself may have an excellent pathogen removal efficiency. Therefore, to bring about improved health benefits, to educate the users on basic health and hygiene as well as on the necessity to strictly follow the instructions on the operation and maintenance of the filter, is a crucial requirement.

***Breakthrough point**:* during filtration, the As adsorption capacity of the filter bed gradually gets saturated and reaches the breakthrough point when the concentration of the effluent water exceeds 50µgL^{-1}. The breakthrough points found were 220-350L in Kalia, and 430-450 in Kumarbhog. These differences of the breakthrough point of the filters at the two locations might be caused by different geological conditions (Figure 6.5) and the complex water chemistry in the groundwater. The iron concentration is higher in Kumarbhog, while the salinity is higher in Kalia. During the field trial in Kumarbhog village, the breakthrough point was 400-450L for As-contaminated water with a concentration ranging from 150 to 950µgL^{-1} As for one continuous filtration process, without changing the filter bed materials. In the field trial, the six filters did not reach the breakthrough point after a one-month operation. The other two filters had reached breakthrough points because more As-contaminated drinking water was filtrated, due to the drinking water consumption by the members of big households.

Disposal of As-rich wastewater and spoils: the process of reusing the arsenic–laden sands and brick chips of the MGH filter after breakthrough reduced the volume of disposable filter bed materials by a factor half. This reuse technique is more precautionary and acceptable than dumping these materials in the reducing environment of landfills (Sarkar et al., 2008) or water bodies. It is evident that no leaching of As occurs from the As-rich iron oxide-impregnated brick sands from the filters to the groundwater. The environment and groundwater rarely contain a high concentration of As through the leaching from As-enriched waste of filter materials (Islam et al., 2003). No or a negligible amount of As will be released to the environment if As-situated spoils come into contact with flowing or stagnant water, such as ponds, ditches or large water bodies. The earlier investigation by TCLP testing shows that the leached As concentration of the bricks was below the EPA regulatory TCLP limits (Rouf and Hossain, 2001). Other studies indicate that filter spoil can be used as construction materials and/or can be disposed on the cow dung stockpile. Another recommendation is to dispose the spoil into the sealed septic tank of the toilet (BAMWSP/DFID, 2001; Berg et al., 2006). Scientifically, maybe these are not recommended safe disposal options for the spent filter materials; they should not be followed until a further, detailed investigation has been done on this issue. The spent sands and brick chips can be stored in the dedicated areas, but the location for a dumping site should not be the garden or vegetable and agricultural fields, because in an anoxic condition, plant roots may accumulate arsenic, turning agricultural food into a health hazard for humans (Alam, 2003; Williams et al., 2006; Zhu et al., 2008).

In this research, the exhausted filter material was tested by the TCLP and classified as non-hazardous. The As content of the sample showed to be a non-toxic 0.406 mg/kg, which was below the EPA regulatory As limit of 5.0 mgL^{-1} for the TCLP. Therefore, MGH filter spent materials are deemed to be non-hazardous for the environment, due to the possibility of their safe disposal.

Achievement of the MGH filter: As already mentioned, the MGH filter was developed, based on the passive-oxidation adsorption and filtration process. The design of the filter was adopted from the GARNET filter. The original GARNET filter performed poorly in the field application. Only in 8 percent of the tested samples collected from Hajiganj (the southeastern part of Bangladesh) As concentrations were found below 50 μgL^{-1} As, while in other places (Kalaroa in the southwest and Iswardi in the northwest of Bangladesh), the removal efficacy was 54-66 percent (BAMWSP /DFID/WaterAid, et al., 2001b). The newly developed MGH filter was able to remove 95-100 percent As from the treated water samples in the villages of Kalia and Kumarbhog.

The MGH filter is simple to operate and maintain. It requires a simple physical demand, in line with the traditional domestic water handling by women, as opposed to costly treatment systems based on mechanical or electrical power. Technically, it has shown the best performance, while it has a low cost and can be made with locally available materials. In operation, the MGH filter merely needs a chemical addition: the locally available and low-cost $Ca(OCl)_2$ solution (bleaching powder) for the occasional disinfection of the treated water. The MGH filter, like other, similar filters, has a high removal efficiency with regard to iron and the turbidity of the contaminated water (Neku and Tandukar, 2003). During the filtration process, the turbidity of the feed water was reduced from 2.79 to 1.5 FTU. There is no need for regular washing the filter bed materials (the sand and brick chips beds in the bucket), like in the case of the Sono filter and other filters, to prevent the flow rate from clogging (see Chapter 5). Therefore, the filter has a high flow rate of about 16-18 liters of water per hour, and economically it is cost–effective and viable.

In this study, the main focus was on low-cost technology by considering the construction of a filter with local materials. The capital cost of the filter is about Tk 1000-1250 (Euro 10.8-13.4[3]), depending on the quality of the filter unit materials. The total cost comprised the cost of one wooden/steel frame for holding two buckets (of 50 L), two small buckets (of 10 L), two small steel plate cloths, connected outlet pipes, filter materials (sand and brick chips), and bags made with polyester cloth and calcium hypochlorite. The operational costs of the filter are low; they include the cost of sand and brick chips for reinstalling the filter. The estimated operational cost of the filter is Tk 10-13 (Euro 0.11-0.14[4]) per 100 liters, which is low-cost in comparison to other available treatment technologies for As removal in Bangladesh.

Therefore, the technical validation shows that the MGH filter is more efficient than other As removal technologies. It was developed based on the sand filters at the household, to make it relatively less expensive, and it requires no chemical pre-treatments. It is simple to operate and maintain and produces water that is less turbid and iron free, at a high flow rate, with a 99-100% As removal efficiency.

6.5 Conclusions

Based on passive oxidation-adsorption-filtration technology, a new filter was developed, called the MGH filter. Both the structural, operational and maintenance characteristics were optimized, based on the experimental findings. The MGH filter was found to performing be satisfactorily, reducing As concentrations over a wide range, from 959 to zero μgL^{-1}. The filter comprises two buckets containing filter beds of sand and brick chips. The investment cost of the filter unit is about Tk 1000-1250 (Euro 10.8-13.4) and the operational cost is minimal, Tk 10-13 (Euro 0.11-1.4) per 100 liters of water. The filter produces a small

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[3] At the time of this study, Euro 1 was Tk 93.

amount of spoil and the exhausted filter spent was tested by the TCLP and classified as non-hazardous, which means no problem to handle. Hence, spent filter material of this filter will not be a grave environmental concern, provided spent material is disposed of properly.

In the trial phase, eight filters were used in households to treat tube well water with concentrations of As, ranging from 285 to 500 μgL^{-1}. The concentration of Fe ranged from 5.3 to 10.0 mg/L in the source water. Both concentrations exceeded the allowable limits for drinking water in Bangladesh (ECR, 1997). The MGH filter removed both As and Fe concentrations from the feed water to a value below the allowable limit. A month-long observation of the filters in operation showed that the As concentration of the effluent (treated) water was near zero during the first week and gradually increased up to the end of the 4th week, to a level of $50\mu gL^{-1}$, depending upon the amount of consumption water that was used by the users.

The major advantages of the developed MGH filter technology for the arsenic removal of contaminated drinking water in rural households may be listed as follows:

- it can be built from local materials at low costs;
- it can produce Fe-free, odorless, transparent and cold water;
- it does not require any daily addition of chemicals;
- it has an acceptable flow rate of about 16-18 liters of water per hour;
- it does not require daily maintenance, such as washing the filter units, sand and bricks;
- it needs disinfection with a BP solution only once a week;
- it does not require regular monitoring of the breakthrough point of the filtration system;
- it does not disrupt the flow rate due to blockage of the outlet device of the filter;
- the filter's spent material is easy to collect and safe to store;
- it is cost–efficient and acceptable to the community.

Therefore, the MGH filter is a promising As removal technology at the rural household level. Users readily accepted this simple, low-cost, robust technology to remove arsenic from contaminated tube well water. The field trial of the technology at the household level was conducted over a period of one month. Hence, it is highly recommended that the technology is further observed over all the year's seasons and in different parts of the country, based on motivated community participation. When this is required, it should be refined.

7

Evaluation of the Filter for As Removal at Household Level

7.1 Introduction

This chapter presents the evaluation of the performance of the MGH filter at field level in Kumarbhog village. The evaluation included the technical validation of its arsenic (As) removal efficiency and the social acceptance of the filter. Social and cultural factors relevant to the introduction and safe application of the filter are essential for its sustainable development (cf. Hoque et al., 2004a; Tomizawa, 2001). They include household characteristics and features of domestic production, particularly those that require the use of water, and are contingent upon women's practical gender needs, since women play a key role in domestic production and are the household water managers (Moser, 1994). Gender roles are culturally defined, as are decision-making patterns and standards of convenience and safety. These all play a role in the adoption of technological innovations by households. Economic constraints have to be placed in a holistic livelihood perspective because they refer to the allocation of scarce household resources (Huq, 2000; Niehof and Price, 2001). Therefore, for the use of a household As removal system to be effective, it is necessary to first assess the applicability of the system in terms of its affordability, household time allocation, convenience and safety, using both a social and a gender perspective.

To evaluate the suitability of the technology in relation to the social and domestic context, a sociological approach was applied, adopting the adjusted model on ecological modernization by Spaargaren and Van Vliet (2000). As discussed in Chapter 3, the original model was modified to include five slots (see below). The MGH As-removal filter was developed in the laboratory (see Chapter 6) and the field trial was performed during one month, March 2008, and evaluated after three months, in July 2008. The filters were distributed to eight households in the study area. Their efficacy was assessed by conducting tests on As-contaminated shallow tube well water (feed water) and filtered water (treated water), in the field as well as the laboratory. For the evaluation of the filter's performance with regard to the social and gender aspects, the case study method was applied to the eight households. To place the case households in perspective and to provide a basis for the selection of the case households, a household survey was conducted (see Chapter 3 for the methodological details).

This chapter will first provide a brief description of the study area, followed by a discussion of the methods and materials used in the field. Subsequently, the characteristics of the households in the study area and the eight case studies are presented. In the second part of the chapter, the evaluation of the technical performance and the social and gender aspects of the operation and maintenance of the filter are discussed. The chapter ends with a discussion and a conclusion.

7.2 Study Area

The study area is located in the village of Kumarbhog, a sub-district of Louhajang, in the Munshiganj district (see Figure 7.1). The great river *Padma* (Ganges) passes at the southern and eastern parts of the district. Louhaganj is one of six sub-districts in Munshiganj. The area is vulnerable to erosion by the *Padma* River. Altogether, the district counts 134 villages. According to the 2006 census (BBS, 2006a), the total population of the sub-district of Louhajang was 153,433, comprising 50.07 percent males and 49.93 percent females. Groundwater is the main source of drinking water, and the shallow aquifers are severely affected by As contamination.

Figure 7.1 Location map of the Louhajang sub-district in Munshiganj.

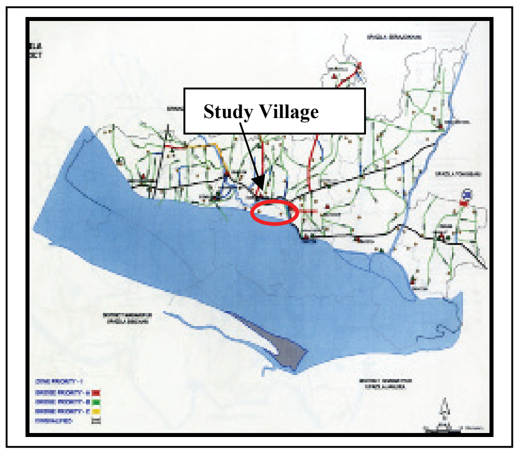


Figure 7.2 Location map of study village Kumarbhog in Louhajang.

In the sub-district of Sirajdikhan, adjacent to Louhajang, it is noted that dissolved As in the groundwater ranged from 0.006 to 0.461 mgL^{-1} (Halim et al., 2008). The study area is Kumarbhog village, located along the *Padma* River (Figure 7.2). Most of its tube wells were identified as being As-contaminated. The National Arsenic Mitigation Information (NAMIC, 2004) indicates that 90 percent of the shallow tube wells are As-contaminated in the Kumarbhog union (Figure 7.3). Out of 748 shallow tube wells (STW), only 74 were As-free and 674 were As-contaminated. Only 22 deep tube wells (DTW) were installed to serve As-safe drinking water to the more than 16.000 people of the area. There is no community-based pipeline water supply system. Sometimes, the village people drink rainwater or water from the river.

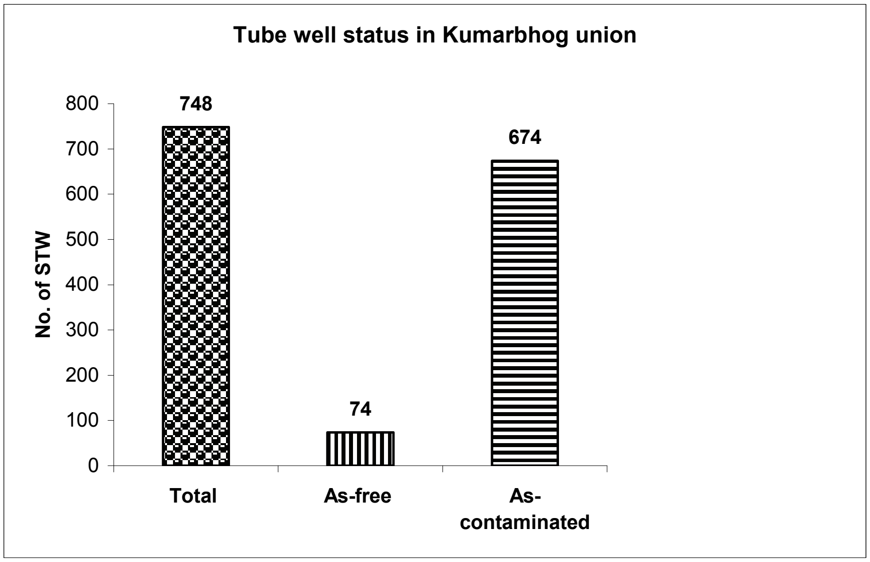


Figure 7.3 Arsenic-contaminated tube wells in Kumarbhog (NAMIC, 2004).

7.3 Method and materials

The technological validation on the performance of the filters was carried out by testing the water samples from the feed water and from water treated by the MGH filters, and by testing the toxicity of the filter spoil materials (see Chapter 6), as well as checking the handling of the waste through observation and interviewing the users. The socio-economic data of the study area were collected through a household survey of 108 households (see Chapter 3 for details). The questionnaire (Appendix 2) was based on the different variables related to the conceptual framework (five slots). It included questions to yield a demographic and socio-economic profile of the households as well as data on water use. In addition, eight case studies were conducted of filter users. The survey data and the results of the case studies were used for an assessment of the social and gender appropriateness of the filter in the field. The five slots are:

S1: Compatibility of the technology with the users' *lifestyle*, convictions, and social identity, also with respect to other life segments than those to which the technology directly appeals. This information is documented in the socio-demographic characteristics of the survey households and case studies.

S2a: Suitability of the technology with regard to domestic *time-space structures*. Data were collected on the type of housing, the room for placing the filter, water access, and so on, as well as on the gender division of labour.

S2b: *Affordability* of the operation and maintenance costs for the household. Data were collected on household incomes, expenditures and assets.

S3: Suitability of the technology in terms of *comfort*, *cleanliness, convenience*, and *safety* within the domestic domain. Data were collected on the health status of the surveyed households and the ways of operating the filters and the disposal of the waste materials.

S4: *Operational modes* of the technology and its requirements of *training* and *discipline*. Interviews with filter users and observation techniques were applied to collect the information on the modes of operation and maintenances of the filters.

The survey was conducted during November 2007. Group meetings and informal discussions were carried out to assess the users' perspective on the performance of the filter. The arsenic concentrations of samples of the feed water collected from the As-contaminated tube wells and of treated water from the MGH filters were tested in the field, using a field kit and the Atomic Absorption Spectrophotometer (ASS) in the laboratory in Dhaka. The levels of bacteriological contamination (TC and FC) were tested in the Dhaka laboratory.

7.4 Characteristics of the households in the study area

7.4.1 Demographic characteristics

Table 7.1 indicates that most household heads are male, female household heads comprising only 6 percent of the total. Except for one Hindu household, all households were Muslim households. Of the total population of 593 household members, 51.5 percent were men and 49.5 percent were women, while 47.2 percent were married and 50.0 percent were unmarried. The unmarried population includes children and teenagers. Eleven women were widows, amongst them the six household heads. Fifty-five percent of the households had four to six household members, whereas 27 percent of the households had seven to nine, and only three had 10 members. The average household size was 5.5.

Table 7.1 Household heads, population, sex, household members, marital status, household size and religion of the households.

Variables	Frequency	%	Variables	Frequency	%
Household Head (HHH)			**Population of HHs**		
Male HHHs	102	94.4	Male	301	51.5
Female HHHs	6	5.6	Female	292	49.5
Total	108		Total	593	
No of HHs members			**Marital Status**		
2-3	16	14.8	Married	280	47.2
4-6	59	54.6	Unmarried	296	50.0
7-9	30	27.8	Widow	11	1.8
>10	3	2.8	Single	3	0.5
			Divorced	3	0.5
Average HHs size	5.5		**Religion of HHH**		
			Muslim HHHs	107	99.1
			Hindu HHH	1	0.9

Source: Socio-economic Survey 2007.

The economically active persons, aged 15 to 65, comprised 65 percent of all household members, the group under the age of 15 comprised 31 percent, while persons aged 65 and above comprised 4 percent (Table 7.2). The demographic dependency ratio was 54.

Most of the households (64%) were nuclear family households. Only 39 households were based on extended families and included parents and/or brothers, sisters, grandchildren and other relatives of the household head. The trend of households being increasingly based on nuclear families rather than extended or joint families (see Chapter 3) is visible in the data.

Table 7.2 Age distribution of household members and household composition.

Variables	Frequency	Percentage
Age distribution of household members		
0-4	48	8.1
5-14	138	23.3
15-64	385	64.9
≥ 65	22	3.7
Demographic dependency ratio	54	
Relation to the household head		
HH head him/herself	108	18.2
Spouse of HH head (wife)	102	17.2
Son	160	27.0
Daughter	131	22.1
Son-in-law	2	0.3
Daughter-in-law	3	0.5
Grandchild male/female	5	0.9
Brother/brother-in-law	20	3.4
Sister/sister-in-law	14	2.4
Mother of HH head	21	3.5
Father of HH head	6	1.0
Nephew or other relative male	7	1.2
Niece or other relative female	14	2.4

Source: Socio-economic Survey 2007.

Table 7.3 Education level, working status, and occupational status of the household head.

Variables	Frequency	%	Variables	Frequency	%
Education			**Working status**		
Illiterate	29	26.9	Housewife	6	5.6
Literate (only able to read and write)	25	23.1	Unemployed/looking for a job	7	6.5
Primary (grade five)	25	23.1	Self-employed in business	24	22.2
Up to grade eight	14	13.0	Employer	19	17.6
Secondary level	13	12.0	Self-employed in agriculture	42	38.9
Higher education	2	1.9	Employed as farm hand	3	2.8
			Old, disabled, retired or student	7	6.5
Occupational status					
Primary occupation	**Frequency**	**%**	*Secondary occupation*	**Frequency**	**%**
Agriculture	24	22.2	Agriculture	45	41.7
Service	11	10.2	Service	4	3.7
Fishing	1	0.9	Fishing	4	3.7
Business and trade	42	38.9	Business and trade	28	25.9
Labourerer	8	7.4	Labourerer	2	1.9
Village doctor (Ayurvedic medicine)	1	0.9	Village doctor (Ayurvedic medicine)	1	0.9
Technician and other	9	8.3	Others	17	15.7
Others	1	0.9	No occupation	7	6.5
No occupation	11	10.2			

Source: Socio-economic Survey 2007.

With regard to education, Table 7.3 indicates that about 27 percent of the household heads were illiterate, 23 percent were able to read and write, and another 23 percent had five grades of primary school. Only 27 percent had an education higher than grade five of primary school. While agriculture is more important as a secondary occupation of household heads than as a primary occupation, with small business and trade it is the other way around. Most of the trade concerns agricultural produce. The labourers mostly work in agriculture. Nineteen household heads employed other people in trade or agriculture.

7.4.2 Socio-economic characteristics

Housing

Table 7.4 summarizes the characteristics of the housing situation in terms of house ownership, the condition of the rooms, the cooking and electricity facilities and the value of the houses of the respondents. Eighty-five percent of the households in the sample were living in their own house; the other households had rented their house or were sharing the house with others. The housing structure of the poor households included a thatched or tin roof and mud walls. Most houses (73%) had tin or wooden walls and a tin roof. Only 5.4 percent of the houses had brick walls and a concrete or tin roof.

Table 7.4 Housing status and facilities, and valuation in Taka.[1]

Variable	No	%	Variable	No	%
Ownership of housing			**Cooking facilities**		
Owns the house	92	85.2	Separate kitchen	85	78.7
Rents the house	13	12.0	No separate kitchen	8	7.4
Shares the house	3	2.8	Shares with others	15	13.9
Type of housing structures	**No**	**%**	**Valuation of housing**	**No**	**%**
Thatched or mud walls with thatched roof	3	2.8	≤10,000	7	6.6
Thatched or mud walls with tin roof	18	16.7	10,000-29,999	16	14.8
Tin walls with thatched roof	2	1.9	30,000-99,999	21	19.5
Tin walls with tin roof	68	63.0	100,000-199,999	55	50.9
Wooden walls with tin roof	11	10.2	200,000-499,999	4	3.7
Brick walls with tin roof	1	0.9	500,000-1,000.,000	5	4.6
Brick walls with concrete roof	5	4.5			
Condition of the rooms	**No**	**%**	**Electricity facilities**	**No**	**%**
Hygienic	45	41.7	Electricity connection	62	57.4
Unhygienic	63	58.3			

[1] At the time of the study, USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

Most of the households (79%) had a separate kitchen; 15 households were sharing a kitchen with others. Small open yards adjacent to the house were used as kitchen space in eight households. The inside condition of the rooms of the houses was unhygienic in 58 percent of the cases. More than half of the households (57%) had access to electricity. The value of the houses ranged from Tk. 2,000 to one million, while most of the houses (70.4%) were worth between Tk 30,000 and 200,000.

Sanitation facilities

Table 7.5 indicates that the majority of the households (86%) had a toilet of their own. Still 14 percent of the households were using unsanitary facilities, such as hanging toilets, or used the open field for defecation. However, during flooding, sanitary hygiene declines because the latrines are flooded. This causes concerns about the pollution of the surface and groundwater during flooding. Safe hand washing, using either soap or ashes, was not practiced by all.

Table 7.5 Toilet facilities of the households (N=108).

Variables	Normal period		During flooding	
Types of toilets	**No**	**%**	**No**	**%**
Slab latrine	93	86.1	65	60.2
Hanging/open toilet	9	8.3	15	13.9
No toilet, uses open field	6	5.6	28	25.9

Source: Socio-economic Survey 2007.

Water access for household use

The survey data indicate that 66 households had tube wells, one of them a deep tube well (DTW), the others shallow tube wells (STW). About 39 percent of the households did not own tube wells; they shared the tube well of others (Table 7.6). About 97 percent of the tube wells were As-contaminated, only the deep tube well and one shallow tube well were not. However, only 59 of the 64 contaminated tube wells were marked red to indicate arsenic contamination, as a result of government testing. Most of the tube wells were not embedded in concrete platforms. Some were in bad condition due to a lack of maintenance. In addition to the one private deep tube well, the government had installed a few community DTWs to provide safe water in the village. Deep tube wells are more expensive than shallow ones. In 83 percent of the cases, the costs of installing a shallow tube well were less than Tk. 10, 000.

Table 7.6 Water facilities of the households and valuation of the wells in Taka[1] (N=108).

Variables	Frequency	%	Variables	Frequency	%
Tube well installation			**Valuation of STW**		
HHs installed STW	65	60.2	1,001-1,999	1	1.5
HHs installed DTW	1	0.9	2,000-4,999	29	44.6
HHs not owning TW, sharing with others 42		38.9	5,000-9,999	25	38.5
Total tube wells	66		10,000-30,000	10	15.4
Water Quality			**Valuation of DTW**		
As-uncontaminated TW	2	3.0	40,000-75.000	1	100.0
As-contaminated TW	64	97.0			
Marked green at TW mouth	2	3.0			
Marked red at TW mouth	59	89.5			
Not marked at TW mouth	5	7.5			

[1] At the time of the study, USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

For bathing and washing clothes, households used mostly STW water, whereas many households (44%) preferred to take their bath in the river (see Table 7.7).

Table 7.7 indicates that almost all respondents (96%) usually drink water from DTWs. Twelve percent of the respondents said that, in spite of the risk, they also still drink water from STWs, mainly because of the distant location of the deep tube wells, while they sometimes drink rainwater and river water. For cooking, 49 percent of the households use water from the DTWs, 28 percent from the STWs, 14 percent use water from the river, and nine percent from the ponds. During the monsoon, six percent use rainwater. Sometimes pond water and river water are used for cleaning the cooking utensils. During the 2007 floods, most of the tube wells were submerged. Only 38 percent of the households drank water from the DTW, while 61 percent drank their own STW water because during flooding they could not fetch water; for cooking, 10 households collected water from the ponds and 15 fetched it from the river.

Table 7.7 Sources of water for domestic purposes.

Source of water	STW		DTW		Pond		Dug well		Rainwater		River water	
	No	%	No	%	No	%	No	%	No	%	No	%
Drinking	13	12.0	104	96.3	0	0.0	0	0.0	2	1.9	21	19.4
Cooking	30	27.7	53	49.1	10	9.2	0	0.0	6	5.6	15	13.8
Bathing	65	60.2	5	4.6	30	27.8	0	0.0	3	2.8	44	40.7
Washing clothes	62	57.4	9	8.3	35	32.4	0	0.0	5	4.6	5	4.6
Kitchen garden	108	100.0	0	0.0	11	10.2	0	0.0	0	0.0	17	15.7
Livestock	107	99.1	3	2.8	7	6.5	0	0.0	0	0.0	31	28.7
Cleaning house	96	88.9	2	1.9	0	0	0	0.0	0	0.0	28	25.9
Toilet	96	88.9	3	2.8	20	18.5	1	0.9	1	0.9	33	30.6

Source: Socio-economic Survey 2007, multiple responses considered.

All households took STW water for their kitchen garden and livestock, but sometimes also pond and river water. Similarly, for cleaning the house premises and toilet use, most households (89%) fetched water from the STW as well as from the ponds and the river.

7.4.3 Asset ownership

Households' productive assets

Table 7.8 indicates considerable variation in the value of households' productive assets. Fifty-seven households owned land, the total value of the plots varying from Tk. 10,000 to more than Tk. 500,000. Most of them owned only small plots, just enough for a small house. Four households had orchards and 25 households had ponds worth Tk. 75,000 to 500,000.

Table 7.8 Households' productive assets in taka1 (N=108).

Household assets	Valuation in Taka[1]					
	≥ 2,000	2,000-9,999	10,000-74,999	75,000-99,999	1,00,000-4,99,999	≥ 500,000
Land	0	0	21	15	18	3
Orchard	0	0	2	1	1	0
Pond	0	0	19	4	2	0
Homestead	0	11	46	13	12	0
Shop	0	0	5	1	11	2
Plowing equipment	1	1	0	0	0	0
Farm tools*	101	5	0	0	0	0
Rickshaw	0	6	0	0	0	0
Van	0	1	0	0	0	0
Cattle	0	3	6	1	1	0
Goat and sheep	0	10	0	0	0	0
Poultry	78	7	3	0	0	0

[1] At the time of the study, USD 1 was Tk. 69.

Source: Socio-economic Survey 2007. *=spade, axe, boring device, knife, et cetera.

Nineteen households had a small shop. Almost all households had some sort of farm equipment; six households had a rickshaw, one household a van. Almost all households had poultry, since poultry-rearing is common in the area, but only 11 households had cattle and ten households had goats.

Household appliances

Table 7.9 indicates that the majority of households had furniture, the value of which ranged from Tk. 2,000 to Tk. 75,000. Fourteen households owned a radio and/or a television set, 62 households had electric goods like a fan and lamps, 12 households owned a refrigerator, and 48 households had a mobile phone. Two households had a motorcycle and 14 households a bicycle. Other assets included a sewing machine (three households).

Table 7.9 Households' appliances assets in taka[1] (N=108).

Appliances asset	Valuation in Taka[1]				
	≤ 2,000	2,000-9,999	10,000-74,999	75,000-99.,999	≥ 100,000
Furniture	1	70	30	4	3
Radio/ TV	5	9	5	0	0
Electric fan & lamps	11	46	5	0	0
Refrigerator	0	0	12	2	0
Telephone & mobile	0	40	8	0	0
Motorcycle	0	0	1	1	0
Bicycle	0	14	0	0	0
Other assets	0	3	6	0	0

[1] At the time of the study, USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

7.4.4 Household income and expenditure

Monthly income

Table 7.10 gives the categorization of households according to economic status into very poor, poor, lower middle, upper middle and rich households, based on their monthly income. About 34.3 percent of the households were very poor to poor, having monthly incomes ranging from Tk. 1,500 to 3,000, about 53.7 percent were in the lower to upper middle income categories, and only 12 percent were comparatively rich. In the survey, we found that in the 108 households, altogether 170 persons were contributing to the monthly household income. Most adult women were involved in handicraft work, such as stitching garments or embroidery, and used the money earned for personal necessities as well as household needs. Their monthly earnings (Tk. 500-1,500) represented 13.5 percent of the total earnings of the 108 households.

Table 7.10 Monthly income of households (N=108).

Monthly income in Taka[1])	No	%	Category of households
1500-2499 (22-36 US$)	6	5.6	Very poor
2500-2999 (36-43 US$)	31	28.7	Poor
3000-4999 (43-72 US$)	32	29.6	Lower middle
5000-9999 (72-145 US$)	26	24.1	Upper middle
≥ 10.000 (≥ 145 US$)	13	12.0	Comparatively rich

[1] At the time of the study, USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

A significant correlation ($p<0.01$) was observed between the monthly income of households and households having a tube well installed (Table 7.11). Most of the very poor households do not possess tube wells; whereas rich and medium-income households do have their own tube well.

Table 7.11 Correlation between monthly income and the installation of tube wells

Monthly income (Taka[1])	Tube well installation		
	Yes	No	Total
1500-2499	1	5	6
2500-2999	16	15	31
3000-4999	21	11	32
5000-9999	18	8	26
≥ 10,000	13	0	13
Total	69	39	108

[1] At the time of the study, USD 1 was Tk. 69.
Pearson Chi Square value = 15.535, P value= 0.004.

Yearly income

Households' yearly income includes the sum of monthly incomes and income from other sources, such as crops and livestock. Table 7.12 presents the ranges of yearly household income according to source of income. The highest yearly income comes from business activities, followed by income from agriculture. Ten households had yearly incomes from their business, ranging from Tk.100,000, to 500,000. Most of the households were involved in small businesses with small capital investments. Between Tk. 50,000 and Tk. 100,000 was earned yearly by 24 households from crops, by one from fishery, by eight from services, by four from business, and by one from farm labour. Although the income generated from it is low, a high number of households (74) was earning money from livestock-rearing and poultry.

Table 7.12 Yearly household income according to source of income (N=108).

Sources of income	Income (Taka[1]/ year)				
	≤ 2,000	2,000-9,999	10,000-49,999	50,000-99,999	100,000-500,000
Agriculture	2	20	23	24	0
Timber and wood	8	8	0	0	0
Livestock /poultry	70	7	3	0	0
Fishing	0	2	2	1	0
Services	0	0	4	8	3
Business	0	49	8	4	10
Rickshaw and van	0	1	0	0	0
Farm labour	0	2	7	1	0
Non-farm labour	0	1	7	0	0
Other	3	12	8	0	0

[1] At the time of the study, USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

Yearly expenditures

Table 7.13 shows that expenditures on food rank highest in comparison to other yearly expenditures. Fifty-five percent of the households spent Tk. 25,000 to 50,000 on a yearly basis on food, followed by 25 percent spending Tk. 10,000 to 25,000 and 20 percent spending Tk. 50,000 to 100,000. The expenditures on clothes, education and medicine were less than Tk. 2000 for most of the households. Expenditures on sanitation, tube well maintenance, farm equipment, transportation, electricity, and fuel were mostly also less the Tk. 2,000. Fifty-one households spent Tk. 2,000 to 10,000 on housing, while 13 households spent more. Households spent at least some money, but no significant amounts, on festivals and other purposes.

Table 7.13 Yearly expenditure of households for the past year (N=108).

Expenditure items	Expenditure in Taka[1]/ year)				
	≤ 2,000	2,000-10,000	10,001-25,000	25,001-50,000	55,001-100,000
Food	0	0	27	59	22
Housing construction/repair	14	51	8	5	0
Household effects	18	36	0	2	0
Clothing	70	38	0	0	0
Education	41	7	0	0	0
Medical	32	7	1	0	0
Sanitation	5	0	0	0	0
Tube well maintenance	5	0	0	0	0
Farm inputs & equipment	25	9	1	2	1
Paying back interest against a loan	0	1	2	0	0
Festivals	60	25	16	7	0
Transportation	79	29	0	0	0
Electricity	58	4	0	0	0
Telephone	8	36	4	0	0
Firewood & kerosene	27	18	0	0	0
Miscellaneous	70	28	7	3	0

[1] At the time of the study USD 1 was Tk. 69.
Source: Socio-economic Survey 2007.

The household budget

Household budgeting can be done according to a collective or a unitary model. The latter assumes that either all household members share the same preference function, or a single decision maker acts for the good of the entire household, whereas the first assumes differences and more than one decision maker (Quisumbing and Brière, 2000). As Table 7.14 indicates, the question on household budgeting yielded multiple responses. Fifty-two percent of the households said to budget and expend household income both individually and as a unit.

Table 7.14 Responses to question on household budgeting (N=108).

Types of responses (multiple answers)	No of HHs	Percentage
Unitary model: household head as the single decision maker	102	94.4
Individuals spend their own income on their own preferences	14	13.0
Both individual and collective expenditures	56	51.9

Source: Socio-economic Survey 2007. Multiple responses considered.

Table 7.15 shows income contributed by household members and control over household income according to source and level of income during the previous year. Household incomes were earned from different sources by different household members. Male household members contribute most to the household income, although wives and daughters contribute as well. Female household members were involved in various income-generating activities, but dominated in livestock-rearing. Male household heads were the main decision makers. While wives participated in controlling the household money to a certain extent, daughters did not. The pattern reveals the resilience of patriarchal culture, which is a major barrier to women's access to resources. Although this cannot be inferred from the table, it is assumed that the share of the household income earned by women influences their power in resource allocation (Saad, 2008).

Table 7.15 Income contributed and money controlled by household members according to source and level of income.

Sources of income	Yearly income during the past year in Taka							Income by HH members	Money controlled by HH members
	≤ 2,000	2,000-4,999	5,000-24,999	25,000-49,999	50,000-99,999	100,000-199,999	≥ 200,000		
Agri-culture	6	2	13	6	1			HHH=25, S=2 O=1.	HHH=25, S=2, O=1.
Timber/ wood	4	8	1					HHH=9, W=4.	HHH=9, W=2, S=2.
Livestock	32	5	3	1				HHH=8, W=31, S=1, D=1.	HHH=15, W=25, S=1.
Fisheries	2		3		1			HHH=1, S=5.	HHH=1, S=5
Services				7	7	8		HHH=18, W=2, S=1, D=1.	HHH=19, W=2, S=1.
Business			2	9	17	11	6	HHH=38, W=4, S=7, D=4.	HH=44, W=5, S=5.
Rickshaw /van			3	1	1			HHH=4, S=1.	HHH =4, S=1.
Farm labour			5	2				HHH =7.	HHH=7.
Non-farm labour			6	6	3			HHH=10, S=3, GF=2.	HHH=12, S=1,GF=2.
Loan				2	3	7	7	HHH =13, W=4, S=2.	HHH=16, W=2, S=1.
Other		2	19	3				HHH=19, W=3,S=1,D=1.	HHH=20, W=3, S=1.

Notes: HHH =Household head, W=Wife, S=Son, D= Daughter, GF=Grandfather, O=Other male member.
Source: Socio-economic Survey 2007. Multiple responses considered.

7.4.5 Gender division of labour

Reproductive activities

Table 7.16 shows the role of female household members in the gender division of tasks regarding household water management. Wives and female household heads (77%), daughters (46%) and other female members (53%), were found to fetch drinking water, whereas insignificant numbers of male household heads (10%) and sons (10%) were found to do so. Furthermore, washing clothes, cleaning the house, sweeping the household premises, and cooking are carried out mostly by the female members of the household.

Table 7.16 Gender division of work related to water fetching and water use.

Person involved	Fetching drinking water		Fetching cooking water		Washing clothes		Cleaning house & premises	
	No	%	No	%	No	%	No	%
HHHs (male), n=102	10	9.8	18	17.6	14	13.7	17	16.7
Spouse of male HHHs + female HHHs, n=108	80	75.0	77	71.3	77	71.3	23	21.3
Son, n=160	23	14.4	10	6.3	24	15.0	2	1.3
Daughter, n=131	57	43.5	46	35.1	45	34.4	24	18.3
Other male member, n=39	0	0.0	0	0.0	31	79.5	4	10.3
Other female member, n=53	38	71.7	41	77.4	35	66.0	31	58.5

Source: Socio-economic Survey 2007. Multiple responses considered.

As Table 7.17 shows, about 94 percent of the wives and 28 percent of the daughters were involved in cooking. Childcare and elderly care were mostly done by wives and female members of the households, not by husband and sons. Sons and other male members of the households were mostly involved in livestock-rearing, while wives, daughters, and other female members were rearing poultry and ducks. The kitchen garden is the women's domain, whereas it is men who go to the market for shopping and trade. This confirms the pattern generally found in Bangladesh, where women are usually not allowed to go out for shopping, especially in rural areas (Ali, 2005).

Table 7.17 Household's gender division other tasks.

Person involved	Cooking		Nursing the old		Child care		Going to market		Rearing livestock		Kitchen gardening	
	No	%	No.	%	No.	%	No.	%	No.	%	No.	%
HHHs (male), n=102	4	3.9	2	2.0	10	9.8	90	88.2	4	3.9	10	9.8
Spouse of male, HHHs + female, HHHs, n=108	102	94.4	80	74.1	90	83.3	21	19.4	20	18.5	20	18.5
Son, n=160	0	0.0	7	44.4	2	1.3	34	21.3	40	25.0	5	3.1
Daughter, n=131	36	27.5	68	51.9	22	16.8	0	0	9	6.9	28	21.4
Other male member, n=39	0	0.0	11	28.2	9	23.1	31	79.5	12	30.8	13	33.3
Other female member, n=53	44	83.0	32	60.4	32	60.4	0	0.0	10	18.9	19	35.8

Source: Socio-economic Survey 2007. Multiple responses considered.

Gender involvement in productive and community activities

Although invisible from the outside, women's unpaid work in the household allows the male household members to earn an income. Similarly, women's work in the field during harvesting time is seen as just helping the husband, whereas men's work is seen as productive and yielding an income. These gender imbalances are clearly visible in Table 7.18. Only a few women were found earning money from small trade or livestock-rearing. Men dominated participation in community activities. However, according to the respondents, some women had received loans for their income-generating activity.

Presently, in Bangladesh villages, women are increasingly involved in NGOs, attending village group meetings and participating in community activities.

Table 7.18 Gendered involvement in the productive and community activities.

Person involved	Productive		Community activities			
	Income earning		Participation in men's group meeting		Participation in women's group meeting	
	No.	%	No.	%	No.	%
HHH (male), n=102	97	95.1	30	29.4	0	0.0
Spouse of male HHHs + female HHH, n=108	16	14.8	0	0.0	22	20.4
Son, n=160	68	42.3	2	1.3	0	0.0
Daughter, n=131	22	16.8	0	0.0	0	0.0
Male member, n=39	21	53.8	0	0.0	0	0.0
Female member, n=53	0	0.0	0	0.0	0	0.0

Source: Socio-economic Survey 2007. Multiple responses considered.

7.4.6 Health status, disease patterns, and health-seeking behavior

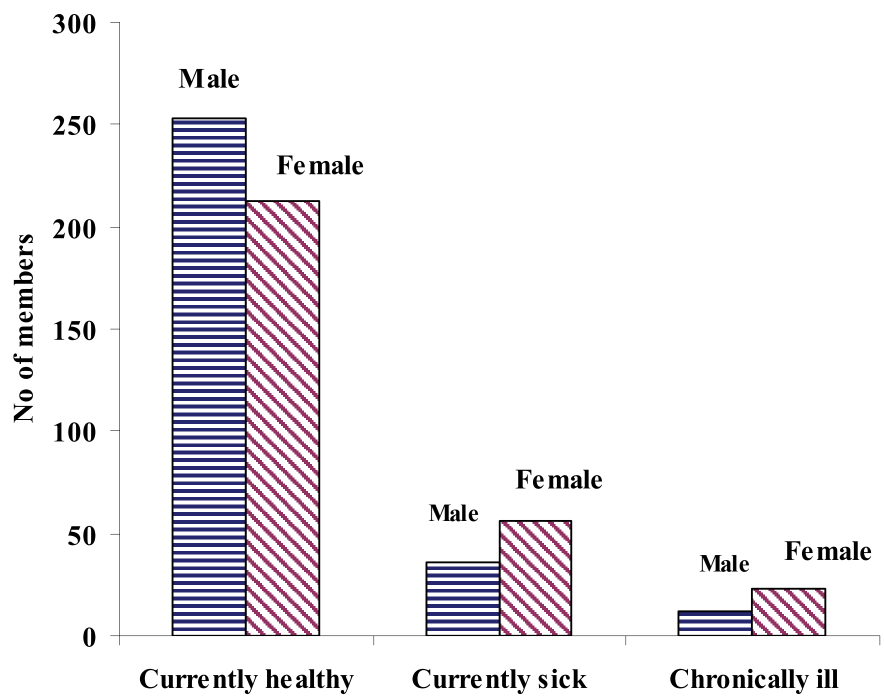


Figure 7.4 Current health statuses of male and female household members.

Figure 7.4 presents the figures on the health status of household members at the time of the survey.

The figure indicates that 84 percent of the men and 73 percent of the women among the surveyed population were currently healthy. Twelve percent of the men and 19 percent of the women were currently sick, whereas chronically illness was found among eight percent of the women and four percent of the men.

Table 7.19 Diseases of adult men and women during the past five years and the past year.

Type of disease	During the past five years				During the past year			
	Male N=124	%	Female n=96	%	Male N=36	%	Female N=56	%
Diarrhea	22	17.7	17	17.7	5	13.9	7	12.5
Dysentery	13	10.5	6	6.3	0	0	5	8.9
Fever	23	18.5	10	10.4	1	2.8	9	16.1
Spotted skin disease	2	1.6	2	2.1	3	8.3	3	5.4
Spotted hand	0	0.0	1	1.0	3	8.3	2	3.6
Spotted foot	1	0.8	2	2.1	2	5.6	2	3.6
Respiratory problem	3	2.4	2	2.1	1	2.8	1	1.8
Kidney problem	4	3.2	3	3.1	1	2.8	3	5.4
Ache	6	4.8	18	18.8	3	8.3	7	12.5
Accident/Surgery	4	3.2	7	7.3	3	8.3	3	5.4
Gastrointestinal	16	12.9	10	10.4	6	16.7	7	12.5
Hypertension	5	4.0	1	1.0	2	5.6	4	7.1
Other	25	20.2	17	17.7	6	16.7	3	5.4

Source: Socio-economic Survey 2007.

Table 7.19 indicates the morbidity pattern experienced of males and females during the past five years and the past year. Both men and women suffered from similar types of illnesses, but to a different degree. Most of the respondents found it difficult to recall the incidences of disease in the household during the last five years. Fever followed by diarrheal diseases ranked first among the men, while unspecified aches ranked first among the women, followed by diarrheal disease. During the past year, 17 percent of the men and 12 percent of the women suffered from gastrointestinal diseases, followed by diarrhea for men and fever for women.

Figure 7.5 presents the survey data on persons suffering from As-related afflictions. Skin lesions are the most common manifestation of exposure to arsenic. During the survey, a number of respondents were identified with spots on the skin, specifically on their feet and hands (Figure 7.5). Two persons asked for medicine for their *arsenicosis*. They said that they had heard about arsenic disease from many people but that nobody gave them any medicine. The survey data show that more patients with the disease were reported during the past year than during the previous five years, which indicates drinking of As-contaminated water. According to the NAMIC report (NAMIC, 2004), in 2004, 21 female and 11 male patients were identified in Kumarbhog. When asked about the presence of arsenic in the drinking water, 94 out of 108 respondents said that they knew about a*rsenic mukta pani* (As-free water) and a*rsenic jukta pani* (As-contaminated water) and the effect of the latter on health from the local NGOs, schoolteachers, village elites and the radio. A few respondents (14) said that they did not know about arsenic poisoning.

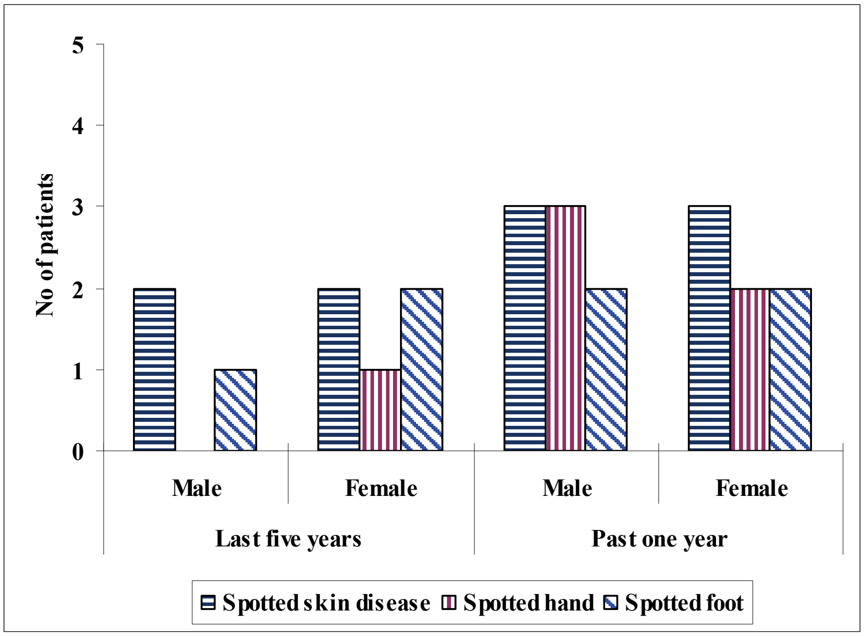


Figure 7.5 Arsenic-affected patients identified in the survey

Table 7.20 indicates the differences in health-seeking behavior between men and women. More women than men seek the help of traditional healers, while men more often consult herbalists and use ayurvedic medicine. However, the popularity of traditional treatments seems to be decreasing.

Table 7.20 Health-seeking behavior by gender during the past year.

Health-care sought	During past five years				During past one year			
	Male n=124	%	Female n=96	%	Male n=36	%	Female n=56	%
Homeopath	5	4.0	6	6.3	1	2.8	7	12.5
General physician	3	2.4	5	5.2	2	5.6	9	16.1
Specialized doctor	10	8.1	12	12.5	12	33.3	10	17.9
Para-professional	12	9.7	7	7.3	1	2.8	4	7.1
Village-trained doctor[1]	14	11.3	15	15.6	8	22.2	9	16.1
Medical assistant /NGO health worker[2]	11	8.9	22	22.9	5	13.9	6	10.7
Traditional treatment								
Herbalist/Ayurvedic	55	50.0	5	5.2	1	2.8	3	5.4
Traditional healers	7	5.6	24	25.0	6	16.6	8	14.3

[1] Trained village doctors have some sort of medical formal training.
[2] Medical assistants or NGO health workers have some sort of formal medical training.
Source: Socio-economic Survey 2007. Multiple answers considered.

7.5 Field application of the MGH filter at household level

7.5.1 Filter distribution to households

Eight households were selected for a field trial of the MGH filter, which was evaluated after three months, to assess the effectiveness of the filter developed in the laboratory (see Chapter 6). Before distributing the filters, during two days, the women of the eight households were given motivation and training by the researcher and the research assistant. The training concerned the filter's construction, operation and maintenance. Topics included: washing and drying the filter bed materials (sand and brick chips); the thickness of the filter bed materials; the filter's flow rate; the bleaching treatment during the filtration process; and the disposal of the spent filter materials.

The MGH filter unit[5] with accessories, provided to the household users, consisted of:
- a pair of buckets of about 50 L capacity for the two-buckets filter unit;
- two small steel plates to keep at bottom of the buckets over the outlet pipes with valves;
- six bags made by polyester cloth to fill the filter-bed materials (bricks and sands);
- sand and first-class brick chips bought at the market in Mawa, which were washed thoroughly with As-free water and were dried in the sun during a whole day before use;
- one packet of 250 mg calcium hypochlorite $Ca(OCl)_2$;
- a pair of small buckets of 10L capacity, one for storage of the treated water and one for the collection of the feed water from the tube well;
- a steel filter stand.

The demographic characteristics and socio-economic status of the eight case households are presented in Tables 7.21 and 7.22.

Table 7.21 Demographical characteristic of the eight households.

Case No	Filter ID	Age of woman	Education	Household size			Relationship to HHH
				Male	Female	Total	
1	Id 1	25	Grade 8	8	4	12	wife
2	Id 2	50	Illiterate	3	2	5	wife
3	Id 3	40	Literate	2	3	5	wife
4	Id 4	22	Up to 10	7	5	12	daughter
5	Id 5	55	Illiterate	4	3	7	wife
6	Id 6	30	Grade 8	2	3	5	wife
7	Id 7	40	Illiterate	2	3	5	wife
8	Id 8	53	Illiterate	2	2	4	wife

Source: Socio-economic Survey 2007.

[5] The design of the MGH filter unit is presented in Chapter 6 and Appendix 4.

Table 7.22 Socio-economic status of the eight households.

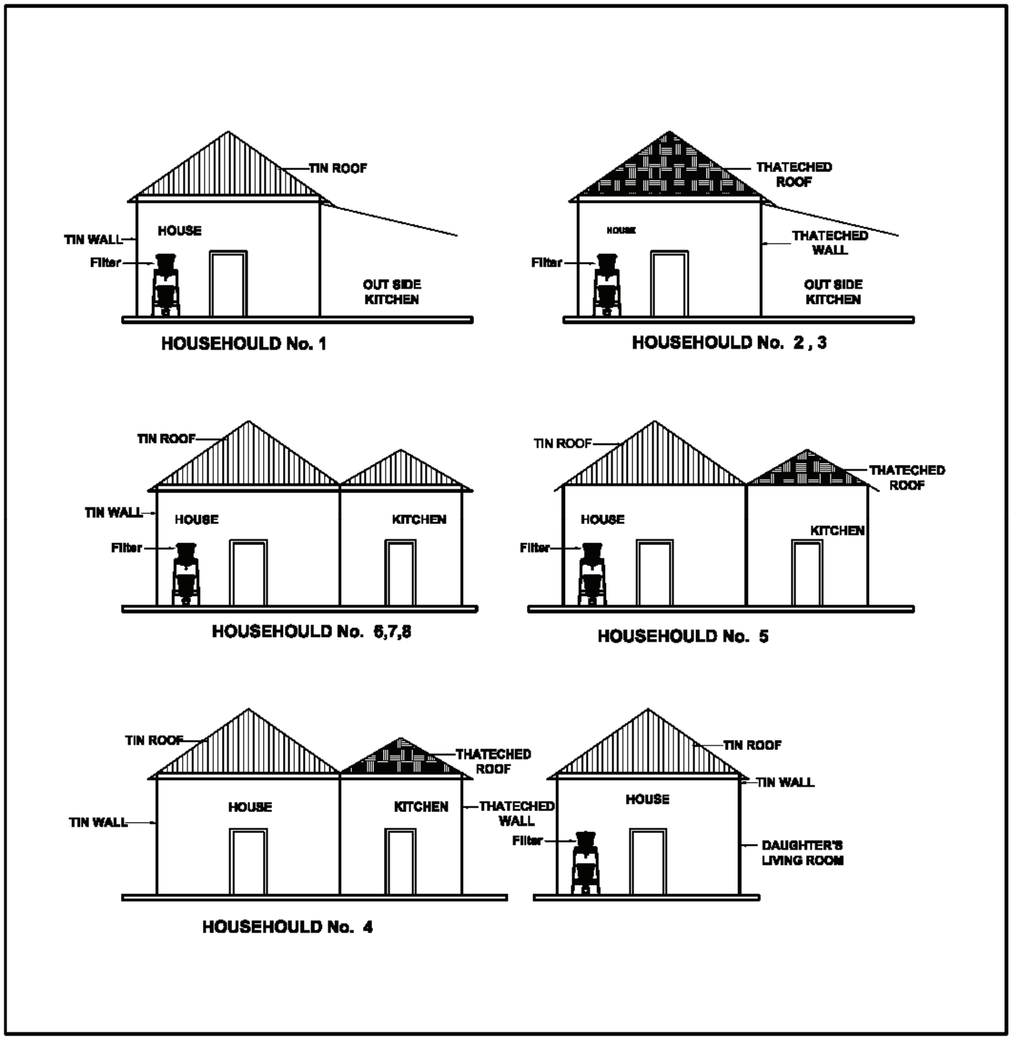
Case No	Primary occupation of HH head	Monthly income	Socio-economic class	Housing			
				Structure type	Kitchen	STW	Toilet
1	business	6,000-7,000	Upper middle class	Tin wall and tin roof	Outside	Self	Ring slab
2	business	2,000-3,000	Very poor	Thatched wall and roof	Outside	Self	Ring slab
3	business	4,000	Lower middle class	Thatched wall and roof	Outside	Share	Ring slab
4	business	2,500-4,500	Lower middle class	Tin wall and tin roof	Separate, inside	Self	Ring slab
5	agriculture	5,000	Lower middle class	Thatched wall and tin roof	Separate, inside	Self	Ring slab
6	services	5,000	Lower middle class	Tin wall and tin roof	Separate, inside	Self	Ring slab
7	business	3,000	Very poor	Tin wall and tin roof	Separate, inside	Self	Open, hanging
8	agriculture	3,000	Poor	Tin wall and tin roof	Separate, inside	Self	Ring slab

Source: Socio-economic Survey 2007.

The socio-economic status of the eight households was classified as poor, lower, and upper middle class. Six household heads were engaged in business as primary occupation, one in services and one in agriculture. Most of the wives and daughters were involved in stitching garments or other handicrafts. The monthly incomes were US$ 36-43 (n=2), US$ 43-72 (n=4) and US$ 72-145 (n=2). The houses of six households had a tin wall and roof (Cases 2, 4, 5, 6, 7 and 8), one house had a thatched wall with a thatched roof (Case 1), and the last one had a thatched wall and tin roof (Case 3). Two households had no electricity and both of these did not have a separated kitchen, so they had to use the open space adjacent to their houses for cooking. All households except one (Case 7) had sanitary ring slab toilets. All had their own tube wells except for one household (Case 3) that had to share the neighbour's tube well.

7.5.2 Case studies of the filter users

The selection of the eight households was based on socio-economic characteristics and their willingness to use the filter. This section shows how the eight women users were coping with the As problem in the drinking water and how they used the MGH filter in their homes (Map 7.1).



Map 7.1 Housing structures of the eight households and positioning of the MGH filters.

Household 1

Rani Begum is a 25 year-old woman, married to Tara Mia, with whom she has two sons. Rani lives with her in-laws. Her father-in-law, the household head, is 60 years old and her mother-in-law, Sufia Begum, is 55. Her father-in-law has a small shop on the Dhaka-Mawa Highway. Tara has four brothers; one of them is married and lives in the same house with his wife and daughter. Tara is working in the garment industry. The other brothers are students. There are 12 household members, of whom three are children. Rani came to Kumarbhog village five years back, after their previous house was lost due to riverbank erosion. Her father-in-law bought this land and constructed this house.

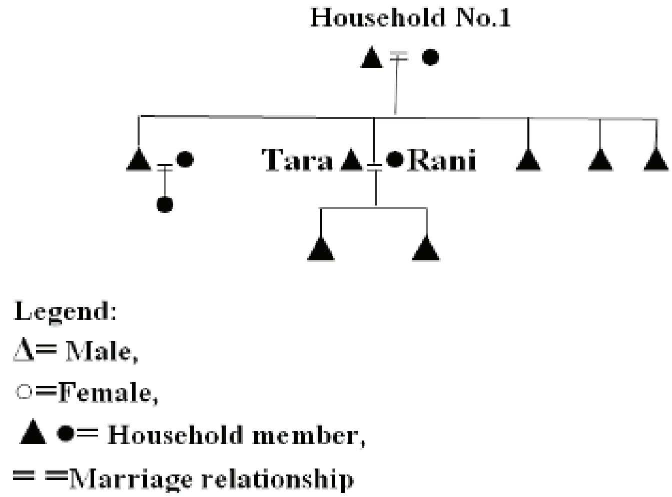


Figure 7.6 Genealogy of Rani.

Rani gets up early in the morning, just before sunrise, and prays. Then she swipes the house and premises, and cleans the kitchen space. She prepares the food for breakfast and around 11 a.m., she cooks lunch. Usually, they eat pulses and vegetables, sometimes fish. Beef or mutton they are only able to eat three to four times a year. Sometimes they eat chicken, when they have a guest. Rani feeds the poultry three times a day and does seasonal kitchen gardening. When she has time, she stitches garments to earn some money.

Rani's father-in-law installed a shallow tube well, which two to three years back was identified by the local NGO as As-contaminated and marked red. Therefore, for safe water they have to go to the deep tube wells installed by the government, the closest of which is located about 800 meters away. This is a problem, because during daytime, there is no man in the house and the male members of the household would not like to fetch water anyway. For this reason, Rani has to fetch water, but her husband does not like her to do it, for religious reasons (*purdah*). However, Rani says that in the interest of the household members' health, especially that of the children, Rani and her sister-in-law used to fetch water two times a day from the deep tube well, in the early morning and afternoon. To be relieved of this burden, Rani took the filter and installed it in her living room. They gladly started to drink the filtered water and Rani's father-in-law took the filtered water to his shop for his customers to try.

Household 2

Shahida Begum is 50 years old and her husband's name is Ataul Hoque. She has one son, one grandson, and a daughter-in-law. Her husband has a small business and her son is agricultural labourer. He could not continue his studies because of the household's economic problems. The house was built 35 years back, when land was very cheap. Shahida gets up to pray before sunrise. Sometimes, she helps her daughter-in-law to prepare the foods for lunch. Usually, they do not cook anything for breakfast and eat *panta bhat* (rice soaked in water) with mashed potato or pulses, and sometimes only tea and biscuits. For lunch and dinner, they eat rice, vegetables, pulses and sometimes fish. Shahida looks after her grandson. She feeds the chickens and does some (seasonal) kitchen gardening.

Ataul Hoque installed the tube well many years ago, but at that time, they did not know about the arsenic in the water. Only last year, they were informed that the water is unsafe. Now, they are drinking water from a deep tube well. Shahida said that fetching water annoys her because the well is too far away to bring a full *kolshi* (pitcher) of water

(10 to 15 liters). Her daughter-in-law is a young woman, so Shahida cannot allow her to fetch water because it would violate the *purdah* rules. Sometimes her son fetches water from the DTW in the morning, but not enough for the whole day. Therefore, she sometimes thinks it would be better to drink water from their own well, in spite of the health risk. When she was offered a filter, she gladly accepted.

Household 3

Rowshanara Begum is 40 years old. Her husband's name is Arob Ali, aged 48. She has one daughter and two sons. The daughter is 15 years old, and both sons are under 10. She got married 25 years back at the age of 15. They used to live in another village, located at the other side of the Padma River. Five years back, her husband bought this land and constructed this house. After morning prayers, Rowshanara does her household chores. In the morning, she prepares breakfast for the family. Everyday, she sweeps the house and the premises, feeds the chickens and ducks, does the washing, and has to cook two times for lunch and dinner.

They do not have a tube well of their own but share the tube well of their neighbours, which turned out to be As-contaminated. To get As-free water, she and her daughter have to fetch water from a deep tube well, located more than one hour of walking (800 meters) from the house, and they have to wait in the queue once there. To be relieved of this burden and save time, she willingly installed a filter in her house.

Household 4

Shimul is 26 years old and is the wife of Biplob. They have been married for nine years. Shimul is living in a big extended family with her in-laws. Arefeen, her mother-in-law, is 57 years old and Shayed Ahmed, her father-in-law, aged 70, is paralyzed and disabled.

Shimul's father-in-law has two houses. They live in one of those; the other is rented by another family. Shimul's husband has a grocery shop. In addition, they monthly get Tk. 1.000 from the rent. Arefeen has two daughters and three sons. Both daughters are married. One son has migrated to Malaysia. The eldest daughter, Lita Khaum, and her sons are part of the household as well, but have a separate outside room. Her husband migrated to the Middle East to work. Shimul's mother-in law Arefeen spent Tk. 0.25 million to send her elder son abroad. Biplob is the second son. The youngest son lives in Dhaka. Arefeen's 35 year-old brother and 40 year-old sister are also part of the household. Both are mentally disturbed. The sister sometimes goes out in the morning and comes back at night, but the brother always stays in the home. They each have a separate outside room. The total household size is 12. Shimul wakes up in the morning and after prayers, she sweeps the house and prepares some light food for her father and mother-in-law. Only rarely do they have rice and mashed potatoes for breakfast. Shimul cooks rice, vegetables and often fish for the family at 11 a.m. After lunch, she does some garment stitching. Every day she feeds the chickens.

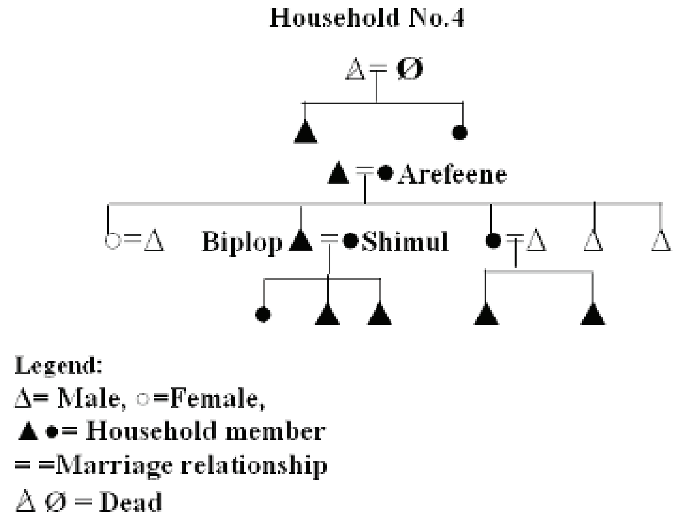


Figure 7.7 Genealogy of Shimul.

They have a tube well, but since 2004, it is As-contaminated. This is why they had to fetch water from the DTW installed by the government, located at a distance of about 750 meters. They often drink As-contaminated water, because to fetch safe water from that distance is a heavy and time-consuming job. Another DTW was installed privately, about 500 meters away. The owner allowed them to fetch water there, but presently, his son has denied them access because he believes that the well's concrete platform will be damaged if the well is used too much. Usually, Shimul and Arefeen's daughter Lita fetch As-free water, since the men are working outside the village. To fetch water, they have to wait for a long time because there is a big queue at the well. Three pitchers (about 18-20 liters) of water are needed daily. Because the main house has only one room and not enough space, Arefeen installed the filter in her daughter's room (see Map 7.1).

Household 5

Rabeya Begum was 55 years old when she was given the filter, and her husband, Mojid Majhi, was 70 years old. During the trial phase, she accepted the filter eagerly, but four months after that she suddenly died. She left two sons and a daughter. All are married. One son and the daughter live elsewhere with their spouses and children. One son with his wife and their two daughters, and one grandson lived with Rabeya.

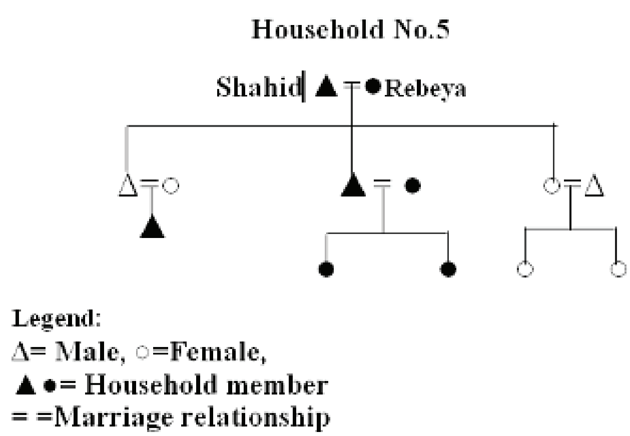


Figure 7.8 Genealogy of Rabeya.

Her son operates a boat in the Padma river, ferrying passengers, and the other son is a day labourer. They have been living in the house for ten years, since their former house collapsed due to riverbank erosion. The total household size was seven when Rabeya was still alive.

Rabeya did the same domestic work as most of the rural women do, together with her daughter-in-law. Rabeya used to cook for lunch. Rabeya said that before they use to have periods of leisure time, when they did not need to fetch As-safe water from a long distance. She felt very tired, so sometimes her daughter-in law used to fetch water. However, Rabeya did not like to let her daughter-in-law or daughter go outside the house every day to fetch water. She always requested her sons to bring the water, but they said they had no time to do so. This motivated her to take the filter into her one-room house.

Household 6

Nasima is 30 years old and her husband, Mintu Sheikh, is 40. Nasima has two children: Tahmina, a girl aged nine, and Masud, an eight-year-old boy. Her mother-in-law, Hashina Begum, also stays with them. The total household size is five. Nasima has been living in this house since her marriage, ten years ago. She studied up to class five. After she married, her in-laws did not allow her to continue school. Her husband inherited the land from his parents. He commutes to Dhaka to work. In the morning, after prayers, she sweeps the house and prepares tea for her mother-in-law, her husband, and herself. She cooks food for the children first, then for the whole household. Usually, they eat rice, pulses and vegetables for lunch and dinner, and they rarely eat meat.

They have their own tube well but it is As-contaminated. For safe water, she has to fetch it from the DTW located about 800 meters away. Her husband cannot do this because he is in Dhaka. There is always a big queue at the well and women are quarrelling about who is first. It takes about one-and-a-half hours to fetch water from the deep tube well, which leaves her little time to earn some money with stitching garments and making handicraft. For cooking she sometimes uses water from the river. For these reasons, she agreed to take the filter.

Household 7

Jahanara Begum is a 40-year-old woman with two daughters and one son. Her husband, Hawladar, is 50 years old. He has a small business as a vendor of scrap iron and steel. They have been living in their present house since their old house was lost due to riverbank erosion, five years back. Then they built this house on somebody else's land and have to pay a yearly rent of Tk. 1,000 for it. In her life, she twice experienced losing her house because of riverbank erosion. Presently, they have a small piece of land on which they have started to grow rice. Usually, Jahanara wakes up in the morning just before sunrise. After morning prayers, she sweeps the house and the premises, and cleans the kitchen. She does not have a separate kitchen but uses a small space adjacent to the house. In the early morning, they drink tea and eat popped rice. Around 10 a.m., they eat rice with water, leafy vegetables and chili. Sometimes they eat only green vegetables and mashed potato. During lunch, they sometimes have one piece of fish, but they eat vegetables and pulses almost every day. They rarely eat chicken. They do not eat beef, except during the Eid festival. After afternoon prayers, Jahanara starts cooking dinner. She could not rear chickens and cattle because her neighbour does not allow any animals to invade his premises.

Prior to getting confirmation of its arsenic contamination, they used to drink water from their own tube well. Later on, they started to fetch drinking water from a deep tube well, located about 700 meters away in front of a mosque. Mostly, they drink As-contaminated water, as it is difficult to fetch water from the DTW every day, especially on

Fridays and during severe raining. Jahanara said that it is very hard to fetch a full pitcher of water for her small son, who is only eight. So her adult daughters have to fetch water and have to queue for a long at the DTW site. They fetch one pitcher of water in the morning and another one in the afternoon. During summer, the collected water becomes warm. During the monsoon period and rainy days, they have to use a small boat or sometimes get wet while moving through the inundated road to reach the DTW site. Therefore, they were eager to get a filter.

Household 8

Rahima is 53 years old. Her husband, Momen Ali, is looking for a job, but is presently working as an agricultural labourer and occasionally doing some small business. They have been living in the village for 25 years and constructed a small house on the village chairman's land, for which they do not have to pay land rent because they are poor. Rahima Begum has six daughters and two sons. Four daughters got married and two are unmarried. Two sons live separately with their wives and children. One unmarried daughter, named Rehana, studied up to class four, but could not continue because she suffered from rheumatic fever eight to nine years back. Presently, she is cured and stays in the house. With handicraft (embroidery, dress stitching) she earns about Tk. 900-1,000 yearly, depending on her production and delivery to the retail businessmen. Her younger sister Shahina does the same work and also still lives at home. Rehana and Shahina spend most of the money they earn on their personal needs, but sometimes they use it for buying basic household goods. The total household size is four.

Rahima is a pious woman. She wakes up at four a.m. to pray, and sometimes she wakes up in the middle of the night to pray. After praying, she starts her daily routine, such as sweeping the room and the yard in front of the room, and serves breakfast and tea to her husband and daughters. She cooks lunch after sweeping the kitchen at around 10-11 a.m.

Before it was identified as being As-contaminated, they drank water from their own tube well. After that, they started to fetch water from a DTW located about 750 meters away, but they had to stop fetching water from that well because they were denied access by its owner. They had to drink contaminated water from their own well again until the local government installed another DTW in the locality. However, fetching water there is a burden. Usually, her daughter Rehena fetches the water from that DTW, which takes her 30 minutes. Rehana said that she feels too tired to fetch water and did not have any leisure time. They need two pitchers of water a day, one in the morning and one in the afternoon. The whole of last month, she could not fetch water because she was sick, so most of the time, they drank the contaminated water from their tube well. Hence, Rahima was happy to install the filter in her house.

7.6 Technical validation of the performance of the MGH filter in the field

7.6.1 Results of the trial

During the trial, the concentrations of arsenic, iron, turbidity, and manganese sulfate pH of the feed water samples of the eight filters were tested. The concentrations As of the filtrate (treated) water samples were tested daily by the As field kit and weekly by the Atomic Absorption Spectrophotometer in Dhaka. Results showed that As concentrations of the feed water samples ranged from 285 to 859 μgL^{-1}, while the turbidity ranged from 17.26 to73 NTU and the content of iron in the feed water ranged from 3.3 mgL^{-1} to 10mgL^{-1}. The concentrations of As in all the treated water samples were found to be almost zero in the first week, after which its concentrations gradually increased (Figure 7.9). At the end of the months, the As concentrations of all the water samples were found to be below the permissible limit of drinking water in Bangladesh (50 μgL^{-1}), except filters Id1 and Id4. These two filters reached the breakthrough point before the others, because of the relatively high water consumption of the households concerned (household size 12).

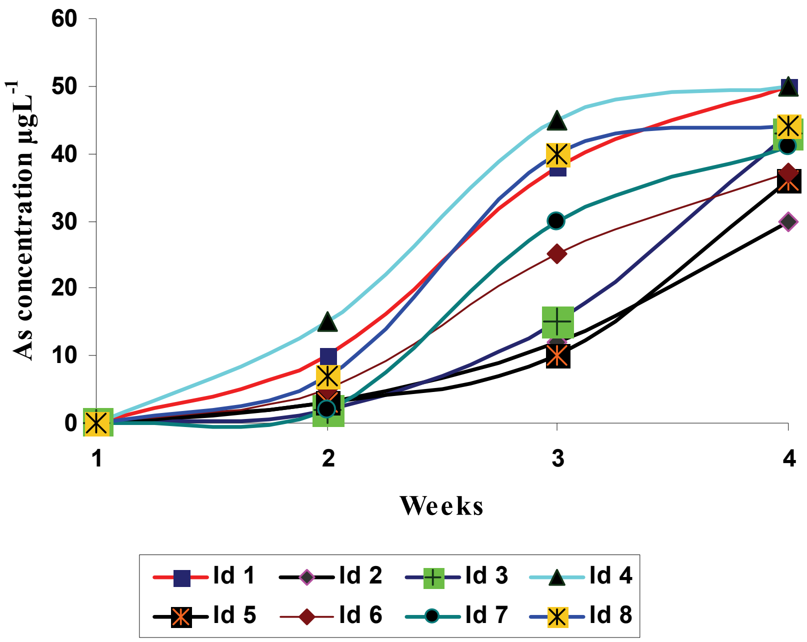


Figure 7.9 As concentrations of the treated water during four weeks in the trial phase.[6]

Bacterial contamination of the fecal coliform and total coliform of the eight feed water (As-contaminated tube well water) samples were tested before filtration and found to be highly bacterially contaminated (see Chapter 6). In the trial phase, the bacteriological contamination of the feed and treated water samples was tested once a week. Results show that the water samples of three filters (Id2, Id4, and Id8) were found to be free from bacterial contamination by fecal coliform, whereas the other water samples were found to be contaminated, although for the samples of three filters (Id1, Id6 and Id7), the counts were not significant. The samples of the remaining two filters (Id3 and Id5) were found to be significantly contaminated. Contamination may have occurred during the transportation of the water from the tube well to the filter, or because the water was not treated with chlorination. Contamination may also have occurred when the filter was not properly covered (see Section 7.7).

7.6.2 Results

During the evaluation phase, five filters (Id1, Id2, Id4, Id6, and Id8) were found to be in operational condition, while three filters (Id3, Id5 and Id7) were not in use. Figure 7.10

[6] The same data are used as in Chapter 6: Trial of the MGH filter in household use.

shows that the concentrations of As in the water samples of two filters (Id2 and Id6) exceeded the permissible limit of 50 μgL^{-1}. Users of these two filters had not changed the filter bed materials since the filters were installed, four months previously.

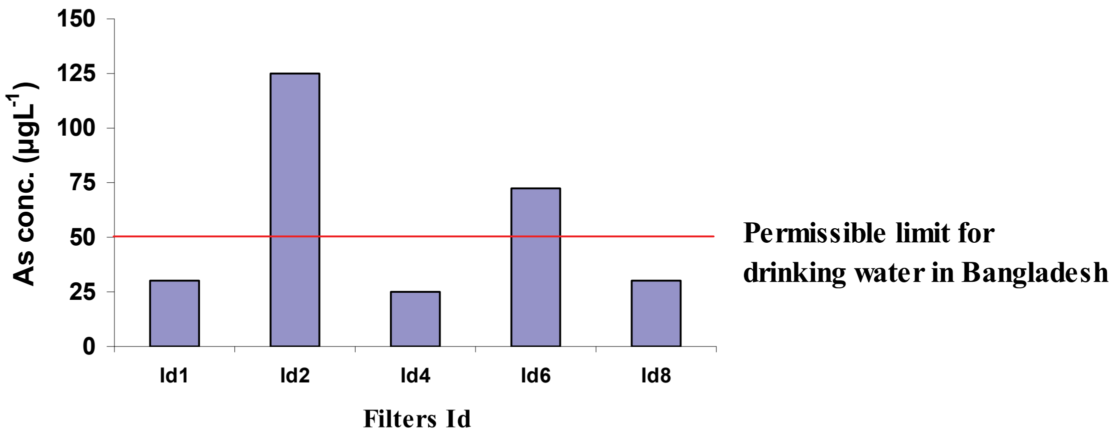


Figure 7.10 As concentration of the treated water during the evaluation phase.

The thermotolerant coliform counts of the treated water samples of the five running filters were done once in a week and the results show that out of 20 tests, only six tested water samples were free from bacterial contamination (Figure 7.11).

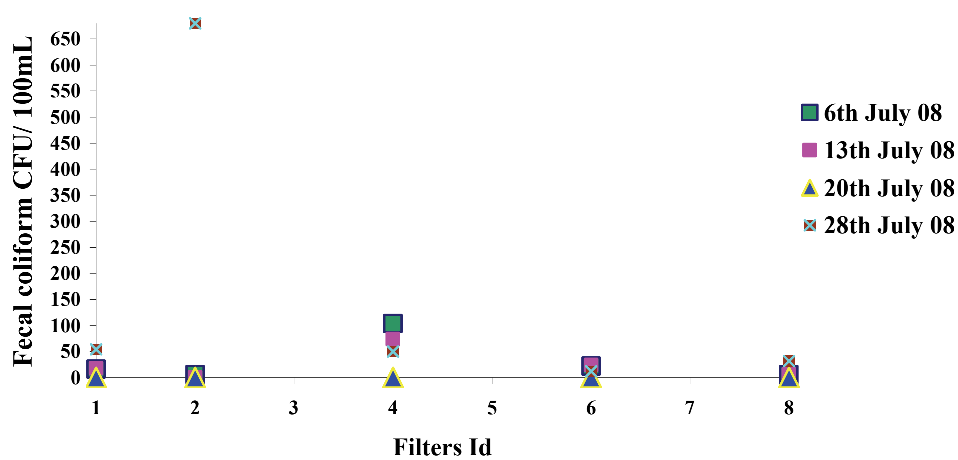


Figure 7.11 Bacteriological contamination of the treated water samples during the evaluation phase.

It appeared that the users were not using the hypochlorite solution ($Ca(ClO)_2$) properly during the filtration process and that, most of the time, the lids of the filter buckets were found to be dirty and the water storage buckets were without cover.

7.7 Handling of the filters at household level

7.7.1 Trial phase: Operation and maintenance of the filters

During the trial, the operation and maintenance of the eight filters was monitored for one month by systematic observations on a daily basis. Figure 7.12 indicates the operational status of the eight filters. In the case of filter Id1, the filter buckets were found to be clean, but on three days, the water inside the buckets was dirty and on 12 days the buckets were without lids. Similarly, on five days, dirty water was observed in filter Id2 and one day in the filters Id3, Id5, Id6, Id7 and Id8. The buckets for storing drinking water were found to be unclean and uncovered for a few filters during the whole month. All filters except Id4 were found without a lid.

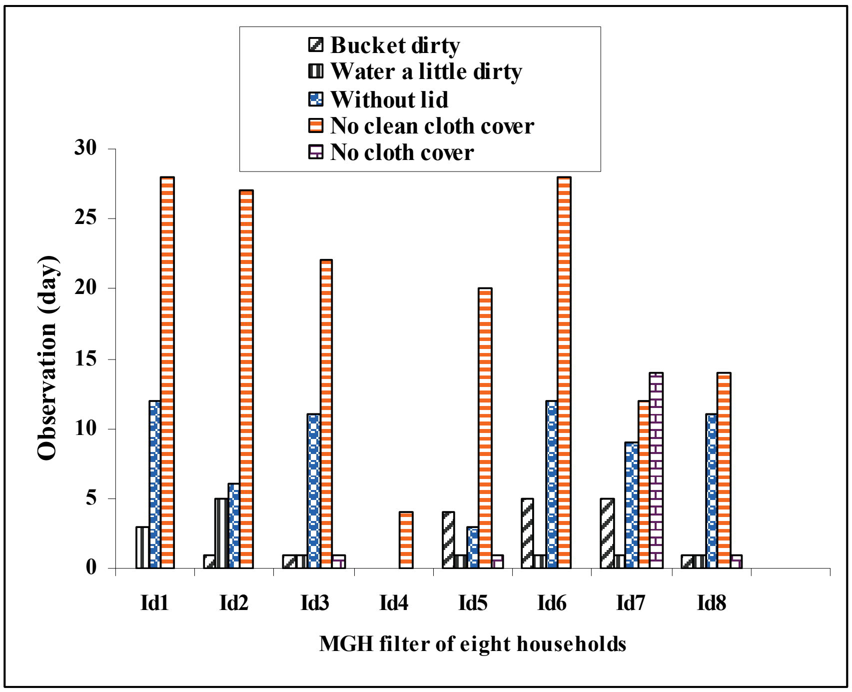


Figure 7.12 Operational status of the MGH filter during the trial phase.

7.7.2 Evaluation phase: Operation and maintenance of filters

At the evaluation after three months, five out of the eight filters were in operation, and the operation and maintenance of these were monitored during one month. Most of the filters were found to be dirty and without lids, and the buckets for storing water were covered by a dirty cloth**.** Figure 7.13 indicates the status of the eight filters during the evaluation phase. Out of the eight, the five filters Id1, Id2, Id4, Id6 and Id8 were under operational conditions.

Three households (filters Id1, Id4 and Id8) had changed the filter bed materials and treated them according to the instructions, whereas in the case of the filters Id2 and Id6, the materials were only washed without changing them. The bleaching solution treatment was carried out by five households. The users of the filters Id3, Id5 and Id7 had stopped the operation of the filters after two to three months.

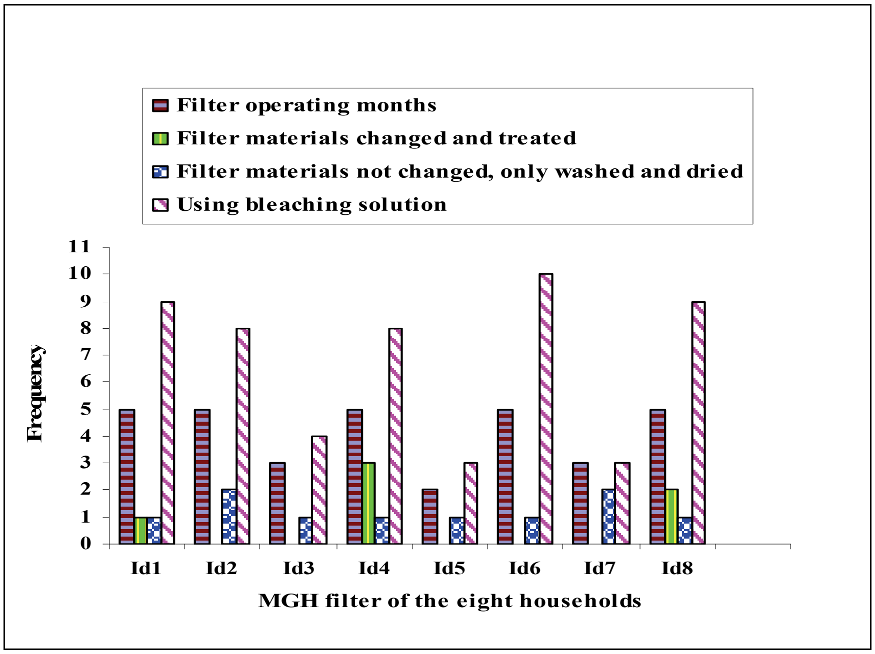
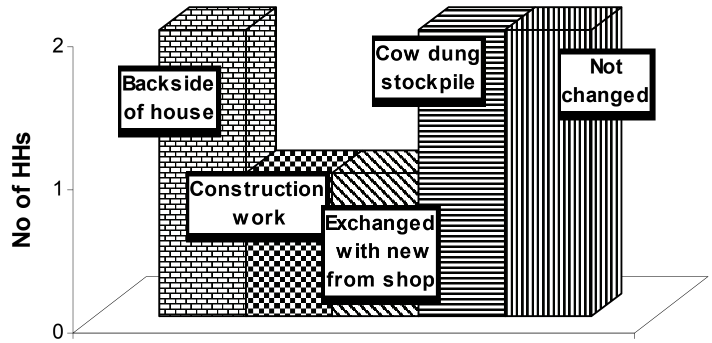


Figure 7.13 Operational status of the MGH filter during the evaluation phase.

7.7.3 Disposal of the spent filter bed materials

Households 2 and 6 did not replace the filter bed materials. They reused the materials after washing them, rinsed them with $Ca(ClO)_2$, and dried them. For the remaining six households, the disposal of the spent filter materials (sand and brick chips) was carried out in different ways (Figure 7.14). Two households (3 and 5) threw the spent filter materials at the backside of their houses on the land. Household 7 used the filter bed materials in construction work. Household 4 replaced the spent materials with new sand and brick chips in the shop for free. The other two households (1 and 8) had disposed of the spent materials on the cow dung stockpile near their house and covered them with cow dung.



Disposal of spent filter materials

Figure 7.14 Handling of the spent filter materials by the eight households.

7.7.4 Users' perception of the filter operation

In the trial phase, all members of the eight households drank the filtered water. They appreciated its quality and taste, and its transparency because it was free of iron. In the evaluation phase, some users could not operate the filters because of certain economic or social reasons. A major concern was the purchase of the filter bed materials. In July 2007, the study area was flooded due to severe raining, which is a common phenomenon in Bangladesh. The area became inundated and the users could not reinstall their filters. Besides, most of the women who operated the filters, faced difficulties reinstalling them. For the washing and drying of the filter materials and moving of the buckets, they needed assistance from other household members. The case studies also revealed that many household heads were not willing to buy the materials. Table 7.23 presents the women's opinion on the filter operation.

Table 7.23 Women users' opinion on the filter operation.

Household	Users opinion on filter operation
HH 1	- One month before the evaluation phase, the user changed the filter materials when the water became odorous. - This month, they could not change the filter materials due to flooding and severe raining, but she plans to reinstall the filter after the rains have stopped. - The purchase of filter bed materials depends on her husband's willingness to buy filter materials. She always depends on the decisions of her husband and father-in-law.
HH 2	- All members have been drinking the filtered water from the installation till now. - They express satisfaction on the filtered water and say that if the filter unit would break down, they will prepare another filter like this. - They did not change the filter media until now because they thought it was not needed, but they frequently chlorinated the filter and wash, dry and reuse the media. - After the floodwater has receded, they will change the filter materials.
HH 3	- The filter was not operated for the last two months when the filtrate water became odorous. - Due to their economic condition, they could not buy the filter materials. - Presently, her husband has agreed to buy the filter materials by earning money, because fetching water from the deep tube well is physically demanding. - After the floodwater has receded, they will reinstall a filter. Her daughter and sons are not interested in helping her to reinstall it, so she has to wait for her husband to help.
HH 4	- She reinstalled the filter according to the instructions after treating 350-450 liters of raw tube well water, by changing the filter bed materials. - Brick chips and sands was brought from the shop and washed and dried properly. - She did not dispose of the spent materials but exchanged them for new materials. However, if needed, they would buy the sand and bricks because they are not expensive. - They would like to continue drinking the filter water as long as possible. - She expressed her heartiest appreciation to the researcher for the filter, because now they do not have to fetch drinking water from far on sunny and severe raining days. - Daughters and sons of the household are well educated, so they know about the importance of the filter.
HH 5	- Stopped the filter operation after two months, because she could not change the filter bed material herself, and her sons and husband were busy harvesting. - They plan to reinstall the filter next month, after the construction of a new house. - Her elder son is interested in drinking filter water and wants to operate the filter, but other members are not interested because the re-installing takes time. - The washing and drying of the materials is a problem now, because of flooding, so they are waiting for sunny days. - They were facing a problem having to fetch drinking water from a deep tube well in the rainy season, so they understood the filter is very effective during the monsoon.
HH 6	- The filter is in operational condition, but they did not reinstall it. They thought the filter water was of good quality, so did not see the need to wash the filter and reinstall it. - According to the given instructions, they were using $Ca(OCl)_2$ after 15 days. Instead of changing the filter bed materials, they washed them with a $Ca(OCl)_2$ solution and dried them before reinstalling the filter. - After the raining stops, they will re-install the filter with the help of her husband.
HH 7	- They did not change the filter bed materials after the trial month. After the two trial months, they stopped drinking the odorous filtered water. - Her husband earns money as a daily labourer, so he has no time to reinstall the filter. - Her children were not interested to operate the filter and her husband did not want to spend money on it. But she has plans to start again after the floods have receded.
HH 8	- All members are drinking filter water, are satisfied and appreciate this research. - They will not stop the filter operation, because it relieves them of the burden to fetch drinking water from far away. - She changed the filter chips and sands and washed them with river water. - When her elder daughter went to Dhaka they had a problem, because her daughter knew how to operate and maintain the filter. - Presently, her son maintains the filter and her younger daughter started to go to school again and could take leisure time. Before, she had to postpone her schooling, stitching and embroidery activities to fetch drinking water from far away.

7.8 Discussion

During the trial phase, eight MGH filters were distributed to women in eight households in Kumarbhog village, after the development of the filter in the laboratory. A filter unit, filter bed materials and $Ca(OCl)_2$ or bleaching powders were provided to the user households. A two-day demonstration was carried out on the operation and maintenance of the filter. One woman from each household participated in the demonstrations. The performance of the filter in terms technical and social aspects were assessed for one month in the trial phase, and for one month in the evaluation phase.

7.8.1 Technical aspects

The technical validation of the filter at the field level was assessed both during the trial and the evaluation. In the trial phase, the MGH filter reduced the concentrations of As of the contaminated water samples satisfactorily below the allowable limit (50µgL^{-1} As). During one month of operation, the concentrations of As in the treated water samples of the six filters (Id2, Id3, Id5, Id6, Id7, and Id8) were found to be below the limit value. In addition, these filters did not reach the breakthrough point, whereas the remaining two filters (Id1 and Id4) reached breakthrough point in the fourth week of filters operation. The breakthrough points of the filters were not reached at the same time, because the consumption of drinking water depends on the household size, which varied from four to 12. It was noted that the MGH filters reached their breakthrough points after the treatment of 400-450 liters of feed water, varying according to the As concentration as well as the composition of the tube well water (also see Chapter 6).

In the evaluation phase, five filters were in operation, while the other three were not functioning. The As concentrations of the treated water samples from the three filters (Id1, Id4 and Id8) were found to be below the 50 µgL^{-1}As, but the remaining two filters (Id2 and Id6) exceeded the limit. It is important to note that the users of these two filters did not change the filter bed material since its installation. This result confirms that after reaching the breakthrough point, the spent filter bed materials of the filter should be changed. Although a frequent regeneration of the spent materials was carried out by using the $Ca(OCL)_2$ solution, the As removal efficiency of the filter was found to be unacceptable, because it did not reduce contamination below 50µgL^{-1}.

In the trial phase, all feed water samples were bacteriologically contaminated (FC and TC). Contamination of the source waters might be due to damage or leakage of the tube well platforms. The concrete platforms surrounding the eight tube wells were found broken. Most of the tube wells in the study area were submerged during the flooding in 2007. The feed water could also have been contaminated during the transportation of water from the tube wells to the filters. Furthermore, the source water samples were found to have a high turbidity, which might be due to high levels of disease-causing micro-organisms such as viruses, parasites and bacteria. The household survey indicates that many persons in the study area suffer from diarrhea and dysentery. In the trial phase, most of the treated water samples were found to be bacteria-free, while in the evaluation phase, only six out of 20 treated water samples were found to be bacteria-free because the users were not careful with the operation and maintenance of the filters.

Regarding the quality of the filtered water, all users found the cold, tasty, transparent, and iron-free. Usually, the stored water becomes red a few hours after collection from the tube wells, but the filtered water remained free from red stains in the storage container for a long time. A significant reduction of the iron concentration in the feed water occurred when treated with the MGH filter (Chapter 6). In comparison, the performance of the MGH filter in removing As and bacterial contamination were found to be more efficient in the trial than in the evaluation phase. The main reason might be the close monitoring under controlled conditions during the trial phase. When the filters were evaluated three months after the trial, on the other hand, there had been no monitoring for three months.

7.8.2 Social aspects

The Arsenic contamination of the groundwater has added to the workload of the women in the study area, as they are the ones who have to cope with the problems caused by it. Therefore, the evaluation of the suitability and appropriateness of the MGH filter focused on the women in eight selected households. The evaluation was guided by the adjusted model of Spaargaren and Van Vliet (2000), using five criteria or slots.

Compatibility with the user household's lifestyle (slot S1): the systematic observations reveal that the filter's operational technology fitted easily within the lifestyle of the users and that neither their level of education nor religious rules (*purdah*) proved to be barriers in adopting the filter. According to the prevailing gender division of household tasks, women are responsible for fetching water. Only a few male household heads and sons were involved in fetching drinking water from the safe deep tube wells. In the survey, the majority of women mentioned the physical burden of fetching drinking water by *kolshi* (pitcher) and pointed to the problems this caused during raining and flooding, when the roads are inundated (Figure 7.15). More than two-thirds of the women mentioned the problem of religious restrictions on female mobility (*purdah*). Most deep tube wells are installed within the community, like in front of a mosque or a school, and close to roads. Women feel shy and inhibited to fetch water from these deep tube wells, and resort to taking water from their own contaminated shallow tube well. Not only is carrying a full pitcher (*kolshi)* of water for a long distance very troublesome and time-consuming, there is also always a big queue at the well during the morning peek hours. Sometimes, owners of private deep tube wells denied others access to keep their wells in good condition. The case studies of the eight women revealed the same pattern of problems with fetching water. Hence, the As removal filter was well accepted.

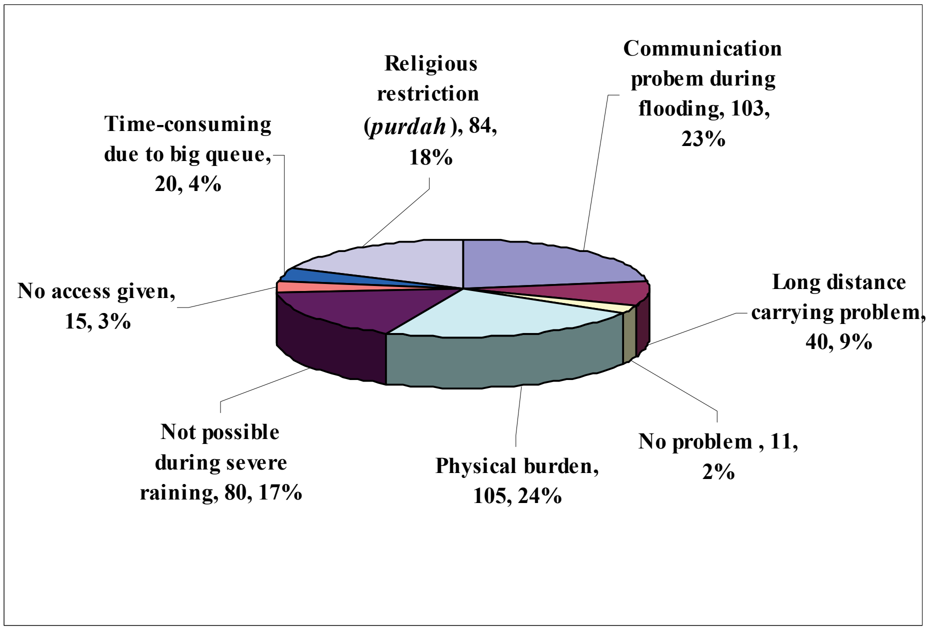


Figure 7.15 Problems the respondents faced with fetching drinking water.

Domestic household allocated time and space structure (slot S2): the operation of the filter was found to be minimally time-consuming compared to fetching As-free drinking water from the nearest DTW. The household survey showed that women are fetching water at the wells at a distance of between 3 to 1000 meters (Figure 9.16). The mean distance was 335.94 meters, median 300, standard deviation 201.95. In the case of 11 percent of the households, including the eight case households, the distance to the nearest DTW exceeded 500 meters.

According to the respondents, the time required for fetching drinking and cooking water was 5 to 60 minutes, while the most time was required for fetching drinking water (Figure 7.17). About half of the respondents said that to collect drinking water usually took them more than half an hour. The survey results reveal that most of the households are fetching water from the closest STW for cooking. Though almost all the respondents reported that they drink DTW water, some also said that they still drink water from the contaminated SWT, in spite of the risk, because they have a time constraint.

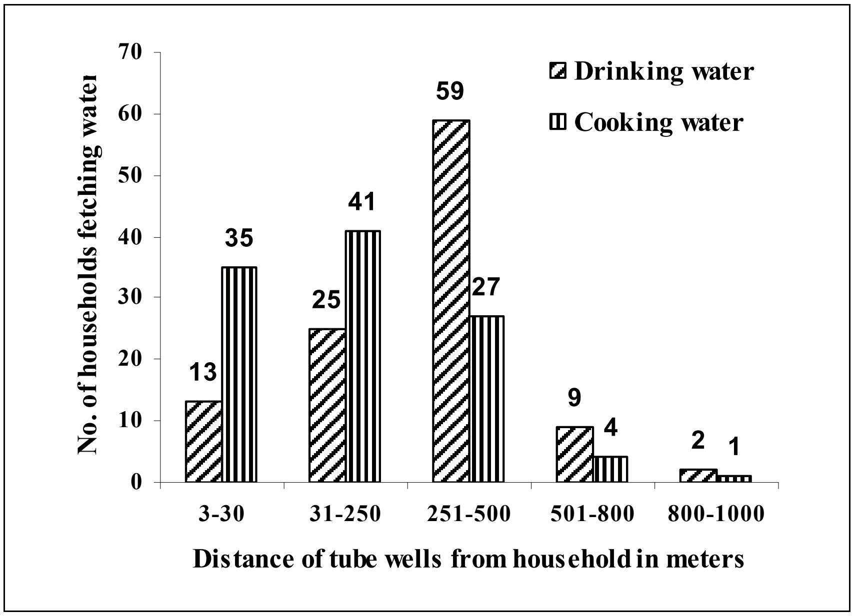


Figure 7.16 Distances to fetch drinking water from the DTWs.

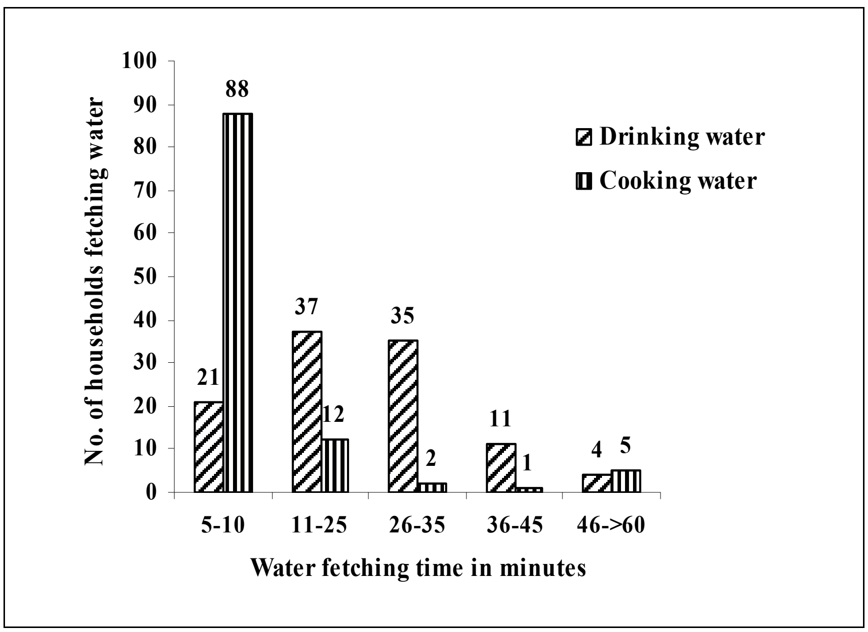


Figure 7.17 Time required for fetching drinking water from DTWs.

In the study area, the livelihood activities are still defined by gender. Although presently, women are increasingly involved in the production sphere, their economically productive role is not yet well-recognized (Ali, 2005). The household survey reveals that men are mostly responsible for farming, trading and marketing, and women for childcare and domestic work like water fetching, sweeping the house, poultry-rearing, and kitchen gardening. The safe water supply from the filter saved women the time they formerly spent on collecting water from the DTW, which left them more time for income-generating activities, and for caring for their children and the elderly (Burger and Esrey, 1995). The women invested their saved time in handicraft work, kitchen gardens, livestock-rearing and small trade. A daughter of one of the households started going to school again.

All the eight households have one room in their house. Since the appliance is small, seven households could easily place the filters in their house. One household (Id4) did not have enough space, so the filter was installed in the daughter's house. It can be concluded that the filter complies well with domestic time-space structures.

Affordability and resource allocation (slot S2b): this study found that households with low incomes and little access to productive natural assets face a higher exposure to the risk of drinking As-contaminated water. We found a significant correlation (p value 0.004, <0.01, Pearson chi-square value of 15.535) between the monthly household income and the installation of a tube well (Table 7.12). Most of the poor households do not possess one. Like in other parts of Bangladesh, in the study area, men are involved in productive work, marketing agricultural produce and purchasing food and other household necessities (cf. IFPRI, 2000). In addition, the male household heads control the household budget. Women only controlled income from livestock-rearing when they were directly involved in the activity.

The differences in the bargaining power of husband and wife affect the distribution of household consumption expenditures. The collective model of budgeting enhances the individual bargaining power of household members, but in all eight case households, the unitary model of budgeting prevailed and the husbands were the only decision makers (cf. Quisumbing and Brière, 2000). This made the women users of the filters totally dependent on their husband's willingness to purchase the filter materials. This is why, in the evaluation phase, three filters were no longer in operation. The main reasons were ignorance and unwillingness of the household head, rather than affordability. All women users said that if their husbands would buy the filter bed materials, they would re-install the filter again. Nobody mentioned a lack of money to buy the materials or a lack of interest to reinstall. All women preferred to use the filter rather than to fetch drinking water from far away, but they had no power and no voice in the decision making, which reflects the general situation in Bangladesh (IFPRI, 2000).

It is evident from the field observations that if users are interested in using the filter, they can do it, even if they are from poor households. The filter's operation is not expensive and was within the users' affordability. This filter is a low-cost technology and can be installed with cheap and locally available materials and chemicals, such as plastic buckets, still plate, sand, bricks and bleaching powder. Therefore, considering affordability (slot S2b), the eight households have the resources to use the filter, but the issue is women's access to these resources.

Comfort, cleanliness, convenience and safety (slot S3): the operation of the MGH filters was found to be comfortable and the appliance easy to clean and convenient for handling. Disposal of the As–rich spent materials posed some problems. The women users found it difficult to wash the filter bed materials (sand and chips) before re-installing the filter, for which they needed help from their husbands or other household members.

The handling of the As-rich spent filter bed materials is a grave concern. In the study, eight men and seven women were found to have symptoms of As poisoning (spotted skin on hands and feet), but because women are the main water users, they are more vulnerable to *arsenicosis* than men In rural areas in Bangladesh, *arsenicosis* is still believed to be contagious or seen as similar to leprosy, which creates serious social consequences for the affected persons. *Arsenicosis* is a disease of poverty and those affected get poorer, which has created a new poverty trap (Barkat, 2004). At present, *arsenicosis* manifests itself in skin lesions, but over the next decade, skin and internal cancers are likely to become a main human health concern arising from As contamination. Therefore, the handling and disposal of the As-rich spent materials is a significant issue for the filter-operating users as well as for the receiving environment. In the evaluation phase, the eight households had disposed of the spent materials in different ways, but none of them was fully safe. Improper and unsafe disposal of the As-rich spent filter materials can cause environmental pollution through arsenic getting back into the water and soil.

Operational modes and maintenance (slot S4): the filter's operation was found easy by the users. It was observed that after a one-day training on the re-installation of the filter, they were capable of reinstalling it. The women reported that they could easily treat about 10 liters of water per day. They found the two 10-liter buckets very useful for measuring the feed and treated water, to know the probable breakthrough point of the filter. The problem faced by the women was that they needed help with changing the filter bed materials after the filtration of 400-450 liters (the breakthrough point). During the evaluation phase, the operation instructions regarding the proper replacement of the filter bed materials, covering the buckets with lids and using clean cloth to cover the storage bucket, were not strictly followed by all users. It should be highlighted here that the As-removal efficiency did not appear to be adversely affected by these irregularities, as testing results showed. Some of the users ignored chlorinating the filter at 15-day intervals, because it was felt as too much work and they did not see the need for it. As a consequence, the treated water was found to be bacterially contaminated and the As-removal efficiency of the filter declined.

However, to the women users the operational mode of the MGH filter was simple and did not require an extensive follow-up or frequent training. Maintenance of the filter was easy, since filter bed materials are locally available at low cost.

7.9. Conclusion

The eight MGH filters used by the households in Kumarbhog village were found to be efficient in reducing the As concentrations of the contaminated water to below the allowable limit of 50 μgL^{-1} As. In the trial phase, the eight women operated the filters for one month. Six treated water samples among the eight filters were observed to be below the limiting value 50 μgL^{-1}, while two filters reached the breakthrough point after four weeks. Because the drinking water consumption by the eight households was not the same, the breakthrough points of the filters after treatment of 400-450 liters of contaminated water were reached at different times. In the evaluation phase, five filters were still in use and the As concentrations of three of them were found to be below the 50 μgL^{-1} As. The remaining two filters had exceeded the limiting value due to a continued filtration without a change of the filter bed materials. In the trial phase, all feed water samples were found to be bacteriologically contaminated (FC and TC), but the treated water samples were found to be bacterial-free after treatment with the MGH filter. During the evaluation phase, on the other hand, only six out of 20 treated water samples of the five filters were found to be free of bacteria, since the users were not chlorinating the filters as instructed.

The suitability and appropriateness of the MGH filter during field use was satisfactory in relation to the social and domestic context. The filters' operation was found to be compatible with the users' lifestyle, level of education, and social and religious norms.

Compatibility was also viewed from a gender perspective, since access to safe water is an important practical gender need of women, directly relating to their domestic or reproductive role. Because of their responsibility for the household's water provision, to get safe water, women had to fetch it from the distant, As-safe deep tube wells. Under these circumstances, the MGH filters were eagerly accepted by the eight women of the case households. The operation of the filters was proven to require a minimal time investment. Although most of the households had one-room houses, they could easily accommodate the appliance because it is small. The users were happy to use the filter instead of having to collect water from the distant deep tube well. It relieved them from a physical burden, while the time saved could be used for leisure and income-generating activities, such as stitching and the embroidery of garments.

The installation of the filters was inexpensive because cheap and locally available materials and chemicals were used. The operation and maintenance costs are also minimal. However, in the evaluation phase, three filters were no longer in operation, because the male household heads were unwilling to buy brick chips and sand. The MGH filters were found easy and convenient to handle by the users. The major advantage of this unit is that it does not require a daily addition of chemicals, only a periodic bleaching treatment. The households disposed of the spent filter materials in different ways, though not all proper and environmentally sound. The operation and maintenance of the MGH filters did not need extensive introduction and prolonged training. According to the users, this filter is a simple, chemical-free and low-cost technology to produce As-free, safe drinking water. Therefore, this study concludes that the use of the MGH filters by rural households provides a suitable short-term solution to the problem of the As contamination of source water.

8

Discussion and Conclusions

8.1 Introduction

This thesis reports the outcome of my research on the development and field trial of an innovative, simple and low-cost arsenic removal technology for household use in rural Bangladesh. The research is based on literature research, laboratory experiments in the Netherlands and Bangladesh, and field work, including a field trial in an arsenic-affected area in Bangladesh. The overall objective of this research was "*to contribute to finding feasible, socially appropriate and gender-sensitive household-level technological solutions to the problem of groundwater Arsenic contamination in rural Bangladesh*". The specific objectives were:

1. Providing the evidence to date of the option of community-level, arsenic-free extracted groundwater from deep aquifers.
2. Providing an overview of the practically available options for household-level technologies aimed at the removal of arsenic, and describing and evaluating these options from a technical, social, economic, gender, and environmental point of view.
3. Providing an overview of currently implemented household-level technologies for the removal of arsenic, and describing and evaluating their strengths and weaknesses from a practical, technical, social, economic, gender, and environmental point of view.
4. Selecting on the basis of (2) and (3), and by means of a multi-criteria analysis, the most promising options for treatment technologies at the household level.
5. Further development of the most promising treatment methods for practical and gender-sensitive applications at the household level.

This chapter provides an overall synthesis of the work done, and indications on how the research findings have contributed to a better technological and gender-sensitive, socially acceptable solution to confront the As problem for drinking water in rural Bangladesh. The summary, based on the main findings and general discussions of the research, is presented in the ensuing sections. The conclusions, policy implication and recommendations for further research are given as well.

8.2 The main research findings

The key findings are summarized in line with the research questions and objectives.

8.2.1 Community–based piped water supply in Bangladesh

The first research question addresses the technological sustainability and the economical and social appropriateness from a gender perspective of the community-based piped water extraction from the As-free deep aquifers.

> ***Research question 1: What is the performance of community-based pipeline water supply systems using deep aquifers in terms of their technological and economical sustainability as well as their social and gender appropriateness****?*

The government of Bangladesh has been constructing the community-based piped water supply systems as an alternative source of As-free, safe drinking in the severely As-affected rural areas. To answer the research question, three community-based pipeline water supply systems were compared and evaluated (see Chapter 4). These systems were installed in different geological areas in Bangladesh, by different organizations: a governmental organization, the Department of Public Health Engineering (DPHE) in Khasial village, falling under Munshiganj, and two non-governmental organizations, Environment and Population Research Centre (EPRC) in Baka village in the Narail district, and Brac in Pakundia village in the district of Narayanganj.

The three systems are working well and were found to be technically sound for the production of safe water. The users are satisfied with the water quality and adequacy of the water supply and these systems are easy to operate and maintain. The community-based water supply systems include extraction of the groundwater from a depth of 150 meters or more in the Pleistocene deposit of the Delta basin. The Pleistocene deep aquifers contain arsenic-free, safe water in many parts of the As-affected areas in Bangladesh, but it may be site-specific. The technical sustainability of the systems in terms of a prolonged use of the deep aquifers depends on many hydro-geological factors and on the groundwater's chemistry. Overextraction of the groundwater from a deep aquifer might cause air or water with dissolved oxygen to penetrate into the deep aquifer, leading to more dissolved As in the groundwater, or inducing a downward migration of dissolved As from a shallow aquifer to the deep aquifer. Only the Baka system has a chlorination treatment facility for the overhead water tank, to prevent bacterial contamination of the supply water. Three systems were found to be environmentally friendly, since they do not produce As-contaminated sludge that has to be disposed of.

The social and gender appropriateness of the systems were found to be satisfactory in all respects, since their users perceived the systems as easy and convenient. Several focus group discussions (FGDs) and informal meetings were carried out with men and women – particularly those who were involved in fetching water from the pipeline water systems. Women are the water managers in the domestic domain as well as beyond. Hence, they are the major beneficiaries of water supply systems. Women users are impressed by the system's reliability and adequacy, as well as by the absence of salinity and iron in the water and its good taste. In addition, piped water is safe from external contamination and can be better subjected to quality control. Moreover, its use is convenient and comfortable because the water can be delivered at close proximity to the users, which saves collection time and effort.

There is no discrimination between rich and poor beneficiaries of the piped water systems; we found 'internal equity' in terms of access to water. Irrespective of the monthly contribution, all subscribers have equal rights of fetching water from the common water taps. However, the systems created 'external inequity' between connected and non-connected households, because the non-connected households do not have access to safe water. The FGDs revealed that some villagers were interested to be connected to the systems after observing its benefits. But they could not be included in the system, as it would require an extension of the network beyond the capacity of the system. At the time, the non-connected households could not contribute to the installation costs due to their poor economic condition, but sometimes poor households are allowed to use the water taps of connected households.

The economic sustainability of the three systems seems satisfactory, although the initial installation costs were endured because of external financial assistance. The level of contribution of the village communities to the total installation cost as well as to the operation and maintenance (O&M) cost is set by the community and the NGO, based on the users' household affordability. At present, the caretakers are not happy with their salary, which comes from leftover money after payment of the system's electricity bill.

So far, the three systems are running well, with only minor disturbances, and the communities are satisfied with their domestic water supply. However, a long-term sustain-ability and sufficient safe water supply require a properly trained management group, including a trained operator (caretaker) and actively participating users, which were found lacking in these three systems. Other factors that need to be addressed include the availability of a community fund and regular meetings of the user community and the management committee on the operation and maintenance (O&M) of the system. Another shortcoming is that no female members are included in the village committees. Gender inequity was also found in the employment of the caretakers of the systems, who are all male. Female participation in the local communities is necessary for a sustainable management of the program, since the management of community water resources will not be achieved without the conscientious participation of local communities, in which the water is managed by women.

8.2.2 Arsenic removal technologies at household use level

Research question 2 addresses the issue of practically available and currently implemented As removal technologies that have been promoted at the rural household level in Bangladesh, as well as research objectives 2 and 3.

> ***Research question 2: What are the available, household-level arsenic removal technologies for drinking water, and which of these have currently been implemented in rural households in Bangladesh?***

Many breakthrough technologies have been developed in Bangladesh to remove As from drinking water. A wide range of conventional and advanced techniques has been developed and applied, based on physico-chemical processes, whereas the biological techniques so far are applicated only a little. The most common technologies utilized in the physico-chemical processes are oxidation, precipitation/coprecipitation, adsorption onto coagulation flocs, ion exchange and membrane filtration. The familiar household As removal filters have been developed based on the technologies of the oxidation and coprecipitation processes, such as the Two-Bucket treatment unit, the DPHE-Danida BTU, coprecipitation with naturally occurring iron, the Stevens Institute Technology system, et cetera. Many As removal technologies have been developed based on the adsorption process, such as Activated Alumina, Fixed bed Granular Ferric Hydroxide, Iron oxide-coated sand, BUET Activated Alumina, Iron filings, the gravel bed containing iron sludge, the Nelima filter, the Sono filter (zero-valent iron), the Alcan filter, the SOES household filter, the BCSIR unit, the Safi Filter, et cetera. The Read-F and Tetrahedron membrane filters include ion exchange resin and membrane techniques. In this study, an inventory of the available 40 As removal technologies was carried out. These have been developed in the laboratory, while some have been tested at field level on a promotional basis. An overview on the available As removal technologies at the household level was carried out in terms of their removal efficacy, strengths and weaknesses of the technical process, costs, and users' acceptability during the field level application of the filters (see Chapter 5). Most of these techniques are not successful, either in terms of their technology or in terms of their social acceptability. Therefore, there is scope for the further optimization, development or modification of these technologies.

8.2.3 As removal technologies currently implemented in Bangladesh

In 2003, the government of Bangladesh approved to promote three As removal filters for household use: the Sono, Alcan and Read-F. The operational performance of these filters was assessed by interviewing users and providers. The non-governmental organization DART implemented these filters in a few villages in the sub-district of Homna (Comilla district). Field observation revealed that the filter units have comparable and sufficient As removal capabilities ($\geq$ 95% As removal). The capital costs of the three filters differ, namely Tk. 270, 2700 and 570 for the Sono, Alcan and Read-F filters, respectively. The prices are subsidized by the government. It set two levels for the contribution of the villagers, according to their socio-economic condition: 10 percent of the price for the very poor and 20 percent for the other villagers. The life span of the filters is three to five years. About 327 households are using Sono filters and some technical problems of the filters could be noted. Users complained that, after a couple of months of operation, the filters flow slower. The appliance and sands need frequent washing to prevent clogging and slowing down of the filter's flow. This caused confusion among the users about the filter's effectiveness and claimed life span. DART had not done any bacteriological testing of the treated water samples of the three different filters since their installation. They had suggested to the users to pour hot water into the filter to kill bacteria every 15 days, but only a few users did so. Only 11 Alcan filters were in operation in the visited village. The filter device is relatively small, resulting in a faster flow rate, and it needs chemical treatment of the raw water. As with the Sono filter, flushing with hot water is required every 15 days to prevent bacterial contamination. Some well-off villagers were interested to buy this filter because of its high flow rate, though the treatment of contaminated water takes more time. Only one Read-F filter was operating in the visited village. This filter is very costly. Some villagers favour the Sono over other filters, because the two buckets of the filter have some resale value. The users were satisfied with the Read-F filter because of its high flow rate and zero risk of bacterial contamination. It is easy to operate and maintain, though treated water is somewhat smelly at the start. The filter users are yet to dispose of the spent filter materials, but they had no idea about how to do this safely, neither did they know about the filter's life span and long-term removal efficiency. There is inequity in access to good and well-performing filters like the Alcan and Read-F, because poor villagers cannot afford them.

8.2.4 Optimization of arsenic removal technologies

Research question 3 addresses the weaknesses, limitations and strengths of the selected arsenic removal technologies in terms of the societal context of rural Bangladesh.

> ***Research question 3: What are the weaknesses, limitations, strengths and advantages of the selected technologies in terms of:***
>
> 1. ***the socio-economic class and lifestyle of the household, particularly with regards to gender roles;***
> 2. ***the household time allocation patterns, availability of space, and capability in view of the characteristics of domestic production and women's practical gender needs;***
> 3. ***the socially accepted standards of convenience, comfort, cleanliness, hygiene and safety;***
> 4. ***the mode of provision, accessibility of the provider, training requirements, and availability of parts of the device;***
> 5. ***the cost-effectiveness of their installation, operation and maintenance.***

The women of Bangladesh are the water collectors, like in other countries in the world. The development of societal and gender-focused technologies for an arsenic removal filter is important. Therefore, to answer research question 3 and its sub-questions, five evaluation criteria (slots) were used to screen the identified 40 listed technologies, based on the adjusted model of Spaargaren and Van Vliet (2000). These were: compatibility with the user household's lifestyle (slot S1); the domestic time-space structures (slot S2a); affordability and resource allocation (slot S2b**);** comfort, ease of cleaning, and convenience and hygiene (slot S3); and modes of provision – the operation and training by providers (slot S4).

To answer research objective 4, a multiple-criteria analysis (MCA) approach was applied, to select the potential technologies for optimization (discussed in Chapter 5). The MCA comprised interdisciplinary criteria regarding technical as well as social aspects to address the efficacy and complexity of a technology, and its social acceptability. The technical, social and economic potential of the technologies was evaluated. In the MCA analysis, the potentiality index (PI) of the arsenic removal technologies is based on technical performance as well as household compatibility in terms of lifestyle, household time allocation, size of the appliance, affordability, convenience and comfort in its operation and maintenance as seen from a gender perspective, and procedures for a safe disposal of filter waste. Technological aspects included As removal efficiency, chemical use, water chemistry and local geological applicability, bacteriological problems, reliability and manageability of the system, the local availability of the materials and chemicals, costs, and safe disposal of the As-rich spent materials. The screening was carried out in two steps. First, all technologies, except three field-implemented ones, were screened and given a relative weight of importance. This was followed by the analysis of the potentiality matrix (PI) of 14 out of 37 technologies (see Chapter 5) for optimization. The analysis shows that the highest PI score was made by the GARNET filter, followed by the SORAS filter.

8.2.5 The development of arsenic removal technology at household level

Research question 4 and research objective 5 address the development of an As removal technology for household use, called the MGH filter. The experimental research for the development of this filter was carried out in laboratories in the Netherlands and in Bangladesh, as well as in the field laboratories in the villages of Kalia and Kumarbhog.

> ***Research question 4: What is the most promising arsenic removal option for rural households in terms of its technological performance, social acceptability and suitability from a gender perspective?***

In this research project, the main focus was the development of a low-cost, simple and chemical-free filter for household use. Few technologies were observed to have sufficient optimization potential for As removal. The GARNET technology was found to be a feasible technology for optimization (see the MCA analysis in Chapter 5). Based on the adapted GARNET technology, the MGH filter was developed in this research (Chapter 6). The design of the MGH filter comprises two buckets with a filter bed in each bucket, the filtration unit consisting of three equally thick layers of sand, brick chips and sand. The filter bed materials are kept inside polyester cloth pillows. The As removal efficiency of the filter was studied under conditions of different filter bed thicknesses, and different types and sizes of the filter media, the flow rate, and the breakthrough point of the filter. The arsenic concentrations of tube well water (feed water) and filtered (treated) water samples were analyzed in the field, using field testing kits and by the Atomic Adsorption Spectrophotometer (AAS) in the laboratory at Dhaka. Non-arsenic water quality parameters such as pH, Fe, Mn, the turbidity of the source water and the bacteriological quality (total coliform (TC) and fecal coliform (FC)) of the feed water and treated water samples were analyzed in the laboratory. To kill pathogenic bacteria, chlorination was applied during the filtration process, using bleaching powder ($Ca(ClO)_2$, BP) solutions. The findings indicate that the MGH filter removes As from the feed water samples containing As concentrations ranging from 156 μgL^{-1} to 959 μgL^{-1} As, to under the detection limit of 50 μgL^{-1} at both study sites (Kalia and Kumarbhog). It also effectively disinfects the treated water (no bacteriological contamination).

The MGH filter technology does not require any chemicals for the As removal, only treatment with a BP solution. The solution was added to the filtration process to disinfect the treated water and enhance the oxidation of naturally occurring Fe(II) and As(III) in the groundwater. After chlorination (one spoonful of BP in 10 liters of water), the treated water was found to be uncontaminated by FC and TC bacteria. The chlorinated water was kept one night in the filter. The following morning, before using the treated water, the filtrate water was decanted until the residual chlorine (RCL) values became < 0.2 mgL^{-1}. The TCLP test of the spent materials (sand) of the filter showed 0.4 mg/kg As in the sludge sample, so, according to the EPA regulations on ‘hazardous waste’, it can be regarded as non-toxic and safe for disposal in the receiving environment, without As leaching into soil and water.

8.2.6 Performances of the MGH filter in the trial and evaluation phase

The performance of the MGH filter during household use was evaluated in two phases after the development and standardization of the filter in the laboratory. Filters were distributed to eight households out of the 108 surveyed households in Kumarbhog village, based on their socio-economic characteristics and willingness to use the filters. In the trial phase, during March 2008, women of eight households operated the filters after getting training on the operation and maintenance of the filters. In July 2008, after three months of the trial, the performance of the filters was evaluated based on the technical validation, and their suitability and acceptability according to the users.

Technologically, the MGH filters were validated and found effective to remove As and bacterial contamination from the feed water in the trial phase. The concentrations of the treated water samples of the eight filters were tested by the field kit on a daily basis and by the ASS once a week. The As concentrations of the treated water samples of the eight filters were below the detection limit after the first week and gradually increased to 50 μgL^{-1}As after one month. Results show that the concentrations of As of six treated samples were below the limiting value of 50 μgL^{-1}As, as set by the Bangladesh authorities. The remaining two filters reached the breakthrough point after one month. Since the consumption of drinking water by the eight households differed, the eight filters reached the breakthrough point at different times (see Chapter 6). During the evaluation phase, five out of eight filters were still operated by the users. Chlorination was done during the filtration process. The concentrations of As of three filters were below 50 μgL^{-1}As, while two filters had exceeded the limiting value because the user households had not changed the spent filter materials according to the operation and maintenance instruction. It is evident that after reaching the breakthrough point of a filter, the BP solution can enhance the removal efficiency to a certain extent. In the trial phase, all feed water samples were contaminated with FC and TC, but most of the treated water samples were found to be bacteria-free after treating the filter with bleaching powder. During the evaluation phase, only six out of 20 treated water samples of the five filters were bacteria-free, since the users were not careful with the chlorination of the filters.

The social acceptability, appropriateness and suitability of the filters for household level use were assessed both in the trial and evaluation phase, by using as follows five evaluation criteria (slots) based on the adjusted model of Spaargaren and Van Vliet (2000):

Compatibility to user household's lifestyle (slot S1)**:** the operation of the MGH filters was found to be compatible with the lifestyle of the eight user households. The users could operate the filter easily, given their level of education, daily life routine, and cultural, social and religious (*purdah*) norms. With regard to the last aspect, it could be noted that the women from the user households face problems when they have to fetch water from the deep tube wells located far away. Hence, the As removal filter fitted well within the gender division of labour in the household and the religious restrictions on women's mobility.

Domestic time or household allocation time and space structure (slot S2a**)**: the case studies and systematic observations revealed that the women users could perform the operation of the filter within their domestic time frame. Moreover, using the filter is less time-consuming than fetching water from the far-away deep tube wells. The women indicated that they now could use the time saved to take up income-generating activities such as stitching, embroidery and other handicrafts. All user households have a one-room house, but the MGH filter is small and could be placed inside.

Affordability and resource allocation (slot S2b**)*****:*** the installation costs of the filter are low, because it is made from cheap local materials and chemicals that are available in local markets. Operation and maintenance costs are low. In the evaluation phase, five out of eight filters were in operation. Some women could not change the filter bed materials due to their husband's unwillingness to buy the materials (sand and brick chips). It was reported that other male household members were not interested to help re-installing the filter either. The severe raining and flooding in the study area was a concern as well. The users also said that they waited to re-install their filter after the rains. It is evident from the household survey that the male household heads control the household budget and expenditures and that they are the decision makers (see Chapter 7). Therefore, non-use of the three filters in the evaluation phase was not due to a lack of means. One household exchanged the spent material (sand and bricks) from the shop with new filter bed materials free of cost. The women planned to re-install their filter after the rains, if their husbands would agree to allocate the money for it.

Comfort, ease of cleaning, convenience and hygiene (slot S3): the eight women did not complain about the operation and maintenance of the filter and could easily clean the appliance. Only one woman claimed to experience difficulties with washing the filter media (sand and chips) and re-installing the filter. For this task, women preferred to get help from other members of the household, especially the men. In the evaluation phase, the filters were found to be less clean due to their unhygienic handling by the users. The users could conveniently handle and dispose of the As-contaminated sand and brick chips produced by the appliance, though not in a fully environmentally safe way. Two women spread the spent material on the cow dung stockpile (recommended by the government), one exchanged the spent material with new bricks and sand from the shop, one reused it in their construction work, and two women threw it away unsafely behind the house.

Modes of provision; operation and training (slot S4): users perceived the operation and maintenance of the filter as easy and not requiring extensive training or a follow-up for a long period. With one day of training on the installation of the filter, they performed well in operating and reinstalling it. Some women said that changing the filter materials is difficult to some extent for single women, but that it does not require any further training.

8.3 General discussion

8.3.1 The arsenic problem in Bangladesh and its solutions

Arsenic in natural waters is a world-wide problem, especially in Bangladesh, which has the largest population at risk among the 21 afflicted countries, followed by India - particularly West Bengal. “The global response to the arsenic crisis in the Bengal Delta has been marked by staggering inertia” (Meharg, 2004: 19; Atkins et al., 2007). Since 1971, polluted surface water in Bangladesh has led to the construction of thousands of tube wells in Bangladesh, to provide safe water and reduce the morbidity and mortality from diarrhea and cholera, but this led to striking water layers (shallow aquifers) replete with severe As poisoning. There are two controversial hypotheses on the release mechanism of As in groundwater: *oxy-hydroxide reduction* and *pyrite oxidation*. Because of the pervasive geological differentiation in Bangladesh, the distribution of As in Bangladesh groundwater has distinct regional patterns and depth trends.

In Bangladesh, water from shallow tube wells, drawn from alluvial aquifers underlying the Ganges and Brahmaputra delta, is consumed by more than 95 percent of the people. In rural areas, almost all people are exposed to naturally occurring arsenic in drinking water extracted from these aquifers. Arsenic is not only toxic to human health; it also causes negative social impacts. Persons suffering from *arsenicosis* have many social problems. They may be stigmatized and marginalized because many people believe that arsenic poisoning is contagious or a curse. Women are especially vulnerable to As-related health risks and its social consequences.

In Bangladesh, large numbers of governmental, non-governmental and private organizations, the UN and donor agencies are involved in As mitigation. To combat the arsenic problem, there are several alternative sources to provide safe drinking water to arsenic-affected people, such as extraction from As-free deep aquifers (by a deep tube well and a community-based pipeline water supply), the use of surface water (from a dug well, a pond or river, which are severely polluted), and As removal technologies at community and household level. The extraction of water from the deeper aquifers is very costly and requires a sustainable infrastructure. The community-based water supply using a deep aquifer is a long-term solution, because it takes time to install infrastructures and achieve community participation and proper administrative and monetary management. To meet the immediate demand for safe water of As-affected rural areas, low-cost, appropriate As removal technologies can be considered a short-term solution.

In this research, the main emphasis was on developing a technically appropriate, simple, low-cost, socially acceptable and gender-sensitive As removal filter for household use in rural areas. The aim was to identify the bottlenecks and prioritize ways for the application of treatment technologies at household level and in a community-based system. The feasibility and efficacy of the available technological solutions were explored, using the same framework for the long- and the short-term options. The framework combined technological, sociological and gender approaches, making it a gendered socio-technological framework, which is – by definition – a multidisciplinary framework. An interdisciplinary approach was applied to evaluate the performance of the three community-based pipeline water supply systems, and to develop and evaluate the household level As removal technology.

Technical, socio-economic and cultural aspects were incorporated in this research to assess the development of a sustainable innovation through multi- and interdisciplinary approaches. The multidisciplinary approach implies collaboration between different disciplines. Interdisciplinarity was achieved by working on the same topic and developing the objectives and research questions together from the start. A drawback of inter-disciplinary and multidisciplinary approaches is that 'end users' are not necessarily and systematically included in the process, which could lead to inappropriate innovations. Therefore, the transdisciplinary approach was also considered in this research. Transdisciplinarity is a recent trend in interdisciplinary academic research, in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from different non-academic sources are incorporated (Swaans, 2008). In this research, social and gender perspectives are included in the process of the development of an innovative As removal filter through the active participation of potential end users and other stakeholders. Thereby a synthesis is achieved of knowledge resulting from disciplinary, open-ended collaboration and local perspectives. Transdisciplinary research ensures an integration of knowledge through the participation of a variety of stakeholders, including end users, and mutual learning between the different stakeholders, such as caretakers, village committees, implementing organizations and donors, users of water, households, and women.

8.3.2 A long-term solution to address the As problem in drinking water

Water extracted from a deep aquifer is free from As and pathogens, but installation of this system is expensive. While initially, communities preferred individual deep tube wells, this study shows rural people's preference for a community-based system. Large-scale contamination, risk awareness, and economic limitations have eventually driven rural people to shift from individual to community-based systems for getting access to safe drinking water. The evaluation of the performance of the three community-based water supply systems reveals them to be ecologically sustainable; the supply water is clean and free from arsenic and there is no problem of disposal of As sludge. The systems are reliable and dependable in their delivery of adequate water supplies, in a way that is convenient and not burdensome for the women users. In only one system chlorination is conducted to prevent bacteriological contamination of the water. This should be done in all community-based pipeline water supply systems, even though the source water comes from deep aquifers that are free from pathogenic bacteria. This is because there are many possibilities for bacterial contamination of the water distribution from the water pump to the end users' water taps, like leakage of the pipes during raining and flooding, while bacterial contamination can occur in the overhead tank as well.

As in the study of Van Wijk Sijbesma (2001), this study also found a low degree of community influence and involvement at the start of the projects. The people were only asked for their contribution and land or locally available material. The implementing organizations (EPRC, DPHE, Brac) took all responsibility for management, operation and maintenance, and then trained the community members and the caretakers to assume these tasks. The communities were involved in discussing the various options during the planning phase of the project, but the final decision-making power remained with the implementing organizations. After implementation, the community had to assume control of the system and become the final decision makers and authority on the projects. Technical support and advice are provided by the implementing organizations at the request of the community. Inevitably, the success of rural community-based water supply systems depends on the capacity of the local governmental institutions and the involvement of skilled and enthusiastic villagers. Installation of community-based piped water systems is most feasible economically in clustered rural settlements. It requires a properly trained management group and actively participating users.

A drawback of the community-based piped water system is its sensitivity to power failure, which is a big problem and the main cause of the disruption of the system. Other shortcomings are the limitations to extending the system to meet the increasing demand. The monetary and administrative management has to be adapted to accommodate the new connections and these new connections may exceed the technical capacity of the water pump and the system. In 1994, the government and donors started installing community-based water supply systems. These were financed by subsidies and through the formation of village groups or community-based organizations, assisted by NGOs, requiring a contribution of 20 percent of the costs from the users. Until now, the government subsidy is only granted when the people provide proof of their share in the installation costs, in cash or in labour. This entails a lot of time-consuming bureaucracy. Although at first glance, it seems a positive shift towards strengthening local involvement, there still is a lack of vision on the consequences of introducing new forms of cooperation and organization between villagers in the systems' monitoring, operating and maintenance. Once a system is implemented, it is technically and administratively difficult to extend coverage to new households. This causes a lack of external equity in access to the safe water facilities. It has to be noted that equal access and external equity can be realized only where there is community participation in terms of sharing cost and labour (BRAC, 2005). To realize the sustainable use of the deep aquifers for the extraction of water in the long term, it is mandatory to check a number of hydro-geological factors. Overextraction of groundwater by community–based water supply systems could cause another disaster by the prolonged use of deep aquifers. More research is needed on the hydro-geological features of the different parts of the country and the conditions of the aquifers need to be mapped as well.

8.3.3 A short-term solution of the arsenic crisis

The short term As removal solutions are technologies that treat As-contaminated water. They are appealing to the rural people because they can be installed within a short period as well as at low cost. Since 1998, the government of Bangladesh is supporting research on As removal technologies. Unfortunately, most of them do not perform well technically under the typical geo-chemical conditions in Bangladesh and are socially not very acceptable. So far, the government of Bangladesh has approved the promotion of three filters: the Sono, Alcan and Read-F. This research concludes that the government's investments in an improved water supply so far have failed to meet the needs of poor villagers, because they are not able to buy the costly Alcan and Read-F filters. Even the relatively cheap Sono filter proved unaffordable for some. Furthermore, assessing the efficiency of As removal and the life span of these filters is difficult at this preliminary stage, as well as predicting how the disposal of the spent filters materials will be carried out by the users. The amount of arsenic leaching from the sludge generated by the treatment processes will depend on the type of removal mechanism and the ultimate sludge disposal process, which is a grave ecological concern.

Most conventional and preferred As removal technologies include the oxidation of As(III) to As(V), which can be separated from the water much more efficiently. Some technologies use a pretreatment and a separation step such as ion exchange to remove the As(V). Most available technologies are not affordable for poor households and lack a gender perspective. But all technologies that aim at providing a safe water supply face these challenges. The lack of users' participation in, and influence on the design choice, costs, maintenance, and management of the systems are major issues. Therefore, the available 40 technologies were assessed for their technologically weak and strong points as well as their acceptability according to their users. Though not all relevant information of all technologies was available, findings from this assessment are potentially useful for researchers in setting priorities for the further development and optimization of As removal technologies. To achieve the final goal of this research project, a specific filter was selected for further development and a household-level trial. The trial and evaluation were carried out using an interdisciplinary and transdisciplinary approach, taking the local circumstances and the perspectives of the (women) users into account.

8.3.4 The development of a simple, low-cost, chemical-free As removal technology

To meet the main research objective, first the development of the As removal household-level technology was carried out in the laboratories, using synthetic and real As-contaminated water. The development was continued in the two villages. The groundwater qualities in the two field sites proved to be different, due to natural processes of sedimentation and the fact that sediment transport creates local variability in As concentration. The mechanism to remove As by the MGH filter can be explained easily. The distribution of the As species As(III) and As(V)) in natural water is mainly dependent on redox potential and pH conditions. Under oxidizing conditions, the predominant species is penta-valent arsenic, which is mainly present with the oxyanionic forms ($H_2AsO_4^-$, $HAsO_4^{2-}$). Naturally present, dissolved Fe(II) precipitates as hydrous ferric oxides (HFO) in the presence of oxygen. In the MGH filtration process, the removal of As may be attributed to the adsorption of oxidized As to HFO, due to the presence of O_2 in the feed water. Aeration occurs during the pouring of the feed water from a distance onto the porous lid of the top bucket, as well as from the top bucket to the porous lid of the bottom bucket. The HFO is removed by the sand filter.

The original GARNET filter proved to perform poorly in the field. Eight percent of the tested samples were found below the drinking water limit of 50 μgL^{-1} As in Hajiganj. In the southeastern part of Bangladesh and in other places in Kalaroa in the southwest and Iswardi in the northwestern part of Bangladesh, the percentages of the As removal were 54 and 66 percent, respectively. The MGH filter was found to remove 95 to 97 percent As from the contaminated water samples in the field sites. The MGH filter has a high removal efficiency of iron and turbidity, hence is not requiring any regular washing of the filter bed materials to prevent clogging, as is the case of the Sono filter and similar ones. Furthermore, the filter has a high flow rate of about 16-18 liters of water per hour. It is simple and does not require any chemical pre-treatment, complex operation and maintenance procedures. Disposal of the filter-spent material does not raise problems like with As removal technologies based on the sand filters. The filter is economically cost–effective and viable, investments cost are about Euro 10.8-13.4[7], depending on the quality of the filter unit materials. The operational cost is Euro 0.11-0.14[8] per 100 liters of treated water.

In this research, the As removal performance of the MGH filter was found satisfactory and appropriate for household use during one month in the trial phase, under controlled conditions, and at the evaluation after three months. However, it is necessary to validate the filter technically for seasonal variation; it needs to be operated by households and evaluated in all seasons in a year.

8.3.5 Social acceptability of the technology

The theoretical objective of the study was to contribute to the interdisciplinary field of the development of socially appropriate and gender-sensitive household-level technologies by identifying the crucial linkages between technological and sociological frameworks. To this end, both quantitative and qualitative methods of data collection and analysis were used in the research. The multi-perspective assessment comprised interdisciplinary and transdisciplinary approaches to evaluate the performance of the filters for household use.

It can be noted that women of eight rural households adopted the technology and ran the filters successfully during the trial phase. In Bangladesh, as elsewhere, rural women are the managers of water for household use. Rural women's role in society is mostly domestic and participation in the production sphere is negligible. Men and women have different patterns of daily time allocation. Women spend time on household work from early morning to noon, having leisure time after lunch. Men work from morning to afternoon and take leisure during the late afternoon or evening. The household survey revealed that sometimes women cannot be bothered to fetch safe water from far away and, instead, drink the contaminated water from their own shallow tube wells. Even drinking safe water from a

[7] At the time of this study, Euro 1 was Tk 93.

deep tube well does not fully protect people in arsenic-affected areas, as they do take in arsenic water when they use it for cooking and when they use edible herbs grown in contaminated water (Mandal et al., 1998). Having the appliance inside the house complied well with the social norms and religious restrictions (*purdah*) that women have to abide by. In these circumstances, the MGH filter was eagerly accepted by the eight households. It relieves women of the social and physical burden to fetch As-free, safe water far from their home. The fact that the male household head controls the allocation of household income and expenditures caused problems when women wanted to re-install their filter. It appeared that some filters were unused because the women could not persuade their husbands to purchase the necessary filter bed materials.

Operation and maintenance of the filter were found to be easy and convenient by the user households. Most of the women users reported that they treated 10 liters of contaminated drinking water a day. Using small buckets made it easy to measure the quantity of treated water. During the evaluation phase, the performance of the filters declined because not all users followed the instructions on their operation and maintenance. Some ignored chlorination, because it was felt as too much work or they did not see the need for it. Cleanliness of the appliance differed, depending on the user. In this research, the filter was field-tested under controlled conditions for a month and evaluated after three months. There was no scope for a longer investigation. Considering the need for arsenic treatment options in Bangladesh and other developing countries, further research on the performance of the MGH technology may have important positive implications for a safe water supply.

8.3.6 Handling and disposal of the spent filter materials

The disposal of the filter-spent material is a significant issue. The eight household users of the MGH filter disposed of their filter's spoil in different ways, not necessarily all technically acceptable and environmentally friendly. Although some studies (Islam et al., 2003; Rouf and Hossain, 2001) report that no or negligible leaching of As occurs from the disposal of As–rich iron oxide-impregnated brick sands of the filter into the groundwater and surface water, and these findings have been confirmed by our TCLP test, there is no guarantee for the non-contamination of groundwater and the aquatic environment in the future. In addition, the reuse of the spent sand and bricks as construction material could represent an environmental hazard due to weathering after long-term exposure. Although the recommended options for the disposal of As spoil are to dispose it into the sealed septic tank of the toilet, or on the cow dung stockpile with cover, there is still the probability of groundwater contamination through leaching from the As sludge, or terrestrial environmental pollution from the exposure of As-containing cow dung (BAMWSP/DFID, 2001b). In rural Bangladesh, most of the toilets, tube wells and cow dung stockpiles are close to the house. In addition, almost all households have a kitchen garden, which is a significant opportunity for As to enter into the food chain. Therefore, it is essential to carry out comprehensive research on the safe disposal of the As-rich waste of the filter and disseminate information to all users in villages where As removal filters are promoted.

8.4 Conclusions, policy implications, and recommendations

8.4.1 Main conclusions

The new MGH filter was developed based on the passive oxidation and adsorption process. The filter is a promising, simple and low-cost As removal filter for rural household use that meets the Bangladesh drinking water standard (50µmL^{-1}As). Its technological performance is better than that of other filters. Major advantages of the technology are that: i) it can be installed and maintained with local materials at low costs; ii) it does not require the addition of any chemicals except an occasional chlorination for disinfection; iii) the flow rate is sufficient without clogging; iv) it does not need daily maintenance through washing the filter units and filter bed materials; and v) spent materials can be properly handled. Developing the MGH filter was not only a technical but also a social challenge. The field trial revealed that the filter is well accepted by the users, complying with their lifestyle, time allocation, and household routine and resources, as well as being safe and convenient to handle.

Selecting the appropriate technology for As removal is still a critical issue, for which many factors need to be considered. These include the information on the process technology, groundwater chemistry, the interference of other elements, and the influence of other factors on the removal efficiency, the cost, the availability of filter materials and chemicals, and the social acceptance as well. Hopefully, the findings of this research can contribute to taking the right decisions for the selection of the appropriate technologies for further research and application, to provide a short- to medium-term solution for the As problem in the country.

Community-based pipeline water supply systems drawing water from deep aquifers constitute a long-term solution, depending on site-specific geological and socio-economical conditions. While at least for the short to medium term, household-level As removal is technically feasible, cost-effective and socially acceptable in rural areas, it is important to realize that delaying research and long–term planning can be a mistake for the country as a whole. Because long–term solutions will take time to develop and have to be tailored to the local environment, it is counterproductive to defer immediate action until long-term alternatives are completely designed. The implementation of appropriate technologies through conducting integrated research on As removal technologies, the improvement of the appropriate water supply options, and its use through community participation and management, can contribute significantly to mitigate the country's drinking water problem (Hoque et al., 2000). What is needed is integrated water resource management (IWRM), which is holistic in approach and focuses on the various uses of water and different categories of users, and which is also geologically site-specific.

8.4.2 Policy implications of the study

In Bangladesh, As-contaminated aquifers do not have a standard pattern, but vary both horizontally and vertically within a short distance. This is a major concern and a serious challenge in the planning of any large-scale use of groundwater for drinking. Mapping the aquifers is an essential prerequisite to make any policy decision on long-term development for groundwater in As-affected areas. There is not one technology that is suitable for the whole country. The government distinguishes four alternatives to address the problem of As-affected areas: the improved dug well, the pond sand filter, rainwater harvesting and deep tube wells, apart from arsenic removal technologies. For a safe and effective use of groundwater in the As-affected areas, it is necessary to assess the applicability of various technologies.

Bangladesh's National Policy 2004 on arsenic mitigation recognizes that different solutions are needed to address the problem on the different locations in the country, and has given preference to surface water over groundwater as the source of the water supply. The findings of this research indicate that community-based piped water supply systems can be considered a good solution for long-term development. It is expected that coverage will increase to about 10 percent by 2015, according to the Millennium Development Goal's Need Assessment and Costing in 2009-2015 (UNPD and Bangladesh, 2009). Although the government prioritized safe water access for the poor, in practice, many poor households could not benefit from the three systems studied in this research and could not be connected at a later stage. When implementing a community–based system, the government should emphasize participation, civic science and deliberative democracy at the local level (Atkins et al., 2007). The success of the system depends on a facilitating institutional environment, commitment by donors, sensitivity to local power structures, and accountability of the community and project personnel. It is essential to ensure that program funds are more equitably distributed, taking into account local social and welfare differentials in the services provided. A tariff system should be worked out that reflects the differences between local households in their ability to contribute to investment and running cost. More attention should be given to the feasibility of expanding the system, so that the level of access and use may be preserved over time. The water points (tap stands) should be properly designed to meet the practical gender needs of women.

The government can play a critical role in the four key areas of *change* (in conditions, needs, expectations), *complexity* (determining cause-effect linkages), *uncertainty* (acting based on incomplete information) and *conflict* (in values and perspectives regarding resources use and allocation) (Alaerts and Khouri, 2004). The *complexity* involves scientific, social, economic and cultural dimensions and can only be addressed through sound strategies and policies that integrate various disciplines and identify workable solutions. To this end, the government must give more attention to applied, research-based, coordinated action plans. It must ensure that the people are properly informed about the cause, extent and health impacts of As poisoning, so that they themselves can take precautionary measures. They can drink water in all seasons from their own contaminated tube well if treating it with As removal filters, or they can fetch water from the community-based piped water systems, deep tube wells, or otherwise. Until suitable alternative drinking water sources are widely available, simple and low-cost technologies for As removal are an immediate and short-term solution.

For long-term sustainability, capacity building is a main issue. In the three community-based systems studied, it was noted that the caretaker had partial training on the operation of the water pumps, little knowledge on mechanical issues, but could do nothing about the electricity problem or the change of local functionaries. Hence, all government projects should provide periodic training. In this respect, implementation of the 'Water Safety Plans' (WSP) in all water supply technologies can play a decisive role. The policy and strategy should aim at gender equity, where men and women should have equal chances to get training in all skills, and there should be local employment opportunities for poor women and men. In the three systems studied, men were the caretakers. If gender equity is practiced, trained women can also easily do this job.

Sustainability of the water sources becomes an issue when several communities in the same watershed area develop domestic water services; it will increase the risk of over-drawing water in the catchment area. The adequacy and quality of the available water supply often decline when the same water sources are used for different purposes. For the success of a community–based system, the methodology of 'participatory assessment' provides a systematic procedure for women and poor people to take part in the assessment activities, and it ensures that their experiences are included in the outcomes (Van Wijk-Sijbesma, 2001). Such an approach will help national and donor agencies to meet their institutional objectives, and will strengthen local development capabilities, while reducing inequities of gender and poverty.

In the household survey, it was found that in the study area, the number of people suffering from As poisoning is increasing; more male patients were found than female patients. Indeed, in rural households, men are found to be more susceptible to arsenicosis than women are (Nahar et al., 2008). In the face of the severity of *arsenicosis* as a health problem and a social issue in the country, there is still a lack of positive mobilization of civil society, particularly in rural areas, to address the urgent As crisis in the country. According to the national As mitigation policy, regular testing and monitoring of groundwater of at least 2 percent of the green (non–contaminated) tube wells, including irrigation wells, should be done on a six-monthly basis. This was not done properly in the study. Some villagers still waited for even the first testing of their well.

The common pattern of the household division of labour assigns responsibility for water fetching to women, so they are the ones who need to understand about arsenic risks and household-level mitigation measures. As revealed in the case studies, there is a problem regarding the buying of the filter materials. Women's authority is too weak to command the attention of the male members of the household, notably their husband, to this matter. So in this situation, women's authority needs to be bolstered by education, awareness and advocacy. Women have to be actively involved in programs in the water sector, also as caretakers in the community-based systems and in the operation of filters. Gender-sensitive policies and programs can only be realized if the gender perspective is systematically included in all institutions and projects regarding safe water provision, and if the representation of women in policy- and decision-making is enhanced, as well as their access to political power. A great deal of work still needs to be done in terms of As removal technologies that are appropriate for rural household use, suitable for the societal context as well as gender-sensitive (Smedley and Kinniburgh, 2002). Approved policies should be regularly reviewed and updated, based on feedback from previous implementation and experience. The government should calibrate their policies to local experience across rural society, spatially varied needs and opportunities. More applied research is needed on different As removal technologies for a safe water supply in As-affected rural areas, which should be assessed in terms of their effectiveness, technical and social sustainability, and their systematic inclusion of a gender perspective.

8.4.3 Recommendations

Based on these research findings, the following recommendations can be formulated:

- Comprehensive research should be done before the deep aquifers are widely used in community-based systems for long-term drinking water supplies, irrigation and other purposes.

- The MGH filter should be pilot-tested and properly developed over a period of at least a year. Social, economic and technical validation of the MGH filter throughout the country should be included in the pilot-testing. Because women are the collectors and managers of drinking water, the validation should be done in different parts of the country, allowing for differences in women's roles and position, depending on local socio-cultural and geographical conditions.

- The government of Bangladesh has a provision for technical certification of a new technology before it is widely promoted for public use. The MGH filter should be submitted for certification after further testing and development.

- The principle of arsenic removal used in the MGH filter may be used to research and develop a community-based, low-cost, arsenic removal water supply system in rural areas.

- Interdisciplinary and transdisciplinary approaches should be applied in the research and implementation projects aimed at increasing the population's access to safe, As-free water.

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Appendices

Appendix No. 1 Solar Oxidation and Removal of Arsenic (SORAS) Experiment

A. Experiments in Wageningen, the Netherlands

The experiments were carried out in the laboratory of sub-department of Environmental Technology, Wageningen University, in the Netherlands.

As-contaminated water: Three types of synthetic As-contaminated water were prepared using: de-mineralized water, de-mineralized water mixed with a $FeCl_3$ solution (10mgL $^{-1}$) and laboratory tap water (see chapter 6).

As-analysis: ICP-AES Varian VISTA-MPX (see chapter 6)

Chemicals: 3 drops lemon juice per 250 ml of water

Testing procedure: The arsenic-contaminated water was poured into a 250 mL PET bottle and 3 drops of lemon juice were added. After shaking the closed bottle was kept in 90 Watt UV light (6 x Philips TUV158) for 8 hours.

Results

Table 1. Synthetic As(V) water samples prepared with demineralized-water

Untreated Water As(V) μgL^{-1}	Treated water As(V) μgL^{-1}	Removal As(V) μgL^{-1}	% Removal As(V)	Average % Removal
45.1	44.8	0.3	0.6	0.7
	44.8	0.3	0.7	
	49.3	-4.2	-	
146.6	144.9	1.8	1.2	1.8
	148.4	-1.8		
	143.1	3.5	2.4	
278.7	250.7	28.0	10.1	3.8
	276.5	2.3	0.8	
	277.1	1.6	0.6	
555.2	551.0	4.2	0.8	1.0
	551.7	3.5	0.6	
	547.0	8.2	1.5	

Table 2. Synthetic As(V) plus $FeCl_3$ 10mg/l water samples prepared with demineralized water

Untreated Water As(V) µgL^{-1}	Treated water As(V) µgL^{-1}	Removal As(V) µgL^{-1}	% Removal As(V)	Average % Removal
48.401	46.41	1.99	4.12	2.34
	47.10	1.30	2.69	
	47.31	1.09	0.23	
89.50	90.32	-0.82		1.06
	88.40	1.10	1.23	
	88.71	0.79	0.88	
241.90	238.00	3.90	1.61	1.19
	239.03	2.87	1.19	
	240.01	1.89	0.78	
454.57	450.01	4.56	1.00	3.15
	455.01	-0.44		
	430.51	24.06	5.29	

Table 3. Synthetic As(V) water samples prepared with tap water

Untreated Water As(V) µgL^{-1}	Treated water As(V) µgL^{-1}	Removal As(V) µgL^{-1}	% Removal As(V)	Average % Removal
54.03	50.16	3.87	7.17	2.54
	54.01	0.02	0.03	
	53.80	0.23	0.42	
150.44	152.58	-2.14		0.66
	149.39	1.05	0.70	
	149.50	0.94	0.62	
226.70	224.88	1.82	0.80	0.98
	227.28	-0.58		
	224.07	2.63	1.16	
	657.15	1.00	0.15	
	657.50	0.65	0.10	0.13
658.15	658.25	-0.10	0.00	

Table 4. Synthetic As(III) water samples prepared with demineralized water

Untreated Water As(III) µgL^{-1}	Treated water As(III) µgL^{-1}	Removal As(III) µgL^{-1}	% Removal As(III)	Average % Removal
73.03	72.45	0.58	0.80	0.78
	72.48	0.55	0.75	
	74.46	-1.43		
196.48	196.40	0.08	0.04	
	196.46	0.02	0.01	0.03
	196.40	0.08	0.04	
	351.49	0.32	0.09	0.10
351.81	351.91	-0.10		
	351.41	0.40	0.11	
643.26	643.00	0.26	0.04	0.04
	643.28	-0.02		
	644.26	-1.00		

Table 5. Synthetic As(III) plus $FeCl_3$ 10mg/l water samples prepared with demineralized water

Untreated Water As(III) μgL^{-1}	Treated water As(III) μgL^{-1}	Removal As(III) μgL^{-1}	% Removal As(III)	Average % Removal
55.83	55.62	0.20	0.37	0.37
	55.62	0.21	0.37	
	55.83	-0.01		
143.39	142.39	1.00	0.70	0.72
	142.40	0.99	0.69	
	142.29	1.10	0.77	
288.57	288.40	0.17	0.06	0.03
	288.67	-0.10	-0.03	
	288.56	0.01	0.00	
550.02	548.02	2.00	0.36	0.97
	545.02	5.00	0.91	
	540.98	9.04	1.64	

Table 6. Synthetic As(III) water samples prepared with tap-water water

Untreated Water As(III) μgL^{-1}	Treated water As(III) μgL^{-1}	Removal As(III) μgL^{-1}	% Removal As(III)	Average % Removal
145.00	144.90	0.10	0.07	0.03
	144.39	0.61	0.42	
	145.00	0.00	0.00	
245.09	245.40	-0.31		1.10
	242.49	2.60	1.06	
	242.28	2.81	1.15	
350.30	348.30	2.00	0.57	0.22
	350.40	-0.10		
	350.01	0.29	0.08	
687.51	685.91	1.60	0.23	0.09
	687.30	0.21	0.03	
	687.50	0.01	0.00	

Table 5. Synthetic As(III) plus $FeCl_3$ 10mg/l water samples prepared with demineralized water

Untreated Water As(III) μgL^{-1}	Treated water As(III) μgL^{-1}	Removal As(III) μgL^{-1}	% Removal As(III)	Average % Removal
55.83	55.62	0.20	0.37	0.37
	55.62	0.21	0.37	
	55.83	-0.01		
143.39	142.39	1.00	0.70	0.72
	142.40	0.99	0.69	
	142.29	1.10	0.77	
288.57	288.40	0.17	0.06	0.03
	288.67	-0.10	-0.03	
	288.56	0.01	0.00	
550.02	548.02	2.00	0.36	0.97
	545.02	5.00	0.91	
	540.98	9.04	1.64	

Table 6. Synthetic As(III) water samples prepared with tap-water water

Untreated Water As(III) μgL^{-1}	Treated water As(III) μgL^{-1}	Removal As(III) μgL^{-1}	% Removal As(III)	Average % Removal
145.00	144.90	0.10	0.07	0.03
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	145.00	0.00	0.00	
245.09	245.40	-0.31		1.10
	242.49	2.60	1.06	
	242.28	2.81	1.15	
350.30	348.30	2.00	0.57	0.22
	350.40	-0.10		
	350.01	0.29	0.08	
	685.91	1.60	0.23	0.09
687.51	687.30	0.21	0.03	
	687.50	0.01	0.00	

B. Experiment in Dhaka, Bangladesh

The experiments were conducted in the environmental laboratory of EPRC in Dhaka**.**

As-contaminated water: water from shallow tube wells collected from Kalia, Narail.

As-analysis: HACH EZ arsenic Test Kit, Cat no. 2817800

Chemicals: 2-3 drops lemon juice

Testing procedure: The arsenic-contaminated water was poured into a 250 ml PET bottle and 2-3 drops of lemon juice were added. After shaking the closed bottle was kept on the roof of the house facing the sunlight from 9.00 -17.00hr.

Results

Table 7. Water from shallow tube wells

Tested by AAS	Tested by field kit				
Untreated water As µgL^{-1}	**Untreated water As µgL^{-1}**	**Treated water As µgL^{-1}**	**Removal As µgL^{-1}**	**% Removal As**	**Average % Removal**
82	75	50	25	33.3	20.33
	90	80	10	11.1	
	90	70	20	22.2	
	80	60	20	25.0	
	100	90	10	10.0	
156	175	150	25	14.3	14.84
	150	125	25	16.7	
	170	150	20	11.8	
	150	125	25	16.7	
	175	175	0	0.0	
428	500	490	10	2.0	4.52
	480	470	10	2.1	
	450	425	25	5.6	
	475	450	25	5.3	
	450	440	10	2.2	

Appendix No. 2 Questionnaire for Households Survey

I. Identification of household (HH) and interview(er)

ID Number: [ ] Date of interview: [ ]
Name of Village: ________________ Household Location : _________
Name of *Upzila*: ________________ Name of district: _________
Name of HH Head: ________________ Father's /Husband's name: _________
Sex: __________ F/M. Religion: _________
How long this HH lives here: __________ Month_______ Year - _________
Where did they come from ____________________
Respondent's (Household head, spouse, both) Name:________________________
Sex: __________ F/M. Religion: _________
Name of the Interviewer ____________________
Signature of the Interviewer__________________

II. HH composition sheet

Sl 1	Details of household composition										
	Name	Age	Sex (1)	Relationship to HH head (2)	Marital status (3)	Education Level (4)	Occupation		Working Status (7)	Monthly Income (8)	Health Status (9)
							Primary (5)	Secondary (6)			

Codes:

(1) Sex: Male = 01, Female =02

(2) HH head=01, Spouse of HH Head= 02, Child=03, Son/Daughter in law =04, Grand child= 05, Brother/sister of HH=06, Brother/sister in law =07, Niece/nephew=08, Mother of HH=09, Father of HH=10, Other relatives= 11, No relatives=12

(3) Martial Status: Married=01, Unmarried=02, Widow=03, Single (wife died) =04, Divoced-05

(4) Education Level: Illiterate (Can not read and write)= 01, Literate (Can read and write)= 02 Primary = 03, Middle (Up to Class=VIII) = 04, Secondary = 05, Higher Secondary = 06, Graduate & above = 07, Doctor = 08, Engineer =09, Vocational =10,

(5 and 6) Agriculture=01, Service =02, Fishing=03, Business=04, labour =5, Doctor=6. Teacher =7, Technician =8, Others=9

(7) Housewife =01, Unemployed /looking for work =02, Self employed= 03, Employer = 04, , Unpaid Household labour = 05, Household labour =06 Too Old =07, Child = 08, Disabled= 09, Retired / Pensioner =10, Remittance receiver =11, Student =12,

(8) <1500=01, 1501-2500=02, 2501-3000=03, 3001-5000=04, 5001-10000=05, >10001=06

(9) Health Status: Currently healthy/ usually healthy= 01, Currently sick/usually healthy =02, Chronically ill/ bad health = 03,

III. Health facilities of HH (health seeking behavior during different illnesses)

1. During the past one year:

Name of diseased person	Health complaints (1)	Duration of sickness	Medical help sought (2)

2. During the past five years:

Name of diseased person	Health complaints (1)	Duration of sickness	Medical help sought (2)

Codes:

(1) Health Complaints: Diarrhea =01, Dysentery =02, Fever =03, Spotted Skin Disease =04, Spotted Hand=05 Spotted foot =06, Respiratory =07, Kidney problem =08, Aches =09, Accident/ surgery =10, Gastrointestinal diseases =11, Hypertension =12, other specify=13

(2) Medical help sought: Homeopath =01, General Physician =02, Specialist Doctor =03, Para-professional =04, Village trained doctor =05, Medical assistant =06, Ayuvedic =07, Hekimi =08, Herbalist =09, Faith Healers/Molubee Doyaa =10

3. Do you aware/hear about Arsenic disease? ______________________

4. Did somebody (NGO/ Village leader/ Imam/ Teacher/ Upazila health officer/pl specify others) told you about Arsenic disease____________

5. Do you know any arsenic diseased person in this village _________Yes _____ No

6. Where he/she lives _____________

IV. HH asset base

i) Name of Assets	Area//No	Unit price (Tk)
1. Land excluding homestead, (dm)		
2. Orchard (dm)		
3. Pond/ghers (dm)		
4. Landless/ Tenant		
4. House and household effects, sanitation and water supply facilities (described by item)		
a) Homestead		
b) Dwelling house		
c) Furniture		
d) Radio/ Television		
e) Sanitary latrines		
f) Hand tube well		
g) Electric fan and light		
h) Refrigerator		
i) Telephone/mobile		
j) Others		
5. Cattle/Buffalo		
6. Poultry /Ducks		
7. Goat and sheep		
8. Farm machineries and equipment: (Item) a. Plowing equipment		
b. Tools (spade, axe, khonta, dao, sickles)		
c. DTW		
d. LLP/Tiller/Tractor		
9. Shops/ Micro-industries		
10. Vehicles:		
a. Rickshaw		
b. Van		
d. Cart		
d. Motor cycle		
e. Bicycle		
f. Others		
11. Ornaments		

V. Housing characteristics

i. Type of house (Tick mark)

Thatched/mud wall & Thatched roof -1 ☐ Thatched /mud wall and tin roof -2 ☐

Tin wall and thatched roof -3 ☐ Tin wall and tin roof -4 ☐

Brick wall and tin roof -5 ☐ rick wall and pucca roof -6 ☐

Wooden wall and tin roof -7 ☐ No. of room-8 ☐

ii Separate kitchen: Yes -1 ☐ No-2 ☐ Outside the room -3 ☐

If no, Living room - 4 ☐ Area of the room -5 ☐

Room space enough -6 ☐ Room space not enough -7 ☐

Room condition Good/ Hygienic - 8 ☐ Unhygienic -9 ☐

iii Toilet: Slab toilet -1 ☐ Pit toilet -2 ☐

Hanging toilet/ open toilet -3 ☐ Open Field -4- ☐

Toilet use during flooding Slab toilet -5 ☐ Pit toilet -6 ☐

Hanging toilet/ open toilet -7 ☐ Open Field -8 ☐

iv Electricity availability around the house: Yes - 1 ☐ No -2 ☐

v. Tube well installed Yes -1 ☐ No - 2 ☐

Shallow tube well -3 ☐ Deep Well - 4 ☐

vi. Quality of water: With arsenic-1 ☐ Arsenic free- 2 ☐ Don't know -3 ☐

vii. Tube well mouth marking (Please note) Green – 1 ☐ Red - 2 ☐ None -3 ☐

viii. Do you have access to the neighbouring tube well? Yes- ☐ No -2 ☐

VI. Water access and use plus time requirement

i) Water uses

Activities	Sources of water							Distance to source of water	Time Require to fetch water
	Shallow Tube well (1)	Deep Tube well (2)	Pipe water (3)	Pond (4)	dug well (5)	Rainwater (6)	River water (7)		
Drinking									
Cooking									
Bathing									
Washing of cloths									
Kitchen gardening									
Livestock									
Cleaning the house premises									
Water in toilet									

ii) Do you use your own tube well? Yes-1 No-2 ☐ ☐

iii) If not, from where do you fetch your drinking water________________

iv) Do you have some restriction for your women to neighbouring tube well ?.. ....Yes-1 No-2 ☐ ☐

VII. Gender division of labour

HH Composition	Reproductive										Productive	Community		
	Child care	Old nursing	Cooking	Fetch drinking water	Fetch cooking water	Washing Cloths	Cleaning house premises	Going to market,	Rearing Livestock	Kitchen gardening	Income earning	grouping of men	grouping of Women	Activities
HH head														
Spouse of HH Head														
Child														
Son/ Daughter														
Son/Daughter in Law														
Brother/sister of HH														
Brother/sister in law														
Niece/nephew														
Mother of HH														
Father of HH														
Other relatives														
No relatives														

VIII. Resources and assets management

i) Income and family expenditure of the past one year

Sl. No	Source of income	Total annual income (Tk)		Sl. No/	Item of Expenditure	Total Expenditure (Tk)		
		Monthly	Yearly			Weekly	Monthly	Yearly
a.	Field corps, vegetables, fruits spices, etc.			1	Food (including drink, beverages, etc.)			
b.	Timber/firewood/ bamboo etc.			2	Housing (Construction/repairs etc.)			
c.	Livestock and poultry			3	Household effects (utensils etc.) and furniture			
d.	Fisheries			4	Clothing			
e.	Services (salary)			5	Education			
f.	Business			6	Medical			
g.	Rickshaw/Van pulling/boatman			7	Farm equipment, machinery and tools			
h.	Farm labour earning			8	Sanitation			
				9	Tubewells maintenance			
i.	Non-Farm labour earning			10	Inputs (seed, fertilizer., water, electricity, pesticide hired labour, etc.)			
g.	Income from Loan			11	Paying back interest against loan			
	Others (specify			12	Ceremonies/ Festivals			
				13	Transportation			
				14	Electricity and Gas			
				15	Telephone			
				16	Firewood + Kerosene			
				17	Miscellaneous			

ii Income from loans: _______ Expenses on Interest: __________ Paying back debit: _________

IX. Control of HH resources

Source of income	Total income		Income of household members (2)	Who controls the money (3)
	(Tk)	(1)		
Field corps, vegetables, fruits etc.				
Timber/firewood/ bamboo etc.				
Livestock and poultry				
Fisheries				
Services (salary income)				
Business				
Rickshaw/Van pulling/boatman				
Farm labour earning				
Non-Farm labour earning				
Loan				
Others				

Codes:

(1) Total Income : Weekly =01, Monthly =02, Yearly =03

(2) and (3): Household Head =01, Wife =02, Son=03, Daughter= 04, Grandfather =05, Other specify)

X. HH recourse budgeting:

i) Earned money from different HH members is paying for different HH expenditure: Yes-1 No-2 ☐ ☐

ii) All income is collected together and HH budgeting is done jointly: Yes-1 No-2 ☐ ☐

iii) Combination of (i) and (ii) are done for family expenditure: Yes-1 No-2 ☐ ☐

Appendix No. 3 Screening matrix on strengths, weaknesses, cost, users' opinion and development status of the technologies in Bangladesh.

Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
Simple Aeration filter	Oxidation/ precipitation, sedimentation	–	–	√	√	√	√	√	√		√							√			√		√		
SORAS treatment	Photochemical oxidation, precipitation and filtration	–	+	√	√		√	√	√												√		√		
Passive sedimentation filter	Sedimentation-co precipitation with iron on oxidation	–	+	√	√	√	√	√	√		√							√		√		√	√		
Garnet Homemade filter	Passive coagulation with iron from brick chips and adsorption to sand	–	+	√	√	√		√	√		√							√		√			√	√	
Sono 3-Kolshi /Pitcher filter	Passive Precipitation / Sedimentation (Zero-valent iron)	+++	+++	√	√	√	√	√	√					√	√			√	√						√
Naturally-occurring Fe/ Mn	Co-precipitation and filtration (coagulation with iron)	+	++	√	√	√	√	√	√		√							√			√		√		
Iron coated sand filter	Co-precipitation and filtration (sand is mixed with 2M ferric nitrate and 10 N sodium hydroxide solution)	++	+++		√	√	√		√	√		√		√			√			√		√	√	√	

Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
UNESCO-IHE family filter.	Adsorption onto iron oxide coated sand- a by-product of iron removal plants	+++	+++	√	√	√	√					√	√			√			√					√	
Shapla Arsenic removal filter	Adsorption and filtration though a pair of earthenware column, media constitues iron-coated chips made by ferrour sulfate soln	+++/-	+++/-			√	√		√	√		√		√				√		√				√	
Nilima As removal unit (NARU)	Oxidation by areation, sand filtration and adsorption on iron oxide media	+++/-	+++/-						√	√		√		√						√		√	√	√	
Gravel bed containing Fe-sludge	Co-precipitation or sorptive filtration	++	++				√			√	√							√			√	√	√	√	
Rajshahi University /New Zealand Iron Hydroxide slurry filter	Coagulation, filtration with alum coagulation	++	++						√			√									√	√	√		
STAR household filter	Co-precipitation filtration process with Fe coagulant and hypochloride	+++	+++	√		√	√	√	√					√				√	√				√	√	
Earth Identity Project (EIP) -Star Stevens	Coagulation floculation process using ferric sulfate and calcium hypochlorite	+++/-	+++/-					√	√			√			√					√				√	

Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
CIWP filter	Coagulation floculation process using ferric sulfate and sodium hypochlorite	+++/-	+++/-					√	√			√			√					√				√	
Iron Filings in Jerry Can	Adsorption, precipitation, and sedimentation	–	–	√			√											√			√		√		
DPHE/ Danida Bucket Treatment unit	Oxidation, coagulation and adsorption, (Al-sulfate and KMnO4	++/-	+++/-		√	√			√		√	√		√				√	√					√	
BUET two bucket filter	Oxidation /coagulation/filtration FeCl3/Fe(SO4)3	++/-	++	√					√	√		√		√	√			√		√			√	√	
Two bucket treatment unit tea bag	Oxidation /coagulation/ bleaching powder, ferric chloride and fly ash	++/-	++/-	√				√	√			√		√				√			√		√		
BUET Activated Alumina filter	Oxidation, sedimentation, filtration, Active Alumina	+	+++						√	√	√	√		√	√			√		√			√		
Granular Activate Carbon filter	Adsorption on ganular activated carbon	++	++									√				√							√		
AMAL Household Filter with AA	Adsorption on activated alumina (AA)	++/-	+++	√			√			√		√	√	√			√				√		√		

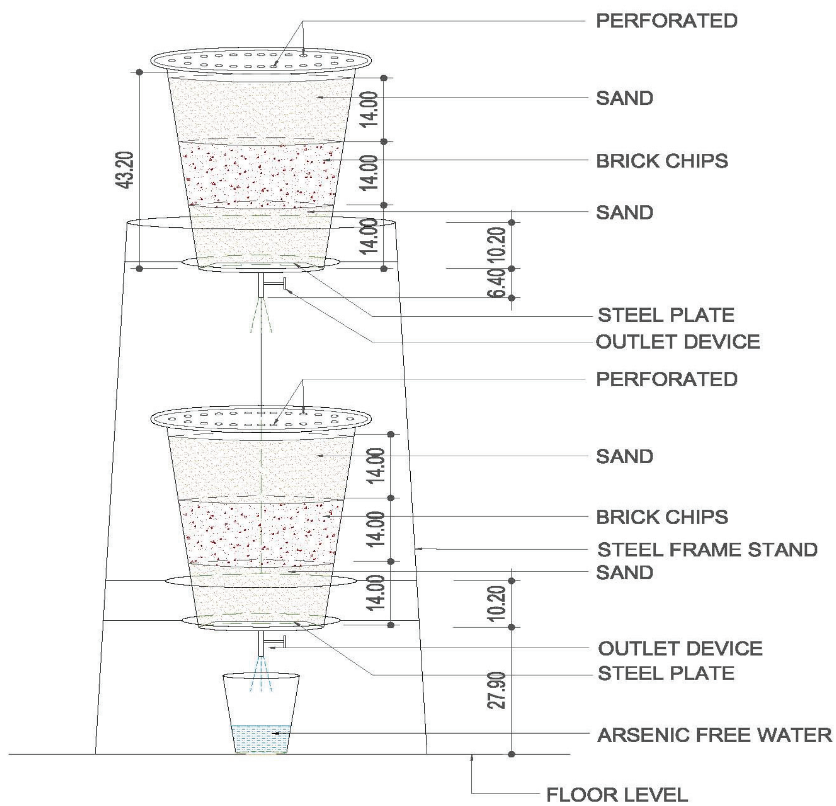
Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
Fixed bed GFH (AdsorpAs®)	Coagulation–precipitation process as, chemisorption, Re-generable adsorptive media	+++	+++	√			√	√				√	√			√			√						√
SOES Household Filter and Tablet system	Adsorption and filtration two jar system	+++	+++			√	√	√	√			√			√				√						√
Bijoypur clay filter /	Bijoypur Clay/ Processed Cellulose	+	++	√														√			√	√	√		
BCSIR filter	Co-precipitation/ Adsorption-coagulation with an iron based chemical & sand filtration	+	++	√			√			√	√	√									√		√		
Adarsha Filter	Passive sedimentation and adsorption to clay/ carbonized organic candle	–	+	√				√	√									√			√	√	√		
Safi filter	Adsorption on ceramic candle made by chemical mixture of laterite soil, ferric oxide, manganese di-oxide, aluminium hydroxide and mezoporous silica	+++	+++	√	√		√			√		√			√				√	√	√				

Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
Indigenous Raw Materials -- Coconut Shells, Coir, Husks Filter	Adsorption on oconutshell, husk etc.	–	+							√		√			√					√		√	√		
Kanchan ™ As /Biosand filter	Based on slow sand filtration and iron hydroxide adsorption. Gravel, coarse sand and fine sand, Fe and brick chips	+++/++	+++/++				√	√	√	√	√	√		√	√		√		√				√	√	
Biological Filtration for Arsenic removal	Biological filtration (co-precipitation or adsorption. Fixation of As(III) on the iron oxides produced by the bacterial activity.	++	++						√		√	√		√							√	√		√	
Alcan Enhanced AA system filter	Sedimentation, filtration, activated alumina (AAFS-50)	+++	+++	√		√	√	√								√			√						√
Ion Exchange with Chloride-form strong-base resins	Ion Exchange Process	+++	+++	√	√		√			√		√			√						√				
Fead F Filter	Adsorption, READ -F is an adsorbent composed of an ellylene-vinyl alcohol copolymer (EVOH) and hydrus cerium oxide (CeO2.nH2O), effectively adsorbeding both As (III) and As (V)	+++	+++	√		√	√	√								√			√						√

Option	Process Technology	As Removal Efficiency		Advantage						Disadvantage						Cost			Social Acceptability				Development Status		
		As (III)	As (V)	1	2	3	4	5	6	7	8	9	10	11	12	H	M	L	PA	NA	NF	NIA	L	C	F
Tetrahedron ion exchange resin filter	Ion exchange column resin	+++	+++	√	√	√	√			√		√			√				√						√
Apyron Arsenic Treatment Uni Aqua-Bind™	Activated hybrid aluminas and alumina composites	+++	+++	√	√	√	√	√	√	√	√				√	√			√	√			√		
Low-pressure Nanofiltration and Reverse Osmosis	Membrane filtration, NF and OR have appropraite pore size for asremoval	+++	+++										√			√			√					√	
MRT-1000 and Reid system, ltd	A wider -spectrum RO system	+++	+++													√					√		√		
Bioremediation by Algae	Immobilized *Chlorella vulgasris* algae used in combination of other adosrbentto accumulation of As	++/-	++/-										√				√				√	√	√		
Techno-food water technology	A wider -spectrum RO system	++/-	++/-									√				√					√	√	√		

Notes: As removal efficiency, +++ = > 90% , ++ = 60-90%, + = 30-60%, - = < 30-0,1=Easy Process, 2=Less/ no chemical use, 3=Technology create no problems on water chemistry parameters/ pH, 4= Adequate volume of As free water produced for a HH, 5= Less O & M time, 6= Locally available materials / chemicals, 7=requires pretreatment, 8=Bacteriological problems, 9=Complicated system, 10=Chemicals/ filter not esily availble, 11= Flow rate decrease due to clogg, 12= As toxic large waste sludge, L=Low cost, M=Moderate cost, H= High cost, PA= People accepted, NA= Not accepted due to operational problems, NF= No field test, NIA =Not information available, L= lab scale, C=Controlled condition in field/ pilot scale, F=Full scale

Appendix No. 4 Design of the MGH filter



NOTE: DIMENSIONS IN CENTIMETER

Summary

To confront the arsenic crisis in Bangladesh, several options for a safe water supply in the rural As-affected areas are available. Most of these options have shown a minimum scope to mitigate arsenic-related risks because of their poor performance and non-acceptability by the rural households. In this research, therefore, the development of an appropriate technology for an As-free, safe drinking water supply is considered from a local perspective and a societal context. To achieve the goal and objectives of this research, four research questions were formulated (Chapter 1). The first research question is about the technological and socio-economic performance of community-based pipeline water supply systems that use deep aquifers. The second question deals with available and currently implemented household-level arsenic removal technologies in rural Bangladesh. The third addresses the weaknesses, limitations, strengths and advantages of the technologies in terms of a number of technological, social, economic and gender indicators. Fourth, the question is posed of the most promising arsenic removal option for rural households in terms of its technological performance and social acceptability and suitability from a gender perspective. The occurrence of As in the Delta region is of geochemical origin and its distribution in the groundwater has distinct regional patterns and depth trends. An overview of the arsenic problem in Bangladesh is given in Chapter 2.

The overall objective of the research was to develop a socially appropriate and gender-sensitive household-level As removal filter. Technical, socio-economic and cultural aspects were incorporated in this research to assess the development of a sustainable innovation through multi- and interdisciplinary approaches. The technical validation of the systems was carried out through laboratory-based research, to address the efficiency, robustness, operational and maintenance convenience, safety and viability of the technology. For the social research, the model by Spaargaren and Van Vliet (2000) was adjusted to address the filter's suitability in terms of lifestyle, domestic time-space structures, affordability, standards of comfort, cleanliness, convenience and modes of provision. In addition, I also considered the household resource-based affordability during the operation and maintenance phase, in terms of a socio-technological and gender perspective. A conceptual model was developed to guide the research and to answer the research questions (Chapter 1). The socio-economic data on the main concepts of this research work were collected through a survey (Appendix 2).

In this research, a synthesis of knowledge resulting from disciplinary, open-ended collaboration and local perspectives is achieved. Such a transdisciplinary research approach ensures an integration of knowledge through the participation of a variety of stakeholders, including end users, and mutual learning between the different stakeholders, such as users

of the Modified Garnet Homemade Filter (MGH Filter), caretakers, village committees, implementing organizations and donors, users of water, households, and women.

The community–based piped water supply in Bangladesh

There are several alternative sources to get safe and As-free drinking water in Bangladesh. A community-based piped water supply system using deep aquifers is one of them. In this research, three community-based piped water supply systems were compared to evaluate their technological and economic sustainability, the sustainability of using deep aquifers for the long term, and the social and gender appropriateness of the systems, based on the users' perspective (Chapter 4). The technical performance of the three systems in different geological conditions was found satisfactory in terms of their efficacy, water quality, adequacy of the water supply, and operations and maintenance. The water is As- and Fe-free and is of good taste. The concentration of As is below the limiting range of drinking water in Bangladesh ($50\mu gL^{-1}$As), as well as within the WHO and new EPA standards ($10\mu gL^{-1}$As). The sustainable use of deep aquifers for a longer period is a serious issue. To address the sustainability, hydro-geological factors need to be well understood. Overextraction of water from deep aquifers could induce a downward migration of dissolved As and permanently destroy the deep resource. Only one system is practicing chlorination to disinfect the water in the overhead tank, while the other two systems do not have such a provision. However, the field data reveal that the three systems are technologically acceptable and do not require disposal of contaminated sludge.

The women who are using one of the three water supply systems are satisfied about the water supply systems. They think the systems reliable in their delivery of adequate water and convenient and comfortable for the women users. Women can get water close to their house, which saves collection time and a physical burden. The appointed caretakers are operating the systems efficiently, including maintenance and the collection of the monthly bill from the beneficiaries. The economical sustainability seems to be satisfactory, provided the initial costs are subsidized by external financial assistance with only a little contribution from the communities, which varies from five to seven percent of the total capital cost. The community participation in sharing the installation cost for the system and the monthly bill are fixed, based on the economical condition of the households. However, a drawback of the community-based piped water system is disruption of the system due to its sensitivity to power failure, which is a big problem in Bangladesh. Other shortcomings are the limitations to extend the system to meet the increasing demand of the village people. On the long term, economical sustainability factors need to be considered, such as the availability of funds and the participation of the users in the system's management, which were absent in all three systems.

Currently available and implemented household-level arsenic removal technologies

The application of arsenic removal technologies to provide safe drinking water in rural areas plays a vital role where other, alternative options and safe aquifers are not easily available and where community-based pipeline water supply systems are not feasible. In this research, physico-chemical and biological as well as conventional techniques for the removal of arsenic were reviewed (Chapter 5). Based on literature, an inventory was carried out of 40 available and currently implemented technologies at the household level in terms of their arsenic removal efficiency, cost and users' acceptance. All the technologies remove As from the water to a limited extent. Therefore, there is scope for further development of these technologies. A multiple-criteria analysis (MCA) approach was applied to select a technology for the further development of an appropriate arsenic removal filter for household-level use. In the research, based on the integrated assessments by MCA, the GARNET technology was selected for further development.

An assessment of the performances of the three governmentally certified arsenic removal technologies for rural household use was carried out (Chapter 5). This research concludes that the government's investments in an improved water supply so far have failed to meet the needs of the poor villagers, because they are not able to buy the costly Alcan and Read-F filters. Even the relatively cheap Sono filter proved to be unaffordable for the poorest. Furthermore, assessing the As removal efficiency and life span of these filters is difficult at this preliminary stage, and so is predicting how the disposal of the spent filter materials will be carried out by the users. The As leaching from the sludge/waste generated by the three treatment processes is dependent on the type of removal mechanism and the ultimate sludge disposal methods.

Development of a chemical-free arsenic removal technology for household use

In this research, by the active participation of potential end users and other stakeholders, I have included local knowledge and social and gender perspectives in the process of the development of an innovative As removal filter (MGH filter) (Chapter 6). The MGH filter efficiency and breakthrough point were studied at different operational variables, such as filter bed thickness, types of filter media and flow rate. The toxicity of the spent material was addressed by a TCLP test. The developed filter meets the Bangladesh standard for arsenic in drinking water ($50 \mu gL^{-1}$). It can reduce the arsenic concentrations of the shallow tube well water samples from $160\text{-}959 \mu gL^{-1}$ to $0\text{-}50 \mu gL^{-1}$. It can also remove bacteriological contamination in terms of total coliform and fecal coliform counts from >500 to 0 cfu/100 mL^{-1} . The filter consists of two-bucket filters in series, each with three filter material layers of 14 cm thickness each, containing sand, brick chip and sand (Figure 7.1). The first-class brick chips of 1.3 cm size and Sylhet coarse sands were found to be the most efficient. The major advantage of this unit is that it does not require any daily addition of chemicals and can be operated at a high flow rate. It needs to be cleaned regularly to prevent bacterial contamination, while its maintenance requires treatment with bleaching powder at 15-day intervals. The filter is cost–effective and viable; the investments and operational cost are about € 10.8-13.4 and € 0.11-0.14[9] per 100 liters of treated water, respectively.

In this research, a multi-perspective and participatory socio-technological assessment of the filter's performance during the field level application was carried out in two phases: the trial phase during March 2008 and the evaluation phase during July 2008 (Chapter 7). Eight MGH filters were distributed among eight households in the research area in Kumarbhog. In this research, the multi-perspective assessment comprised interdisciplinary and transdisciplinary approaches to evaluate the performance of the filters for household use. Both quantitative and qualitative methods of data collection and analysis were used. The suitability and acceptability of the filters were evaluated through systematic observation, interviewing, FGDs and eight case studies of the filter users. The compatibility and appropriateness of the filter were viewed from a gender perspective, since access to safe water is an important practical gender need of women, directly related to their domestic and reproductive role.

[9] At the time of this research, Euro 1 was Tk 93.

Women of the selected eight rural households adopted the technology and ran the filters successfully during the trial phase. As elsewhere in developing countries, in Bangladesh too, rural women are the managers of water for household use. They hardly participate in income generation. The male household head controls the allocation of household income and expenditures, which caused problems when women wanted to re-install their filter. The household survey revealed that sometimes, women cannot be bothered to fetch safe water from far away and, instead, drink the contaminated water from their own shallow tube wells. Having the appliance inside the house complied well with the social norms and religious restrictions (*purdah*) that women have to abide by. In these circumstances, the MGH filter was eagerly accepted by the eight households, because it reduced women's social and physical burden to fetch As-free, safe water far from their home. In the evaluation phase, some filters were unused because the women could not persuade their husbands to purchase the necessary filter bed materials. During the evaluation phase, the performance of the filters declined compared to the trial phase, because not all users followed the instructions on its operation and maintenance, such as proper chlorination and cleanliness of the appliance. Disposal of spent filter material was carried out in different ways by the MGH filter users, but more investigation is needed to enable an environmentally friendly disposal of the As-rich sludge.

A new filter system has been developed that can be used by women at the household level. In terms of the simplicity of construction, operation and maintenance, As removal efficiency, and bacterial removal efficiency, its technical performance is good. It is also very cost-effective. However, because such a system always needs to be completely safe for producing drinking water, on the long term as well as under local and household conditions other than those investigated in this research project, further evaluation and additional research will be necessary. In this research, the filter was field-tested under controlled conditions for a month and evaluated after three months. Considering the need for arsenic treatment options in Bangladesh and other developing countries, further research on the performance of the MGH technology could have important positive implications for a safe water supply. Therefore, to allow for seasonality, the MGH filter should be pilot-tested and properly developed over a period of at least a year, in different geographical conditions. A social, economic and technical validation of the MGH filter should be included in the pilot-testing in different parts of the country by applying interdisciplinary and transdisciplinary approaches. Because women are the collectors and managers of drinking water, doing the validation in different parts of the country allows for variation in women's roles and position and the local socio-cultural context. The MGH filter should be submitted for certification by the government of Bangladesh after further testing and development. The technological principle of the MGH filter may be used to research and develop a community-based low-cost arsenic removal water supply system in rural areas. The results of this research testify to the feasibility of a gender-sensitive, socially acceptable and technologically sound, sustainable solution to the problem of the As contamination of water for household use in rural areas in Bangladesh.

Samenvatting

Er zijn verschillende opties om de bevolking van de door arseen aangetaste gebieden in Bangladesh te verzekeren van veilig drinkwater. De meeste ervan zijn echter niet voldoende effectief gebleken in het reduceren van de risico's en bleken niet acceptabel voor rurale huishoudens. In dit onderzoek staat daarom het ontwikkelen van een vanuit een lokaal en sociaal perspectief geschikte technologie voor de productie van As-vrij drinkwater centraal. Om dit doel te bereiken werden vier onderzoeksvragen geformuleerd (zie Hoofdstuk 1). De eerste onderzoeksvraag betreft de werking en doeltreffendheid vanuit een technologisch en sociaal gezichtspunt van gesloten waterleidingsystemen in rurale gemeenschappen waarin water uit diepere arseenvrije lagen in de grond wordt opgepompt. De tweede onderzoeksvraag behandelt de stand van zaken wat betreft de implementatie van technologieën voor de huishoudelijke verwijdering van arseen in Bangladesh. Bij de derde vraag gaat het om de zwakke en sterke punten van de technologieën aan de hand van een aantal technologische, sociale, economische en gender indicatoren. In de vierde plaats werd de vraag gesteld naar de meest veelbelovende optie voor huishoudelijke verwijdering van arseen uit drinkwater in termen van technologische, sociale en gender geschiktheid. Het voorkomen van arseen in de Delta van Bangladesh heeft geo-chemische oorzaken en varieert regionaal en qua diepte waarop het arseen zich in de grond bevindt. Hoofdstuk 2 presenteert een overzicht van het probleem.

Het doel van dit onderzoek was het ontwikkelen van een filter die niet alleen aan technologische eisen zou voldoen maar ook sociaal aanvaardbaar is en rekening houdt met de rol en verantwoordelijkheden van vrouwen in huishoudelijk watergebruik. Gebruik makend van een multi- en interdisciplinaire benadering werden technische, sociaaleconomische en culturele aspecten in het onderzoek geïncorporeerd om tot een duurzaam systeem te komen. In het laboratorium werd het systeem technologisch gevalideerd, teneinde de efficiëntie, de robuustheid, het gebruiks- en onderhoudsgemak, veiligheid en technische haalbaarheid van de technologie te bepalen.

Voor de sociaalwetenschappelijke component van het onderzoek werd het model van Spaargaren and Van Vliet (2000) aangepast. De geschiktheid van de filter werd niet alleen geëvalueerd in termen van levensstijl, huishoudelijke tijd- en ruimtebeperkingen, gebruiksgemak, en toegang tot de benodigde middelen en informatie, maar ook wat betreft de kosten van installatie, gebruik en onderhoud. Een conceptueel model werd ontwikkeld om het onderzoek te structureren (zie Hoofdstuk 1). De sociaalwetenschappelijke concepten werden geoperationaliseerd en door middel van een huishoudsurvey (zie Appendix 2) werden de relevante sociale en economische gegevens verzameld. Het onderzoek vormt de weerslag van een open samenwerking tussen vertegenwoordigers van verschillende disciplines vanaf het begin. Omdat tevens, van het begin af aan, de gezichtspunten en belangen van de lokale gebruikers en andere belanghebbenden werden meegenomen, kan het onderzoek niet alleen multi- en interdisciplinair, maar ook transdisciplinair genoemd worden

Waterleidingsysteem op gemeenschapsniveau in Bangladesh.

Er zijn verscheidene alternatieven om arseenvrij drinkwater te krijgen in Bangladesh. Een waterleidingsysteem op gemeenschapsniveau dat een diepe grondlaag (aquifer) gebruikt is er een van. In dit onderzoek zijn drie waterleidingsystemen op gemeenschapsniveau vergeleken om een evaluatie te maken van hun technische en economische kenmerken, de duurzaamheid van het gebruik van diepe aquifers op lange termijn, en, vanuit het perspectief van de gebruikers, de sociale gepastheid en vrouwvriendelijkheid (Hoofdstuk 4). Het is aangetoond dat onder verschillende geologische omstandigheden de drie systemen in technisch opzicht voldoen voor wat betreft rendement, waterkwaliteit, betrouwbaarheid van waterlevering, gebruik en onderhoud. Het water is vrij van Fe en As en smaakt goed. De concentratie van As is lager dan de drinkwaternorm in Bangladesh ($50 \mu g L^{-1}$ As) en ook lager dan de WHO- en nieuwe EPA-standaard ($10 \mu g L^{-1}$ As). Het duurzame gebruik van diepe aquifers is een serieus probleem. Hydro-geologische factoren moeten goed bekend zijn om de duurzaamheid vast te stellen. Extractie van te grote volumes water uit de diepe aquifer kan leiden tot een neerwaartse migratie van As die de diepe aquifer permanent verontreinigt. Bij slechts een van de drie systemen wordt in de buffertank chlorering toegepast voor desinfectie; de andere systemen hebben zo'n voorziening niet. Echter, de veldgegevens tonen aan dat de systemen in technisch opzicht voldoen en dat er geen slib hoeft te worden gedumpt.

De vrouwen in de die dorpen zijn tevreden over de systemen en beoordelen ze als betrouwbaar en prettig in gebruik. De vrouwen hebben nu toegang tot water dicht bij huis, hetgeen tijd en arbeid bespaart. Degenen die zijn aangesteld om het functioneren van het de systemen te faciliteren en controleren, doen dat goed. Zij innen ook de rekeningen. De economische duurzaamheid is voldoende, mits de initiële kosten extern worden gesubsidieerd. De bijdrage van de gemeenschap aan de investering was vijf tot zeven percent. Het aandeel in de bijdrage van de gemeenschap aan de investering en de betaling van de maandelijkse rekening worden vastgesteld op basis van de economische status van de huishoudens. Echter, een nadeel is onderbreking van het systeem door het uitvallen van de elektriciteit, een veelvoorkomend probleem in Bangladesh. Een andere tekortkoming is de beperkte mogelijkheid om het systeem uit te breiden om in de toenemende vraag naar water van de dorpsbewoners te voorzien. Op lange termijn moet economische duurzaamheid gewaarborgd worden door de beschikbaarheid van fondsen voor onderhoud en de participatie van de gebruikers in het beheer. In de drie onderzochte systemen waren deze elementen afwezig.

Huidige beschikbare en geïmplementeerde technologieën voor huishoudelijk gebruik

Technologieën voor de veilige verwijdering van arseen uit drinkwater zijn van groot belang als geschikte aquifers niet aanwezig zijn en een veilige waterleiding op gemeenschapsniveau niet haalbaar of mogelijk is. In dit onderzoek werden fysisch-chemische, biologische en conventionele technieken voor verwijdering van arseen op hun merites onderzocht (Hoofdstuk 5). Op basis van de literatuur werden 40 technologieën voor huishoudelijk gebruik getoetst die beschikbaar zijn en worden geïmplementeerd. Beoordelingscriteria waren de effectiviteit van de arseenverwijdering, kosten, en aanvaardbaarheid voor de gebruikers. Alle technologieën verwijderen arseen tot op zekere hoogte. In dit opzicht is er ruimte voor verbetering. De verschillende criteria werden in één analyse gecombineerd in een *multiple criteria analysis* (MCA) benadering. Op basis hiervan werd de GARNET technologie geselecteerd voor verdere ontwikkeling.

Het functioneren en de effectiviteit van de drie systemen die een certificaat van goedkeuring van de regering van Bangladesh hebben, de Alcan, Read-F en Sono filter, werden geëvalueerd (Hoofdstuk 5). Er moet worden geconcludeerd dat de pogingen van de regering om mensen in de rurale gebieden van veilig water te voorzien tot dusverre niet tegemoet komen aan de behoeften van de armen. Zij kunnen zich de kostbare Alcan en Read-F filter niet veroorloven. Zelfs de relatief goedkope Sono filter bleek onbetaalbaar voor de armste dorpsbewoners. Voorts is het testen van de efficiëntie van de filters lastig in dit begin stadium en is het nog niet te zeggen hoe de gebruikers het afval probleem zullen oplossen. Het al of niet lekken van arseen uit het filterafval na het behandelingsproces is afhankelijk van de wijze waarop de technologie het arseen verwijdert.

Ontwikkeling van een chemicaliënvrije As-verwijderingstechnologie voor huishoudens

In dit onderzoek is, met gebruikmaking van de actieve deelname van potentiële eindgebruikers en andere belanghebbenden en lokaal aanwezige kennis, en rekening houdend met sociale en gender aspecten, een innovatief filter voor arseenverwijdering ontwikkeld (MGH-filter) (Hoofdstuk 6). Onder verschillende operationele condities, te weten dikte van het filterbed, type filtermedium en debiet, is de efficiëntie en het doorbraakgedrag van de filter onderzocht. De giftigheid van het gebruikte filtermateriaal werd onderzocht met een TCLP-test. Het MGH-filter levert water dat voldoet aan de standaard voor drinkwater in Bangladesh ($50 \mu g L^{-1}$). Het is in staat om zowel de arseenconcentratie van het ondiepe bronwater van 160 – 959 $\mu g L^{-1}$ te reduceren tot 0-$50 \mu g L^{-1}$ als de bacteriële verontreiniging te verminderen. De filter bestaat uit twee emmers in serie, elk met drie lagen van 14 cm filtermateriaal: zand, baksteenscherven, zand (Appendix 4). Eerste klas baksteenscherven van 1.3 cm en Sylhet grof zand waren het meest efficiënt. De belangrijkste voordelen van de filter zijn dat deze geen dagelijkse toevoeging van chemicaliën nodig heeft en met een hoog debiet kan worden bedreven. De filter moet om de 15 dagen behandeld worden met bleekpoeder om bacteriële verontreiniging te voorkomen. De investeringskosten bedragen €10,80 – 13,40 en de operationele kosten zijn €0,11 – 0,14 per 100 liter water.

Het onderzoek werd uitgevoerd in twee fasen: een proef fase in maart 2008 en een evaluatie fase in juli 2008 (Hoofdstuk 7). Er werd een MGH-filter geplaatst in acht huishoudens in het onderzoeksgebied in Kumarbhog. Er werden zowel kwantitatieve als kwalitatieve methoden van dataverzameling gebruikt. De geschiktheid en acceptatie van de filters werden geëvalueerd met behulp van systematische observatie, interviews met de gebruikers, focus-group gesprekken (FGDs) en acht case studies. De geschiktheid van de filter werd vanuit een gender perspectief beoordeeld vanwege het feit dat vrouwen, op basis van hun reproductieve verplichtingen en verantwoordelijkheden, degenen zijn die een belangrijke rol spelen in huishoudelijk watergebruik en het meeste belang hebben bij toegang tot veilig water.

De vrouwelijke gebruikers van de filters in de acht geselecteerde huishoudens gebruikten de filters met succes gedurende de proef fase. Ook in Bangladesh zijn het vrouwen die verantwoordelijk zijn voor de huishoudelijke watervoorziening en het huishoudelijk watergebruik. Ze hebben in het algemeen geen eigen inkomsten uit economische activiteiten. De man is het hoofd van het huishouden en hij beslist over de huishoudelijke uitgaven. Dit veroorzaakte problemen bij de vervanging van de filtermaterialen, waarvoor de vrouwen geld nodig hadden. Het onderzoek wees ook uit dat vrouwen het soms te veel moeite vinden om ver weg veilig water te halen. Bovendien belemmeren religieuze normen (*purdah*) de bewegingsvrijheid van vrouwen in de publieke ruimte. Ze gebruikten dan toch het arseen bevattende water uit hun eigen ondiepe put. Een voorziening voor veilig water in hun eigen huis komt aan al deze bezwaren tegemoet, reden waarom de MGH-filter voor de vrouwen zo welkom was. In de evaluatie fase bleek dat sommige filters niet meer werden gebruikt omdat de vrouwen hun echtgenoot niet konden overtuigen geld uit te geven voor vervanging van de filtermaterialen. Het bleek tevens dat de filters minder goed functioneerden dan in de proef fase omdat niet alle gebruikers de gebruiksinstructies, zoals het tweewekelijks chloreren en het goed schoonhouden van de installatie, volgden. Oplossing van het afval probleem behoeft ook nog verder onderzoek.

In dit onderzoek werd een nieuw systeem ontwikkeld om arseen uit drinkwater te halen dat in huishoudens door vrouwen kan worden gebruikt. De filter functioneert technisch goed, is eenvoudig te bedienen en is betaalbaar. Er is echter meer onderzoek nodig naar het functioneren van de filter op langere termijn en ook in andere omstandigheden, om de veiligheid van drinkwater duurzaam te kunnen garanderen. De seizoensinvloeden, bijvoorbeeld, dienen te worden getest. Gegeven de grote urgentie van het probleem is verder onderzoek onvermijdelijk. Vervolgonderzoek moet ook gebruikmaken van een geïntegreerde toepassing van een combinatie van disciplines. De validering van de geselecteerde technologie dient te gebeuren in verschillende locaties, om zo de variabiliteit in geografische condities, sociaal-culturele context en – gegeven de centrale rol van vrouwen in het huishoudelijk watergebruik – de positie van vrouwen, in de validering te integreren. Na verdere ontwikkeling en validering moet de MGH-filter ter certificering worden voorgedragen bij de regering van Bangladesh. De technologische basisprincipes van de MGH-filter kunnen ook worden gebruikt voor de ontwikkeling van een systeem voor de voorziening van veilig water op gemeenschapsniveau. Dit onderzoek bewijst dat het mogelijk is een technologisch effectieve, betaalbare, vrouwvriendelijke en duurzame oplossing te vinden voor het arseen probleem in Bangladesh.

Curriculum Vitae

Nahid Amin was born on the 30th October, 1958, in Hydrabad, Pakistan. She completed her BSc (Hons.) in Chemistry in 1981 and her MSc in Organic Chemistry in 1983 at the University of Dhaka, Bangladesh.

She started her career in July 1983 as a research fellow of the Bangladesh Council of Science and Industrial Research (BCSIR) at Bangladesh. Then she joined the Dhaka Water Supply and Sewerage Authority (DWASA) as a chemist and between 1985 and 1988 occasionally worked as an in-charge at the laboratory. In 1993, she was admitted to the Masters Program in Environmental Engineering and Sustainable Infrastructure at the Royal Institute of Technology (KTH) in Stockholm, Sweden. She completed the MSc in 1995. Since 1995, she was employed at the Bangladesh Consultants Limited (BCL) as an environmental engineer. She was involved in different infrastructure projects as a consultant and conducted many environmental studies in different infrastructural development projects financed by donor agencies, such as the Asian Development Bank (ADB), World Bank, Japan International Corporation Agency (JICA), Islamic Development Bank (IDB), and DANIDA. In 2005, she obtained a sandwich fellowship from WOTRO, the Netherlands, to start her PhD program with the Sub-department of Environmental Technology and the Sociology of Consumers and Households Group at the Wageningen University. In July 2010, she started to work at the Padma Multipurpose Bridge Construction Project under the Bangladesh Bridge Authority, where she is working as an advisor of the Safeguard Unit.

Nahid Amin is married and has one daughter. The family lives in Dhaka.

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SENSE & WASS PhD courses
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- Research Context Activity: Writing of a chapter on: Integrating safe drinking water technology and flood impact in Bangladesh
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- Quantitative Research Methodology
- Theoretical Issues of Households and Gender

Other PhD and MSc courses
- Rural Gender Studies
- Techniques for Writing and Presenting Scientific Papers
- Project & Time Management
- Information Literacy
- Scientific Publishing
- Writing Grant Proposals
- Working with EndNote
- Career Perspectives

Research Skills
- Contribution to preparation WOTRO PhD research proposal
- Laboratory training on chemical analysis by ICP equipment

Oral Presentations
- Developing a filter for Arsenic removal for household use, UNESCO-IHE Seminar, 7 April 2009, Delft, The Netherlands

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