Chapter 7

ARSENIC CRISIS

7.1 Introduction

Arsenic is found in aquifers, usually underlying river deltas, around the world. In Bangladesh, arsenic levels are highest in the southern part of the country, presumably because the arsenic accumulated there when the Ganga and Brahmaputra rivers washed soil down from the Himalayas to the Bay of Bengal (Figure 7.1). Around this Bengal deltaic region, the presence of this poison in groundwater is an alarming situation and already it is reported to be the biggest arsenic calamity in the world in terms of the affected population. In West Bengal, a minimum of 6 million people belonging to 9 out of a total of 18 districts were drinking arsenic contaminated water which contains more than 50 mg/L arsenic (Rahman and Al-Muyeed 2009). The presence of shallow aquifers with abundant groundwater, the groundwater being free from pathogenic microorganisms and the ease of tubewell installation at affordable cost, has meant the number of domestic water supply wells, particularly in rural areas of Bangladesh, has increased by many times over the last three decades. Around 97% of the population in Bangladesh had access to drinking water. Unfortunately, arsenic contamination of primarily shallow aquifers in many parts of the country (Table 7.1) has made water extracted from these aquifers unsafe for drinking purposes and has reduced this water supply coverage (water supply within one kilometer of their home or 30 min total collection time) to around 74%. The blanket screening test data of around 4.73 million tubewells (55% of total tubewells) in around 54,000 villages (62% of total villages) in the country (Table 7.1) shows that groundwater from approximately 1.4 million

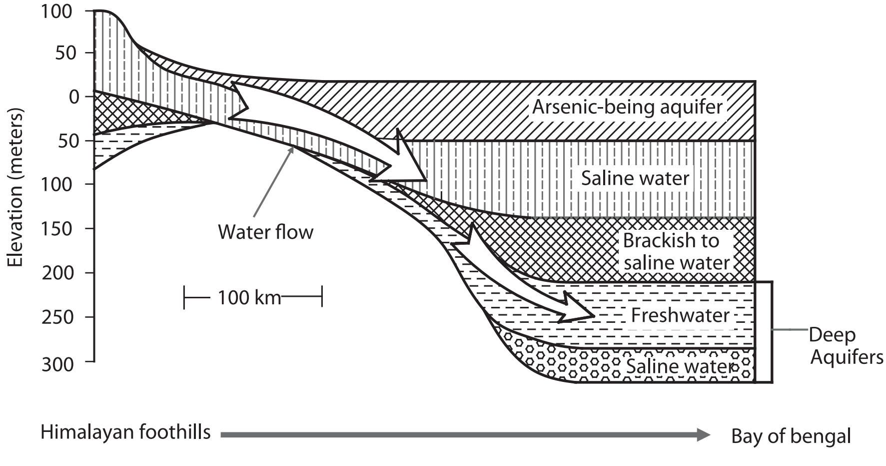

Figure 7.1: **North-South cut through Bangladesh delta (Chowdhury 2004)**

tubewells (29% of tested) is contaminated with arsenic exceeding the concentration of 50mg/L (Bangladesh standard for drinking water). It is also apparent from the DPHE–BGS–MML (1999) and BAMWSP (2001) studies that around 25% of their tested samples exceed the concentration of 50mg/L and 42% of tested samples exceed the concentration of 10 mg/L, the provisional World Health Organization (WHO) guideline value for arsenic in drinking water. The percentage of contaminated tubewells increases if only shallow tubewells are considered. Then 27% of tested samples exceed the concentration of 50mg/L and 46% of tested samples exceed the concentration of 10mg/L (Table 7.1).

Table 7.1: **Arsenic contamination situation in Bangladesh**

Total population (million) of the country in 2007 (est.)	150.5
Total area (sq. km.) of the country	147,570
Estimated total number of villages in country	87,319 (100)
Estimated total number of villages screened	54,041 (62)
Estimated total number of villages not screened	33,278 (38)
Total number (million) of tubewells in the country	8.61 (100)
Total number (million) of tubewells tested for As	4.73 (55)
Total number (million) of tubewells marked green (safe)	3.33 (39)
Total number (million) of tubewells marked red (unsafe)	1.4 (16) (29% of total tested tubewells)
Villages where less than 40% of the tibewells are contaminated	70,610 (81)
Villages where 40–80% of the tubewells are contaminated	8331 (10)
Villages where 80–99% of the tubewells are contaminated	6062 (7)
Villages where all tubewells are contaminated	2.316 (3)
As affected shallow tubewells above 0.05 mg/L	27%
As affected shallow tubewells above 0.01 mg/L	46%
As affected deep tubewells (strainer depth . 150 m) above 0.05 mg/L	1%
As affected deep tubewells above 0.01 mg/L	5%
Number of arsenicosis patients reported so far	38,000
Population (million) exposed to arsenic contamination . 0.05 mg/L	28.1–32.5 (22.4–25.9%)
Population (million) exposed to arsenic contamination .0.01 mg/L	46.4–56.7 (37–45.2%)

Source: Rahman and Al-Muyeed (2005)

At present several thousand people are suffering from arsenic-related diseases and millions are at risk of arsenic poisoning from drinking ground water with arsenic in excess of the acceptable limit. (DPHE 2001) furnish two estimates of population exposure based on the projected population of 125.5 million in 1999. The total population exposed to arsenic-contaminated water above 50 mg/L and 10mg/L is estimated as 32.5 million (25.9% of total population) and 56.7million (45.2%), respectively. Based on thana (precinct) statistics the total population exposed to arsenic-contaminated water above 50mg/L and 10mg/L is estimated as 28.1 million (22.4%) and 46.4 million (37%), respectively. The magnitude of the problem is increasing as more information becomes available (Rahman and Al-Muyeed 2005). Thus access to safe water is an urgent human need in Bangladesh to minimize the health hazards from arsenic poisoning. A number of treatment technologies exist that are capable of efficient removal of arsenic from water, but the socio-economic conditions that prevail in developing countries in general and Bangladesh in particular, do not permit the implementation of most of them on cost grounds. In most cases, except for a few cities and towns, there is no centralized water supply system. Individual households or small groups have their own or community tubewells. The solution to the problem of arsenic contamination in most situations in Bangladesh demands the development of technologies that can be implemented at the household or small community level at a relatively very low cost. Hence this paper is aimed at identifying the arsenic contamination problems of groundwater in Bangladesh and then an overview of treatment methods and technologies used for arsenic removal is presented. This chapter demonstrates the use of safe water supply options currently being practised in arsenic-affected areas of Bangladesh.

7.2 Causes of Arsenic Contamination

Intermittent incidents of arsenic contamination in groundwater can arise both naturally and industrially. The natural occurrence of arsenic in groundwater is directly related to the arsenic complexes present in soils. Arsenic can be liberated from these complexes under some circumstances. Since arsenic in soils is highly mobile, once it is liberated, it results in possible groundwater contamination. The alluvial and deltaic sediments containing pyrite has favored the arsenic contamination of groundwater in Bangladesh. Most regions of Bangladesh are composed of a vast thickness of alluvial and deltaic sediments, which can be divided into two major parts – the recent floodplain and the terrace areas. The floodplain and the sediments beneath them are only a few thousand years old. The terrace areas are better known as Madhupur and Barind Tracts and the sediments underlying them are much older than the adjacent floodplain. Most of the arsenic is occurring in the younger sediments derived from the Ganges Basin. The investigators found that there is a layer containing arsenic compounds at a depth of 20–80m. This layer is rich in arseno-pyrite, pyrite, iron sulfate and iron oxide, as revealed by geological investigations. The researchers also inferred that, although arsenic is occurring in the alluvial sediments, the ultimate origin of arsenic is perhaps in the outcrops of hard rocks higher up the Ganges catchment. These outcrops were weather-beaten in the recent geological past and then the eroded soil was deposited in West Bengal and Bangladesh by the ancient courses of the Ganges. Arsenic in sediment or water can move in the adsorbed phase with iron, which is available in plenty in the Himalayas. Here about 100–300 mg/kg arsenic combined with iron oxides can be found in the sediments under aerobic conditions. When these sediments were deposited in the Bengal Basin under a tidal environment, it came under anaerobic conditions. The sulfate available in the Bengal Basin was reduced to hydrogen sulfide in the presence of sulfur-reducing bacteria. Iron minerals and hydrogen sulfide rapidly bond together to form iron sulfide. Arsenic had been absorbed on the surface of the iron sulfide and produced arseno-pyrite. This mineral usually remains stable unless it is exposed to oxygen or nitrate. In the aerobic environment, arseno-pyrite is oxidized in the presence of oxygen and arsenic adsorbed by iron sulfide becomes mobilized. The groundwater in Bangladesh has declined progressively due to the excessive extraction of water for irrigation and domestic water supply, lack of water management and inadequate recharge of the aquifer. The groundwater declined beyond 8m in 12% of the area of Bangladesh in 1986. This extent rose to 20% of the area in 1992 and 25% in 1994. The study on forecasting groundwater level fluctuation in Bangladesh indicated that 54% of the area of Bangladesh is likely to be affected up to 20m in some areas, particularly in the northern part of the country (Safiuddin and Karim 2001). Excessive groundwater extraction may be the prime reason for creating a zone of aeration in clayey and peaty sediments containing arseno-pyrite. Under aerobic conditions, arseno-pyrite decomposes and releases arsenic that mobilizes into the subsurface water. The mobilization of arsenic is further enhanced by the compaction of aquifers caused by groundwater withdrawal.

7.3 Effects on Health

Arsenic is the twelfth most abundant element in the biosphere, and is said to be essential for some animal species. But any form of arsenic compound is not desirable for human consumption. The toxic effect of arsenic species mainly depends on their chemical form, route of entry, age, sex, dose and duration of exposure. The organic form of arsenic is several orders of magnitude less toxic compared to the inorganic form. Again, trivalent arsenic (As^{3+}, arsenite) species are approximately an order of magnitude more toxic compared to the pentavalent arsenic (As^{5+}, arsenate) species. The consumption of arsenic-contaminated food and drinking water is the main source of arsenic toxicity. Skin diseases are the common effects of arsenic poisoning. Long-term exposure to excessive arsenic generally causes changes in skin pigmentation and hyperkeratosis, and promotes the development of ulceration of the skin, skin cancer and a number of internal (liver, bladder, kidney, etc.) cancers. Around 38,000 arsenicosis patients (Table 7.1) have been reported in Bangladesh so far (APSU 2005). Using the EPA model and the distribution of population exposed to different levels of arsenic, Rahman and Al-Muyeed (2009) estimated the incidence of excess lifetime skin cancer for different levels of arsenic contamination of drinking water for the then total population of 129.25 million in Bangladesh. The incidences of excess skin cancer are 0.29%, 0.043% and 0.012% for drinking arsenic-contaminated water at existing levels of arsenic contamination, satisfying the Bangladesh standard (50mg/L) and satisfying the WHO guideline value (10mg/L), respectively.

7.4 Treatment of Arsenic Contaminated Water

Arsenic in groundwater is present mainly in non-ionic trivalent As (III) and ionic pentavalent As (V) inorganic forms in different proportions, depending on the environmental conditions of the aquifer. The solubility of arsenic in water is usually controlled by redox conditions, pH, biological activity and adsorption reactions. The reducing condition at low pH values converts arsenic into a more mobile As (III) form, whereas at high pH value As (V) is the major arsenic species. As (III) is more toxic than As (V) and is difficult to remove from water by most techniques. There are several methods available for the removal of arsenic from water in large conventional treatment plants. The most commonly used processes of arsenic removal from water have been described by (J.M.G, Lelyveld et al. 1981). A detailed review of arsenic removal technologies has been presented by Shrestha et. al. (2003) has documented several advances in arsenic removal technologies. In view of the lowering of the standard of the US Environmental Protection Agency (EPA) for the maximum permissible levels of arsenic in drinking water, a review of arsenic removal technologies was carried out to consider the economic factors involved in implementing more stringent drinking water standards for arsenic (Chen et al. 1999). Many of the arsenic removal technologies have been discussed in detail in the AWWA (American Water Works Association) reference book (Pontius 1990). A review of low-cost well water treatment technologies for arsenic removal, with a list of companies and organizations involved in arsenic removal technologies has been compiled by Murcott (2000). Comprehensive reviews of arsenic removal processes have been documented by Ahmed et al. (2001) and Johnston & Heijnen 2001. The AWWA conducted a comprehensive study on arsenic treatability options and evaluation of residuals management issues. Rahman et al. (2002) critically examined the arsenic crisis in Bangladesh and further extended examination was reviewed by (Rahman and Al-Muyeed 2005). The basic principles of arsenic removal from water are based on conventional techniques of oxidation, coprecipitation and adsorption on coagulated flocs, adsorption onto sorptive media, ion exchange and membrane filtration. Oxidation of As (III) to As (V) is needed for effective removal of arsenic from groundwater by most treatment methods. The most common arsenic removal technologies can be grouped into the following five categories:

- oxidation,
- coagulation, co-precipitation and adsorption,
- ion exchange,
- activated alumina,
- membrane.

The principal mechanisms and technologies for arsenic removal using the above technological options are described in detail in the following subsections.

7.4.1 Oxidation

Arsenic occurs in water in several different forms, depending upon the pH and oxidation potential of the water. Arsenite (As^{+3}) is difficult to remove from water using the usually available treatment processes. So, many treatment systems include an oxidation step to convert arsenite to arsenate (As^{+5}). The commonly used oxidants are chlorine, ozone, permanganate, hydrogen peroxide and oxygen. These chemicals are more effective under a wide range of conditions and air oxidation may take weeks to oxidize arsenite to arsenate. But oxidation alone does not remove arsenic from solution and should be combined with removal processes like coagulation, adsorption and ion exchange.

7.4.2 Coagulation, co-precipitation/ passive sedimentation, in situ oxidation, adsorption

Excellent arsenic removal is possible in coagulation and sedimentation/filtration processes either with ferric or aluminum salts if an oxidant is added. Alum coagulation is more effective at a pH of 7 or less, but iron precipitation is less sensitive to pH up to a value of 8.5 or less. (Cheng, Liang et al. 1994) reported 99% removal of arsenic in laboratory conditions in a coagulation process under optimal conditions, and a residual arsenic concentration of 1 mg/L. The best method to determine the types and dosages of chemicals for arsenic removal by coagulation/flocculation is to conduct site-specific testing. Arsenic in the coagulation process is removed through the following three main mechanisms (Edwards 1994):

- precipitation;
- co-precipitation and
- Adsorption.

A lime softening process can effectively remove arsenic at alkaline pH values of 11 or above. If an oxidant is added the efficiency of the process increases but removal efficiency is more sensitive to pH even with an oxidant. Kartinen & Martin (1995) reported 80% removal of arsenic at pH 10.5 or above but the removal efficiency was very low (about 15%) up to pH 10.5. When chlorine is added the removal efficiency increased to 95% at pH 11. A number of processes remove iron and/or manganese from water by oxidizing iron and/or manganese from their soluble state (Fe^{+2}) to a higher valance (Fe^{+3}) to form a precipitate. Then arsenic can be co-precipitated with the naturally occurring iron and/or manganese (passive sedimentation process). With the use of different chemicals, (Kartinen and Martin 1995) reported 90% removal of arsenic in this process. (Matthess 1981) reported in situ oxidation of iron and arsenic in an aquifer containing high ferrous iron, high arsenite and low pH, where 29 tons of potassium permanganate was injected directly into 17 contaminated wells. This yielded a reduction of arsenic concentrations from 13,600 mg/L to 60mg/L, where arsenite was oxidized and co-precipitated with ferric iron. (Rott and Friedle 1999) reported the use of atmospheric oxygen to reduce arsenic concentration in situ from approximately 20mg/L to 5mg/L, and this also lowered the iron and manganese levels.

7.4.3 Ion exchange

This is an adsorption process in which water passes through a column containing an ion exchange resin. Pre-treatment of these resins using sodium chloride creates an abundance of chloride on the exchange sites. When arsenic-containing water passes through this resin bed, the chloride ions are exchanged for the arsenic ions such that the water exiting the beds is lower in arsenic but higher in chloride than the water entering the bed. At exhaustion, the exchange site is loaded with arsenic, which can then be regenerated by passing concentrated sodium chloride solution through the column, usually in the opposite flow direction. In this process, sulphate ions compete with arsenic for the adsorption sites and therefore higher sulfate concentration in the feed water results in a shorter resin life. In low-sulfate waters, ion exchange resins can easily remove 95% of arsenate, and treat from several hundreds to over a thousand bed volumes before arsenic breakthrough occurs (Johnston and Heijnen 2001). Accordingly, US EPA recommends that ion exchange resins not be used in waters with. 120 mg/L sulfate or 500 mg/L total dissolved solids, and are more effective in waters with an even lower sulfate level of 25 mg/L. Arsenite, being uncharged, is not removed and therefore an oxidation step is needed as a precursor to arsenic removal.

7.4.4 Activated alumina

Activated alumina, a granular form of aluminum oxide (Al_2O_3), with very high specific surface area (about 200–300 m^2/g) could remove arsenic from water. The mechanisms of arsenic removal are similar to those of a weak base ion exchange resin, and often collectively referred to as 'adsorption', though ligand exchange and chemisorptions are more appropriate term. Arsenic removal efficiency is excellent (typically. 95%) for both arsenate and arsenite, but arsenic removal capacity varies significantly and is controlled by pH (Johnston and Heijnen 2001). Arsenate removal capacity is best in the narrow pH range from 5.5–6.0, where the alumina surfaces are protonated, but acid ions are not yet concentrated enough to compete with arsenic for sorption sites (Johnston and Heijnen 2001). Phosphate and fluoride are adsorbed by activated alumina and therefore their presence reduces the arsenic removal efficiency. Activated alumina can be regenerated by flushing with a solution of 4% sodium hydroxide, which displaces arsenic from the alumina surfaces (Johnston and Heijnen 2001).

7.4.5 Membrane

High-pressure synthetic membranes, such as nanofiltration (NF) and reverse osmosis (RO), have pore sizes appropriate for the removal of dissolved arsenic (both arsenite and arsenate), which is in the metal ion size range. According to (Waypa, Elimelech et al. 1997), the NF membrane tested performed well, comparably to the RO membranes, even though the operating pressure was much lower (40–120 psi, compared to 200–400 psi). Membrane filtration requires relatively high quality influent water. Colloids, particularly organics, iron and manganese can foul it. The main advantages of this technology are its minimal operation and maintenance requirements, chemicals are not required and it produces no extra sludge. The main disadvantages of this system are that this requires high pressure, it is costly and water recovery rates are very low, often 10–20%.

7.5 Arsenic Removal Technologies Practised In Bangladesh

A comprehensive review of low-cost well-water treatment technologies for arsenic removal with a list of companies and organizations involved in arsenic removal technologies is available in (Murcott 2000). Most of the documented experiences of arsenic removal technologies include largescale applications. In the context of the prevalence of high concentrations of arsenic in the groundwater in Bangladesh, several methods/technologies of treating water for arsenic reduction from drinking water have been tried by a number of organizations/researchers in Bangladesh to identify innovative technologies for arsenic removal in order to implement them in rural isolated communities. Most of these technologies are introduced on small experimental scales. A brief overview of some of these documented technologies is presented here.

7.5.1 Passive sedimentation

Arsenic has been found to co-exist with iron in a large part of Bangladesh (about 65% of the area) in excess of 2 mg/L and in many acute iron problem areas the concentration of iron is as high as 15 mg/L. In such situations, arsenic can be removed by both co-precipitation and adsorption onto the precipitated $Fe(OH)_3$ by oxidation of this water during collection and subsequently storing them at the household level. This process removed more than 60% arsenic, where raw groundwater arsenic and iron concentrations were in the range of

150–713 mg/L and 8–14 mg/L, respectively (Rahman and Al-Muyeed 2009). The rapid assessment of this technology in (BAMWSP 2001) showed that it failed to reduce arsenic to the desired Bangladesh standard in most cases.

7.5.2 In situ oxidation

In situ oxidation of iron and arsenic in the aquifer has been tested under the DPHE–Danida Arsenic Mitigation Pilot Project where the aerated tubewell water is stored in a tank and then the stored water is discharged into the aquifer through a tubewell pipe under the pumphead. Water collected by tubewell fromsuch aquifers, followed by in situ oxidation of iron and arsenic, showed about 50% removal of arsenic.

7.5.3 Solar oxidation

A transparent bottle containing water is exposed to sunlight for solar oxidation of arsenic in the presence of other oxidants, followed by precipitation of arsenic with naturally occurring iron. Experiments in Bangladesh showed that the process could lower the arsenic content of water to about one-third, and removal efficiency increased to about 45–78% when 50mL citrate or 100–200 mL (4–8 drops) of lemon juice/L is added (Shrestha, Shrestha et al. 2003).

7.5.4 Arsenic and iron removal plants (AIRPs)

In conventional small-community-type arsenic and iron removal plants (AIRPs) (Figure 7.2), groundwater drawn by hand tubewell drops into a storage (aeration/sedimentation) chamber for oxidation of iron and arsenic with air to coprecipitate. Water from the storage chamber passes through a filtration chamber due to the pressure head of the aeration/sedimentation chamber and subsequently is collected in a storage tank for public use. Filtration media used for AIRPs comprise of brick chips, charcoal and sand and is periodically (3–4 times a year) backwashed. The sludge is collected in a holding pond. Iron and arsenic removal efficiencies of these AIRPs operating in small communities are shown in Table 7.2. The average installation, operation and maintenance costs of a typical plant are presented in Table 7.4. It is evident from field surveys that these AIRPs are well accepted by their communities. The DPHE, with support from the Dutch Government, constructed three AIRPs for piped water supply systems in small municipalities, where arsenic co-exists with iron in groundwater. In these plants, groundwater is pumped over a series of cascades (Figure 7.3) to aerate the water and it then passes through a filtration unit, which

Figure 7.2: Typical Community Arsenic and Iron Removal Plant

removes iron and arsenic precipitates. Arsenic and iron removal efficiencies of 18-DTP (1999) AIRPs are shown in Table 7.3. The installation costs of the treatment unit and overhead tank are presented in Table 7.4.

7.5.5 Bucket treatment unit

The bucket treatment unit developed by the DPHE–Danida project consists of two buckets (about 20L capacities) placed one above the other. Chemicals (200 mg/L aluminium sulfate and 2 mg/L potassium permanganate) are mixed manually with arsenic-contaminated water in the upper bucket by vigorous stirring with a wooden stick for about 30–60 s and then flocculated by gentle

Table 7.2: Arsenic and Iron removal efficiencies in AIRPs

Location of AIRP plant	Influent Fe (mg/L)	Influent As (mg/L)	Fe removal efficiency (%)	As removal efficiency (%)	As in treated water (mg/L)
Manikgonj	15	540	95	90	54
Chadpur	8.9	808	92	84	129
Munshiganj	7.6	213	90	82	38
Barisal	10	456	92	80	91
Chadpur	7.6	260	84	78	57
Satkhira	6.6	188	87	77	43
Gopalganj	14	334	89	68	107
Chadpur	2.5	126	98	66	43

Source: Rahman and Al- Muyeed (2005)

Table 7.3: **Arsenic and iron removal efficiencies in 18-DTP AIRPs**

Municipality	Influent Fe (mg/L)	Influent As (mg/L)	Fe removal efficiency (%)	As removal efficiency (%)	As in treated water (mg/L)
Manikganj	7.6	85	99	72	24
Sathkhira Polash	5.8	68	95	67	22
Sathkhira Razzak	3.4	57	95	51	28

Table 7.4: **Installation, operation and maintenance costs of selected presently operating water supply options Rahman and Al- Muyeed (2005)**

Technological option	Unit cost (US$)	Population served	Installation cost (US$/person	Operation and maintenance cost (US$/person/yr)
Rainwater harvesting	106	5	21.2	.34
Dug well	560	120-150	4.0	.01
Manikgonj AIRP including overhead tank	223,534	60000	3.7	-
PSF	560	150-200	3.2	.04
Small-community type AIRP	140	40-50	3.1	.07
Deep tubewell	775	250-300	2.8	.05
Shrouded tubewell	175	100-120	1.4	.10
Shallow tubewell	105	120-150	.8	.06

Source: Rahman and Al- Muyeed (2005)

stirring for about 90 s. Mixed water is then allowed to settle for about 1–2 h and the top supernatant is allowed to flow into the lower bucket via a plastic pipe and sand filter installed in the lower bucket (Figure 7.4). Although this technology performs well (with arsenic removal efficiencies in the range of 67–83%), in some cases under rural operating conditions it fails to remove arsenic to the desired Bangladesh standard level. Further more, BUET has modified the system and used 100 mg/L of ferric chloride and 1.4 mg/L potassium permanganate, and it performs very well with arsenic removal efficiency up to 94% (Rahman et al. 2003).

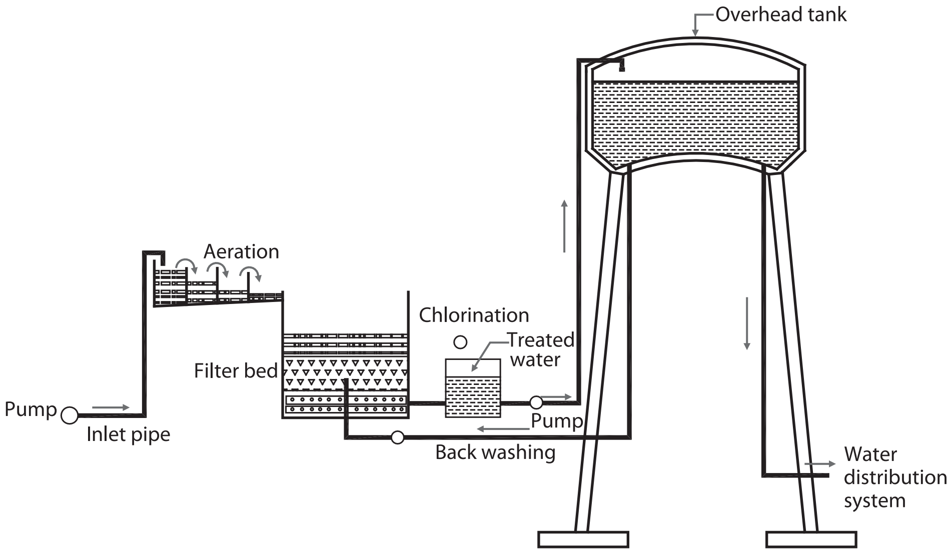

Figure 7.3: **18-DTP arsenic and iron removal plant**

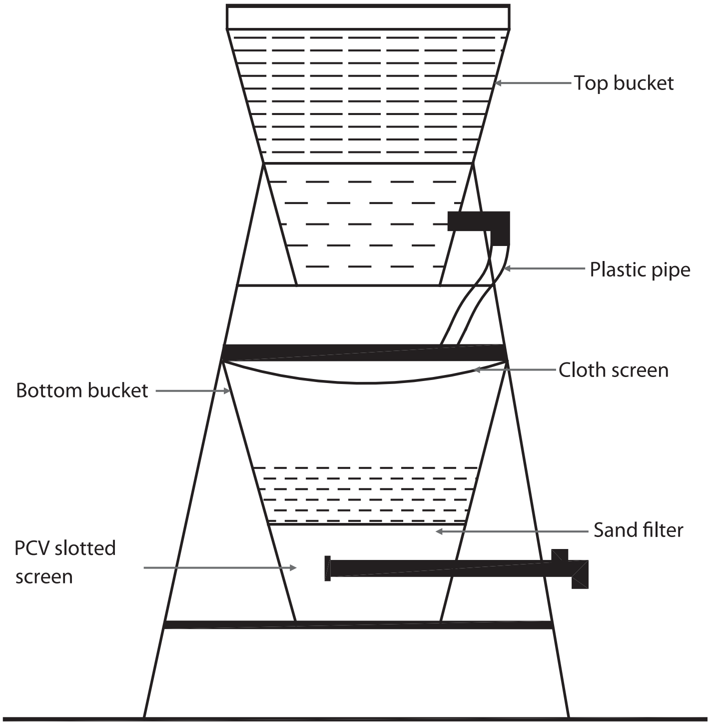

Figure 7.4: **Double bucket household unit**

7.5.6 Steven institute technology

Supplied chemicals (reported to be iron sulfate and calcium hypochloride) in packets are mixed in one bucket and the mixture is transferred to another bucket (Figure 7.5) to separate flocs by the processes of sedimentation andfiltration. The rapid assessment of this technology by BAMWSP, DFID & WaterAid (2001) showed that this technology was effective in reducing arsenic levels to less than 50mg/L in the case of 80–95% of the samples tested. But the sand bed used for filtration is quickly clogged and requires washing at least twice a week.

7.5.7 Sono/ pitcher filter

The Sono 3-pitchers (Kolshi) filter uses zero-valent iron filling and coarse sand in the top pitcher, and charcoal and fine sand in the middle pitcher (Figure 7.6). The bottom pitcher is used to store the treated water. The arsenic removal efficiencies of this system are in the range of 59–95% but it depends on the maintenance of the system and the quality of influent water. But if batches are left for too long, dissolved iron concentrations become unacceptably high (Ramswami, Isleyen et al. 2000). The rapid assessment of this technology by (BAMWSP 2001) showed that this technology was effective in removing arsenic, but the system may quickly be clogged if groundwater contains excessive iron. Recently some NGOs are taking more initiatives to popularize this system in arsenic affected areas. The applicability of these arsenic removal units should be determined through close field monitoring.

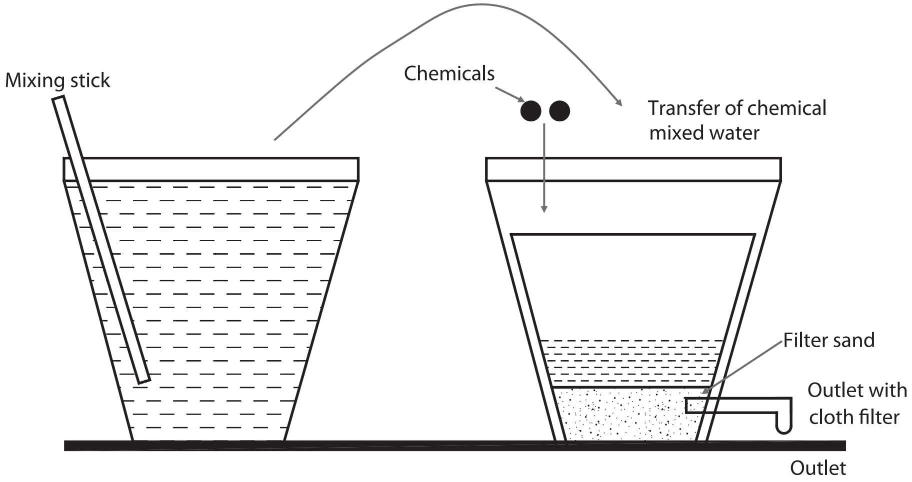

Figure 7.5: Stevens Institute Technology.

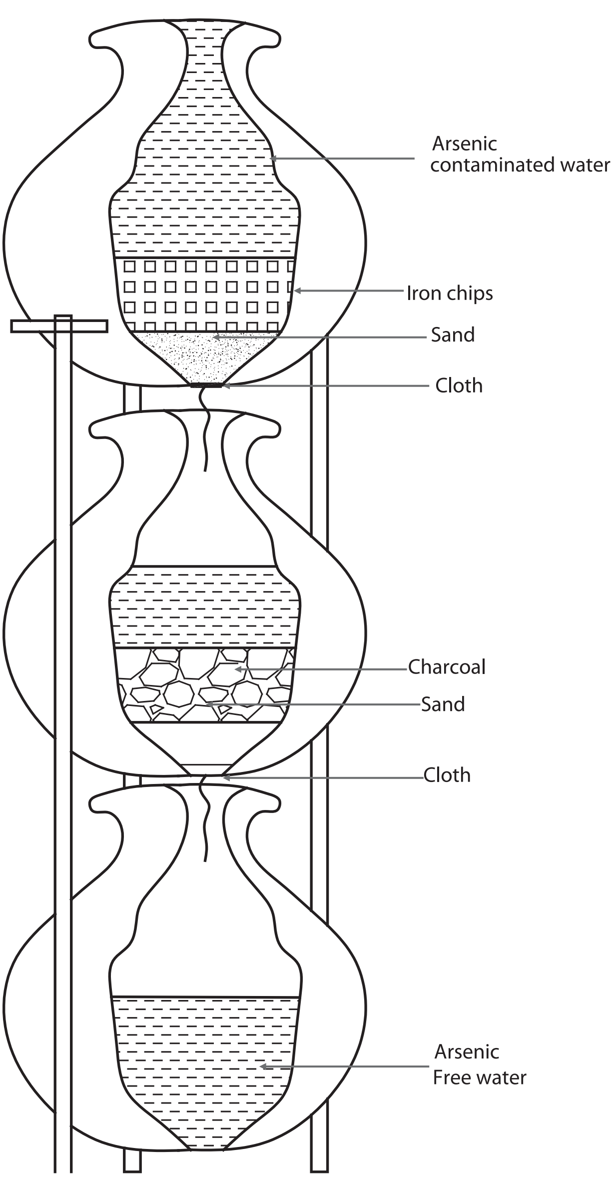

Figure 7.6: **Three-pitcher filter (Chowdhury 2004).**

7.5.8 Activated alumina

Arsenic is removed by sorptive filtration through activated alumina. Some units use pretreatment (for example, oxidation, sand filtration) to increase efficiency.

The Alcan enhanced activated alumina unit is simple and robust in design. No chemicals are added during treatment and the process relies wholly on the active surface of the media for adsorption of arsenic from water. Other ions present in natural water, such as iron and phosphate, may compete for active sites on alumina and reduce the arsenic removal capacity of the unit. Iron present in shallow tubewell water at elevated levels will eventually accumulate in an activated alumina bed and interfere with the flow of water through the bed. This unit can produce more than 3,600 L of arsenic-safe drinking water per day for 100 families. Apyron Technologies Inc. (USA) has developed an arsenic treatment unit in which its Aqua-BindY medium is used for arsenic removal from groundwater. Aqua-Bind contains activated alumina and manganese oxides that can selectively remove As(III) and As (V). The BUET-activated alumina units have oxidation and prefiltration provisions prior to filtration through activated alumina.

7.5.9 Read–F arsenic removal unit

Read-F is an adsorbent produced and promoted by a company (Shin Nihon Salt Co. Ltd./Nihon Kaisui Co. Ltd, Japan), which efficiently adsorbs arsenic (both arsenate and arsenate).

7.5.10 Granular ferric hydroxide

Granular ferric hydroxide (Adsorp As) is a highly effective adsorbentusedfor the adsorptive removal of arsenate, arsenite and phosphate from natural water. It has an adsorption capacity of 45 g/kg for arsenic and 16 g/kg for phosphorus ona dry weight basis. M/S Pal Trockner (P) Ltd, India, and Sidko Limited, Bangladesh, have installed several granular ferric hydroxide-based arsenic removal units in India and Bangladesh. The proponents of the unit claim that Adsorp As has a very high arsenic removal capacity and produces relativelysmall amounts of residual spentmedia.The typical residual mass of spent Adsorp As is in the range of 5–25 g/m^3 of treated water. The typical arrangement of the Sidko/Pal Trockner unit (Figure 7.7) requires aeration for the oxidation of water and prefiltration for the removal of iron flocs before filtration through the activemedia.Chemicon and Associates has developed and marketed an arsenic removal plant based on adsorption technology in which crystalline ferric oxide is used as an adsorbent. The unit has a prefiltration unit containing manganese oxide for oxidation of As(III) to As(V) and retention of iron precipitates.

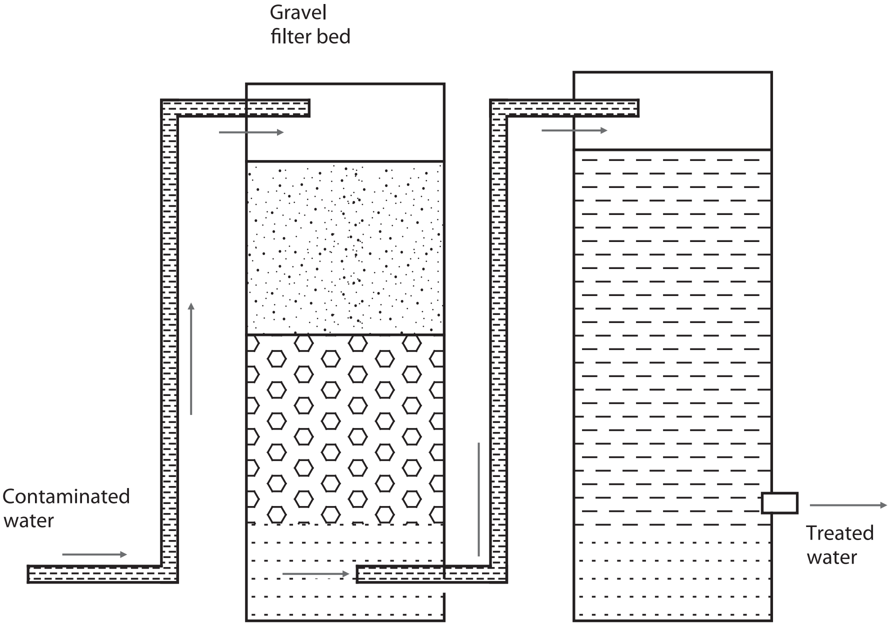

Figure 7.7: Granular ferric hydroxide unit

7.5.11 Ion exchange

The Tetrahedron, Inc. (Tretratreat) ion exchange resin filter tested under the rapid assessment program in Bangladesh (BAMWSP 2001) showed promising results in arsenic removal. The performance and applicability of these arsenic removal units (Figure 7.8) should be determined through close field monitoring.

7.5.12 DPHE-Danida fill and draw unit

The fill and draw system is a community-level treatment unit designed and installed under the DPHE–Danida Project. It has a 600 L capacity (effective) tank with a slightly tapered bottom for collection and withdrawal of settled sludge (Figure 7.9). The tank is fitted with a manually operated mixer with flat blade impellers. The tank is filled with arsenic contaminated water and the required quantities of oxidant and coagulant are added to the water. The water is then mixed for 30 s by rotating the mixing device at a rate of 60 revolutions per minute (rpm) and left overnight for sedimentation. The settled water is then drawn through a pipe fitted at a level a few inches above the bottom of the tank

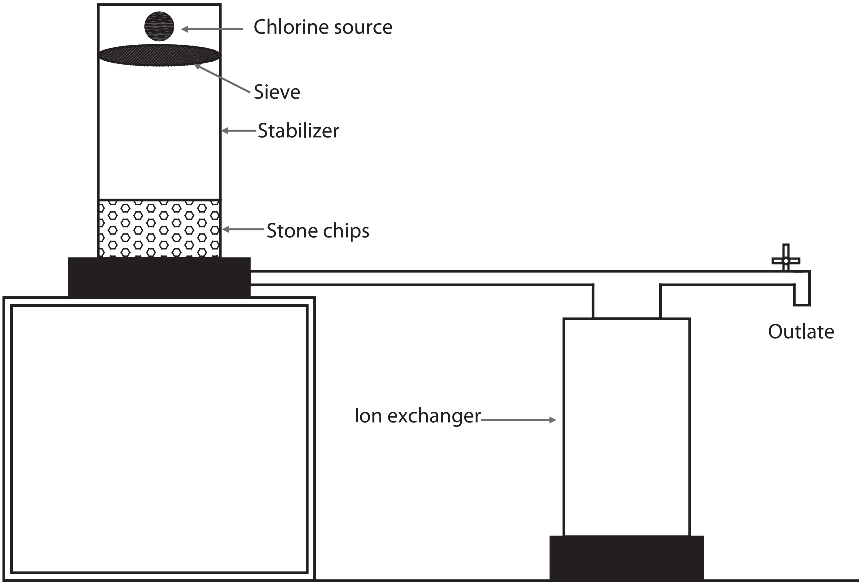

Figure 7.8: Tetrahedron unit

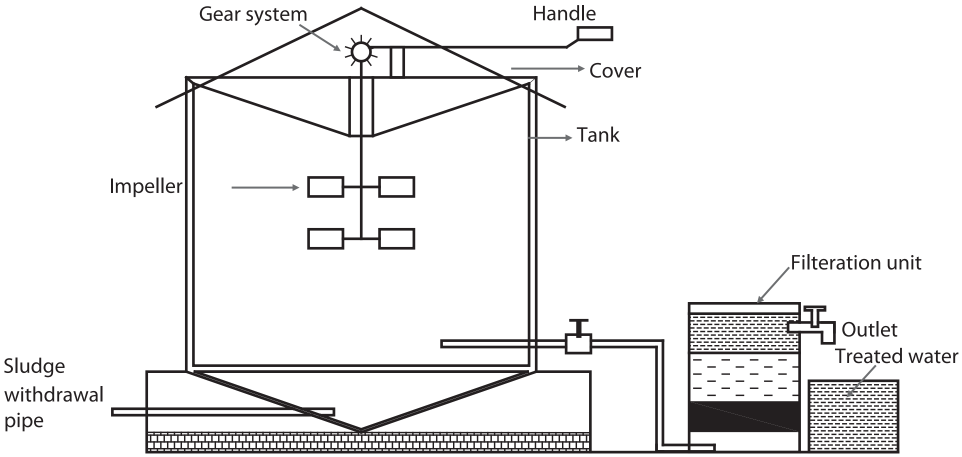

Figure 7.9: DPHE–Danida fill and draw unit

and passed through a sand bed, and is finally collected through a tap for drinking. The mixing and flocculation processes in this unit are better controlled to effect higher removal of arsenic. The experimental units installed by the DPHE–Danida Project are serving clusters of families and educational institutions.

7.5.13 Membrane technique

Wide spectrum reverse osmosis systems include Reid System Limited as well as MRT-1000 manufactured by B & T Science Co. Ltd., Taiwan is promoted in Bangladesh. A nanofiltration process coupled with a bicycle pumping system was examined by (Oh, Yamamoto et al. 2000b) using arsenic-contaminated tubewell water in a rural area of Bangladesh. Arsenite was found to have a lower removal rate than arsenate in ionized form. But the capital and operational costs of these systems are relatively high.

7.5.14 Other arsenic removal technologies

To mitigate arsenic contamination problems in Bangladesh, a number of organizations and industries have been trying to develop indigenous arsenic removal systems and chemicals including:

- Bangladesh Council of Scientific and Industrial Research (BCSIR) filter unit,
- Sapla filter,
- Shafi filter,
- Granet home-made filter,
- Adarsha filter,
- Bijoypur clay filter,
- several cartridge filters,
- iron coated sand,
- tourmaline mineral, etc.

The performance and applicability of these arsenic removal units and chemicals should be determined through close field monitoring. The Government of Bangladesh established environmental technology verification for arsenic mitigation (ETVAM) with assistance from CIDA. They evaluated five technologies, and out of them Alkan, Sono-3-Kolshi, Read-F and SIDKO received provisional verification certificates. The second phase of the verification task has been started with the aim to verify 7–10 more technologies currently used in use in Bangladesh (APSU 2005). The performance of all the above mentioned mitigation technologies of arsenic critically depend on the cost incurred by the local population. Table 7.5 shows a comparison of arsenic removal mechanisms and costs in Bangladesh.

7.6 Comparison of Arsenic Removal Technologies in Bangladesh

As has been mentioned in the earlier section, in Bangladesh many technologically sound methods have been adopted by users. The relative advantages and disadvantages of different arsenic removal processes are compared, where it is evident that even membrane nanofiltration technology may give the highest removal efficiency of arsenic, but it is imperative to consider the cost, especially for developing country like Bangladesh. The comparison of arsenic removal mechanisms considering cost is presented in Table 7.5 (WorldBank 2008). Since the removal of arsenic primarily depends on the initial concentration of arsenic in water, the term 'removal efficiency' represents the reducing arsenic concentration at 0.05 mg/L or less than of this concentration from the sources which has more than 0.05 mg/L concentration of arsenic.

Table 7.5: Comparison of arsenic removal mechanisms and costs in Bangladesh

Type of unit	Removal mechanism	Type	Capital cost/ unit (US$)	Operation and maintenance costs/ family/year (US$)
Arsenic removal unit for urban water supply	Aeration, sedimentation, rapid filtration	Urban water supply (6000 households	240000	1-1.5
Iron-arsenic removal plant	Aeration, sedimentation, rapid filtration	Community (10 households)	200	1
Fill and draw	Oxidation and coagulation-sedimentationfiltration	Household	250	15
Bucket treatment unit	Oxidation and coagulation sedimentationfiltration	Household	6-8	25
Sono 45–25	Adsorption by oxidized iron chips and sand	Household	13	.05-1.5
Shapla filter	Adsorption of iron-coated brick chips	Household	4	11

Source: WorldBank 2008

7.7 Conclusion

Bangladesh is the worst affected country in the world in terms of global arsenic contamination in groundwater. Contaminated drinking water has posed severe health problems in rural Bangladesh. The provision of arsenic free water is urgently needed now to mitigate arsenic toxicity and to protect health. This chapter describes an overview on arsenic mitigation technologies developed and practiced in Bangladesh. Alternative sources of safe water and treatment of arsenic contaminated groundwater are also addressed. It discusses the conventional technologies for arsenic removal including some technologies that utilize indigenous materials for arsenic removal. It also discusses the best available techniques and offers cost comparisons among these techniques. Technical and economic viability, and indigenous capacity, in association with ultra sensitivity, is the essence of successful implementation of arsenic mitigation technology. For all technologies, hygiene education is essential to risk management. Importantly, community-based management is needed to operate and maintain the water sources efficiently in rural Bangladesh.

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