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Article abstract

The scale of arsenic toxicity of the groundwater in Bangladesh is greater than any environmental debacle in the history of human civilization. The main route of arsenic accumulation in the human body is the ingestion of arsenic tainted water. Because of the undetectable nature of arsenic poisoning at the early stage and lack of awareness due to mass illiteracy, poverty and malnutrition, arsenic related ailments may cause death. However, this paper mainly discusses arsenic mitigation measures in Bangladesh. Although a piped surface water supply after treatment is the absolute solution to get rid of this crisis, the weak economic background of Bangladesh does not support supplying such water to every corner of rural areas. Hence research groups have developed their own methods to suit the local environment, using locally available materials and approaches based on the common method of arsenic removal: use of oxidizing agents, followed by flocculation and precipitation. Again, among different alternative water supply options, deep tubewells, which have been used by the communities in Bangladesh during the past few decades, appear to be a more suitable alternate option. Moreover, household-based arsenic filters can be a good choice if proper maintenance can be done.



ARSENIC MITIGATION MEASURES IN BANGLADESH

Mesures d'atténuation de l'arsenic au Bangladesh

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ABSTRACT

The scale of arsenic toxicity of the groundwater in Bangladesh is greater than any environmental debacle in the history of human civilization. The main route of arsenic accumulation in the human body is the ingestion of arsenic tainted water. Because of the undetectable nature of arsenic poisoning at the early stage and lack of awareness due to mass illiteracy, poverty and malnutrition, arsenic related ailments may cause death. However, this paper mainly discusses arsenic mitigation measures in Bangladesh. Although a piped surface water supply after treatment is the absolute solution to get rid of this crisis, the weak economic background of Bangladesh does not support supplying such water to every corner of rural areas. Hence research groups have developed their own methods to suit the local environment, using locally available materials and approaches based on the common method of arsenic removal: use of oxidizing agents, followed by flocculation and precipitation. Again, among different alternative water supply options, deep tubewells, which have been used by the communities in Bangladesh during the past few decades, appear to be a more suitable alternate option. Moreover, household-based arsenic filters can be a good choice if proper maintenance can be done.

Keywords: *arsenic; Bangladesh; contamination; catastrophe; mitigation.*

RÉSUMÉ

L'accroissement du problème de toxicité causé par l'arsenic au Bangladesh constitue une catastrophe environnementale majeure dans l'histoire de l'humanité. La principale voie d'accumulation de l'arsenic dans le corps humain est l'ingestion d'eau polluée par ce contaminant. La nature indétectable de l'empoisonnement à l'arsenic dans les premières étapes, l'insuffisance d'avertissement attribuable à l'analphabétisme, ainsi qu'à la pauvreté et la malnutrition, font en sorte que l'empoisonnement progressif à l'arsenic peut causer la mort. Le présent article discute toutefois les mesures d'atténuation envisagées au Bangladesh. Ainsi, bien que l'alimentation dans des conduites avec de l'eau de surface traitée représente la solution idéale pour résoudre cette crise, l'état économique précaire du Bangladesh ne permet pas d'alimenter en eau de surface traitée toutes les populations des zones rurales. De là, des groupes de recherche ont développé des méthodes spécifiques à l'environnement local en utilisant des matériaux disponibles sur place et basées sur une méthode établie d'enlèvement de l'arsenic : en utilisant des agents oxydants suivi par la flocculation et la précipitation. Parmi les différentes alternatives d'alimentation en eau explorées, la technique de puits profonds, laquelle a été utilisée par les communautés au Bangladesh durant les décennies passées, apparaît être l'option la plus appropriée. De plus, l'emploi d'unités de filtration dans

les résidences peut être un bon choix, dans les cas où celles-ci sont entretenues adéquatement.

Mots-clés : *arsenic, Bangladesh, contamination, catastrophe, atténuation*

1. INTRODUCTION

Prior to the 1970s, contaminated surface water caused unbridled diarrhoeal disease all over Bangladesh; this primarily affected children aged one to four and was prevented by installing tubewells that tapped into pathogen-free aquifers as an alternate source (OPAR *et al.*, 2007). It has been estimated that 95% or more of the population in Bangladesh use groundwater for drinking purpose and there are about four million tubewells which extract this water (ANSTISS *et al.*, 2001). However, in 1993, the Department of Public Health Engineering (DPHE), Bangladesh first detected arsenic contamination in groundwater which added a new dimension to its existing plethora of natural calamities, such as floods and cyclones (HASSAN *et al.*, 2003). This hazard affects between 28 and 57 million people, which is considered as the largest mass poisoning of a population in history (ATKINS *et al.*, 2007), even greater than any environmental disaster seen before, including the accidents at Bhopal, India in 1984 and Chernobyl, Ukraine in 1986 (HASSAN *et al.*, 2003). A recent report states that arsenic contaminated tubewell water is contributing to nearly 125,000 cases of skin cancer and killing 3,000 in Bangladesh each year and the mortality rate is expected to be elevated in the near future (PAUL, 2004). The latest information reveals that in 61 out of 64 districts, tubewells are producing water with arsenic higher than the national standard (HOSSAIN *et al.*, 2005) (Figure 1). While the provisional guideline for drinking water is $10 \mu\text{g}\cdot\text{L}^{-1}$, the national standard value in Bangladesh is five times higher, $50 \mu\text{g}\cdot\text{L}^{-1}$ (HOSSAIN, 2006). Though arsenic contamination has affected the largest population in Bangladesh, arsenic concentrations significantly higher than in drinking water standards have been found in groundwaters from large parts of Argentina, Chile, Taiwan, Inner Mongolia, Western USA and West Bengal in India (HOQUE *et al.*, 2000). It is reported that about six million people of 2,600 villages in 74 arsenic-affected blocks of West Bengal, India are in risk while 8,500 (9.8%) out of 86,000 people examined are suffering from arsenicosis (MANDAL and SUZUKI, 2002). Again, about 25 million people of 2,000 villages in 178 arsenic-affected blocks of Bangladesh are in danger and 3,695 (20.6%) out of 17,896 people have arsenic related ailments (MANDAL and SUZUKI, 2002). The magnitude of this problem is severe in Bangladesh followed by West Bengal, India and China (RAHMAN *et al.*, 2005). Hence it can be said that arsenic poisoning is not only a local but also a global issue. However,

as the worst case of arsenic contamination, the study of the Bangladesh situation is significant.

In order to mitigate the arsenic crisis in Bangladesh, several measures are undertaken such as treatment of arsenic contaminated water, alternate water supply options and some strategic measures. Despite having a number of treatment technologies for arsenic removal, most of them are not cost efficient for a developing country like Bangladesh. In most cases, except for a few cities and towns, there is no centralized water supply system. Hence a relatively low cost and efficient technology is needed at the household or small community level. Thus this paper emphasizes how to diminish this arsenic catastrophe in Bangladesh.

2. ARSENIC HAZARDS IN BANGLADESH

2.1 Sources and causes of arsenic contamination in Bangladesh

Arsenic is ubiquitous in the environment. It occurs in both solid and liquid phases, exhibits both metallic and non-metallic properties and cannot be found in nature in its native state (TRAIN, 1979, cited in HOSSAIN, 2006). In Bangladesh, arsenopyrite (FeAsS) has been identified as the prime source of arsenic pollution (HOSSAIN, 2006). Chemically, arsenic exists as organic and inorganic species. Inorganic arsenic has two main oxidation states, i.e., trivalent [arsenite, As(III)] and pentavalent [arsenate, As(V)]. Inorganic forms of arsenic dissolved in drinking water are the most significant forms involved in natural exposure and it is noteworthy that arsenite is sixty fold more toxic than arsenate (HOSSAIN, 2006). Several anthropogenic sources of potential arsenic contamination in Bangladesh are excessive use of groundwater, indiscriminate use of sub-standard agrochemicals, diversion of surface water from the river Ganges by India, the use of arsenic compounds and disposal of industrial wastes (PAUL, 2004). However, the two principal hypotheses about the genesis of arsenic in groundwater are pyrite oxidation and oxy-hydroxide reduction.

2.1.1 Pyrite oxidation hypothesis

Arsenic is assumed to be present in certain sulphide minerals (pyrites) that are deposited within aquifer sediments at a depth of 20-100 m by the major rivers of Bangladesh and India (PAUL, 2004). Due to overexploitation of groundwater, the underground water drops, creating a gap which is consequently filled by atmospheric oxygen (PAUL and DE, 2000). The inflow of oxygen and pressure from tubewell water help in breaking down sulphide in the arsenic-laden pyrite rock into fine particles which are further dissolved in groundwater (PAUL, 2004). Moreover, seasonal fluctuation of the water table also results in the rapid and regular intake of oxygen

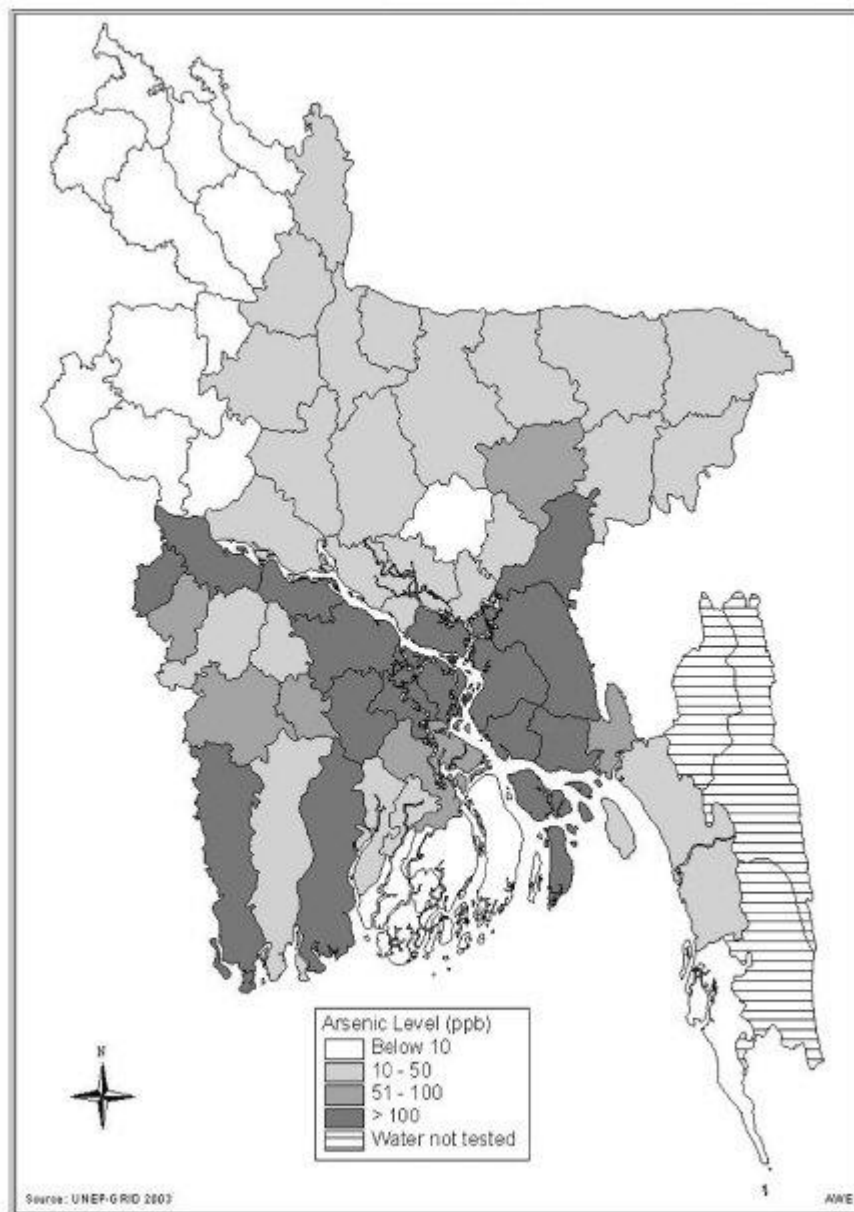


Figure 1. Extent of arsenic concentration in groundwater in Bangladesh by districts (PAUL, 2004, p. 1744).

Niveau de concentration en arsenic dans les eaux souterraines des districts du Bangladesh (PAUL, 2004, p. 1744).

(PAUL and DE, 2000). In accordance with this assumption, the origin of As-rich groundwater can be considered man-made and would be a recent phenomenon (HOSSAIN, 2006).

2.1.2 Oxy-hydroxide reduction hypothesis

According to this hypothesis, the origin of As-rich groundwater is due to a natural process (HOSSAIN, 2006). This implies no relationship with the excessive groundwater withdrawal. Arsenic is assumed to be present in alluvial sediments, concentrated in sand grains with coatings of iron hydroxide under anoxic conditions (KARIM, 2000). These sediments were eroded from the Himalayas and deposited in the Bengal Basin (PAUL, 2004). Organic matter deposited with the sediments reduces arsenic bearing iron hydroxide and

this would lead arsenic to leach into aquifer water (HOSSAIN, 2006). Moreover, reduction of iron hydroxide is further enhanced in this scenario by bacterial activity (PAUL, 2004).

While the British Geological Survey (BGS) and the Bangladesh Department of Public Health Engineering (DPHE) accepted the oxy-hydroxide reduction hypothesis as the plausible cause of groundwater contamination in Bangladesh, rejecting the other hypothesis is, other researchers argue that the oxy-hydroxide reduction hypothesis is not dependable enough to make any conclusion (PAUL, 2004). Therefore, it can be stated that the exact reason of arsenic contamination in Bangladesh is still unconfirmed.

2.2 Food chain aspects of arsenic contamination in Bangladesh

Rice (*Oryza sativa* L.) is the most important cereal grown in Bangladesh, nearly two-thirds of total domestic cereal production (ALAM *et al.*, 2002). Moreover, rice is the major staple food of Bangladesh with a *per capita* consumption of about 150 kg per year, accounting for roughly 73% of calorific intake (ALAM *et al.*, 2002). Depending on local climate and soil conditions, typically three rice crops are grown: *aus* (planted in March/April and harvested in June/July); *aman* (planted in June/July and harvested in November/December); and *boro* (planted in December/January and harvested in April). Both *aus* and *aman* are largely rainfed, while *boro* is mostly irrigated. The country's agricultural production and food security heavily depend on groundwater irrigation during the dry season (SAHA and ALI, 2007). Hence the use of this arsenic contaminated groundwater enhances the possibility of arsenic uptake into crop plants. In a study by RAHMAN *et al.* (2008), it was found that arsenic concentration in rice grains is $0.5 \pm 0.02 \text{ mg}\cdot\text{kg}^{-1}$ with the highest concentrations being in grains grown on soil with $40 \text{ mg As}\cdot\text{kg}^{-1}$ soil. Thus with the average rice consumption being between 400 and $650 \text{ g}\cdot\text{d}^{-1}$ by typical adults in the arsenic-affected areas of Bangladesh, the intake of arsenic through rice stands at $0.20\text{--}0.35 \text{ mg}\cdot\text{d}^{-1}$ while with a daily consumption of 4 litre drinking water, arsenic intake through drinking water stands at $0.2 \text{ mg}\cdot\text{d}^{-1}$ (RAHMAN *et al.*, 2008). Similarly, a study was carried out in West Bengal, India. A significant increase of As concentration was registered in the stems of the rice plants irrigated with As-rich groundwater ($6.55\text{--}7.06$, relative to $0.36 \text{ mg}\cdot\text{kg}^{-1}$ As in the reference plant) (NORRA *et al.*, 2005). Arsenic concentrations in the uppermost soil layers of the rice paddy field ($38 \text{ mg}\cdot\text{kg}^{-1}$) were found to be more than five times higher than in the soil of a rice paddy irrigated with uncontaminated water ($7 \text{ mg}\cdot\text{kg}^{-1}$) (NORRA *et al.*, 2005). Indeed, the higher the arsenic in groundwater, the higher the arsenic in agricultural land soil and plants is observed (ROYCHOWDHURY *et al.*, 2005). A study in Murshidabad district, West Bengal showed that approximately 3.1–13.1, 0.54–4.08 and 0.36–3.45% of arsenic was taken up by the root, stem and leaf respectively, from the soil (ROYCHOWDHURY *et al.*, 2005). Hence arsenic poisoning through rice can no longer be regarded as less significant than that through ingestion of water. Moreover, it is observed from another study by BAE *et al.* (2002) that the concentration of arsenic in cooked rice is higher than that in raw rice and absorbed water combined, suggesting a chelating effect by rice grains, or concentration of arsenic because of water evaporation during cooking, or both. In West Bengal, a median lifetime cancer risk from cooked rice of 7.62×10^{-4} , as calculated for the population in Chakdaha block, is higher than the 10^{-4} - 10^{-6} range typically used by the USEPA as a threshold to guide determination of regulatory values. Furthermore, Bangladesh is blessed with more than 90 vegetables and 60 fruits (ALAM *et al.*, 2003). A study was carried out in Madartola, Bangladesh

and arsenic concentrations in cabbage, cauliflower, mustard and radish were found to be $5.8 \text{ mg}\cdot\text{kg}^{-1}$, $2.6 \text{ mg}\cdot\text{kg}^{-1}$, $2.3 \text{ mg}\cdot\text{kg}^{-1}$, $2.4 \text{ mg}\cdot\text{kg}^{-1}$ respectively while the mean groundwater and soil arsenic concentrations were $156.4 \mu\text{g}\cdot\text{L}^{-1}$ and $3.9 \text{ mg}\cdot\text{kg}^{-1}$ respectively (BARI *et al.*, 2008). Likewise, an investigation of total arsenic in food composites, collected from the villagers, was carried out in arsenic-affected areas of the Murshidabad district, West Bengal where the agricultural system is mostly groundwater dependent (ROYCHOWDHURY *et al.*, 2002). The results revealed that the individual food composite and food groups containing the highest mean arsenic concentrations ($\text{mg}\cdot\text{kg}^{-1}$) are potato skin (293 and 104), leaf of vegetables (212 and 295), arum leaf (331 and 341), papaya (197 and 373), rice (226 and 245), wheat (7 and 362), cumin (48 and 210), turmeric powder (297 and 281), cereals and bakery goods (156 and 294), vegetables (92 and 123), spices (92 and 208) and miscellaneous items (138 and 138) for the Jalangi and Domkal blocks, respectively. Humans can also be poisoned through meat as cattle drink a considerable amount of water and eat straw, husk and plants. Interestingly, another argument is that there appears to be little chance of animals to be poisoned by consuming arsenic contaminated plants because plant injury occurs before toxic concentrations can appear (HOSSAIN, 2006). Nevertheless, the possibility to accumulate arsenic in the human body through food chain pathways cannot be neglected.

2.3 Arsenic induced health hazards

Arsenic is a silent killer. Undetectable at the early stages, arsenic poisoning takes between 8 and 14 years before the manifestation of noticeable symptoms, depending on the amount of arsenic ingestion, nutritional status and immune response of the individual (ALAM *et al.*, 2002). There are four recognized stages of chronic arsenic poisoning (Table 1). In the first or pre-clinical stage, patients show no symptoms but arsenic can be detected in urine or body tissue samples (PAUL and DE, 2000). In the clinical stage, effects are visible on the skin (Figure 2). A more serious symptom is keratosis (Figure 3), a hardening of the skin into nodules, often palms and soles, which may gradually lead to a gangrenous ulcers and has the potential of turning into skin cancer (PAUL and DE, 2000). In the third stage, manifestations become more pronounced and the internal organs are affected (PAUL, 2004). In the final stage, arsenic poisoning may result in gangrene of the distal organs, skin cancer and kidney and liver failure (HADI and PARVEEN, 2004). However, the major portion of absorbed arsenic in the human body is excreted through urine (about 50 percent) and a small portion is absorbed through the face, skin and nails and firmly bound to keratin (PAUL and DE, 2000). A study was conducted in the affected villages of Jalangi block, West Bengal by analyzing a total of 1,600 biological samples including hair, nail and

Table 1. Stages of chronic arsenic poisoning (PAUL and DE, 2000, p. 802).
Tableau 1. Étapes de l'empoisonnement chronique à l'arsenic (PAUL et DE, 2000, p. 802).

Stage	Symptom	Length of exposure (in years)
I	Shows no symptoms	1-5
II	Darkening of skin on palms; dark spot on the body (Spotted melanosis), keratosis, and gangrenous ulcer	5-10
III	Enlargement of liver, kidneys, and spleen; gastrointestinal, neurological, cardiovascular, and respiratory disorders	10-15
IV	Skin, lung or bladder cancer	10-20



Figure 2. Arsenic-induced skin pigmentation (HORE *et al.*, 2007, p. 144).
Pigmentation de la peau induite par l'arsenic (HORE et al., 2007, p. 144).



Figure 3. Keratosis (sole) of a man (HORE *et al.*, 2007, p. 144).
Keratose chez un homme (HORE et al., 2007, p. 144).

urine (RAHMAN *et al.*, 2005). They found that an average 88% of the biological samples contain arsenic above the normal level. Though chronic arsenic poisoning is manifested primarily in skin lesions, it can induce health problems such as melanosis, leukomelanosis, hyperkeratosis, cardiovascular disease, hepatomegaly, neuropathy, diabetes mellitus, adverse pregnancy outcomes, impaired child development, hypertension, respiratory problems and cancer (CHEN *et al.*, 2007a; CHEN *et al.*, 2007b; HADI and PARVEEN, 2004; MILTON *et al.*, 2001; ROSSMAN *et al.*, 2004). Moreover, a study reports that presence of arsenic during DNA synthesis can induce chromosomal aberrations, sister chromatid exchanges and malsegregation of chromosomes (NATARAJAN *et al.*, 1996, cited in KARIM, 2000). Arsenic even appears to act as a new class of endocrine disruptor. According to ALAM *et al.* (2002), arsenic selectively disrupts the ability of the hormone, glucocorticoid receptor (GR) (controls a wide range of biological processes) in exposed cells to regulate the expression of its target genes in the nucleus, with the highest arsenite dose causing more than 50% suppression in Dex-inducible expression. Furthermore, adverse pregnancy outcomes in terms of spontaneous abortion, stillbirth, and preterm birth rates are significantly higher in women of reproductive age (15-49 years) exposed to arsenic contamination (AHMAD *et al.*, 2001). Additionally, there is a chance for the infant to be infected with arsenic through mother's milk. WATANABE *et al.* (2003) conducted a study in North-Western Bangladesh. They collected 25 milk samples: among these, seven samples contained a measurable amount of arsenic (in this particular set of samples, the detection limit of arsenic was as high as $12 \text{ ng}\cdot\text{mL}^{-1}$), up to $38 \text{ ng}\cdot\text{mL}^{-1}$. These high arsenic concentrations in the breast milk were found among the mothers having higher arsenic concentration (approximately $>150 \text{ ng As}\cdot\text{mg}^{-1}$ creatinine). Therefore, it can be concluded that arsenic enters the human body without any symptom and may even result in death.

2.4 Social implications

Arsenic has resulted in numerous tragic social complications. Because of illiteracy and inadequate information, local people confuse the arsenic related skin manifestations with leprosy, which they consider as a contagious killer. Thus those who have early symptoms of arsenicosis do not disclose them to others to avoid certain ostracism (ALAM *et al.*, 2002). Even within the family, they are kept isolated. Moreover, in poor rural households, the adult female is generally undernourished and most vulnerable (ALAM *et al.*, 2002). When the husband discovers symptoms of arsenicosis in her body, he refuses to keep her under the same roof or simply sends her back to her parents for treatment (PAUL and DE, 2000). It has been observed that the divorce rate is high in the areas of elevated arsenic (PAUL and DE, 2000). A divorcee with a fatal disease

is often considered as a social burden. On the other hand, it was also discovered that middle-aged, poor males are more vulnerable to arsenicosis than their wives and children (HADI and PARVEEN, 2004). Indeed, it may take several years before arsenic toxicity results in signs and symptoms and most of the males are involved in physical activity and generally consume more fluid than females; moreover, rich people are known to consume more nutritious food than poor people (HADI and PARVEEN, 2004). This indicates that poor rural people are more vulnerable to arsenic-contaminated water than rich and urban people. Furthermore, in villages, parents find it difficult to get their afflicted daughters married (HASSAN *et al.*, 2005). Affected children may be barred from attending schools and avoided by friends and classmates. Additionally, employers may refuse that arsenic-affected patients continue their job. Thus being disappointed by losing the jobs, they become hopeless and helpless (ALAM *et al.*, 2002). There is evidence that these persons are socially boycotted. For example, it is observed from a study by HASSAN *et al.* (2005) that one tubewell holder is reported to have said to an arsenicosis patient "Don't disrupt us, sink a new tubewell for yourself and tap your water from there". Hence it can be said that poor rural people are more exposed to arsenic contamination and these arsenicosis patients are neglected, not even receiving the minimum sympathy from anybody in the society.

3. ARSENIC MITIGATION MEASURES

In order to drink arsenic free-water, currently several drinking water options are available in Bangladesh. These can be divided into two categories: (i) treatment of arsenic-contaminated water to reduce its arsenic content to acceptable levels, and (ii) the provision of arsenic-free drinking water from sources other than the tubewells (MILTON *et al.*, 2007). In addition to this, there are some strategic measures to mitigate this hazard.

3.1 Treatment of arsenic-contaminated water

3.1.1 Adsorption

Adsorption is a mass transfer operation in which substances present in a liquid phase are adsorbed or accumulated on a solid phase and thus removed from the liquid (CRITTENDEN *et al.*, 2005). Among several granular adsorptive filter media, activated alumina is very efficient, even in comparison with activated carbon, and it can be regenerated *in situ* to extend its useful life (MOHAN and PITTMAN, 2007). However, sorption efficiency is highest only at low pH and arsenites must be pre-oxidized to arsenates before adsorption (MOHAN and PITTMAN, 2007).

3.1.2 Coagulation

Ferric chloride salt ($\text{FeCl}_3 \cdot 6 \text{H}_2\text{O}$) and alum ($\text{AlSO}_4 \cdot 24 \text{H}_2\text{O}$) are the most studied and widely used flocculants in water treatment due to their low price, ready availability and low risk (KHAN *et al.*, 2002). Before adding coagulant, an oxidation step is performed by the addition of chemical reagents such as potassium permanganate, chlorine, ozone, hydrogen peroxide, or manganese oxide (AMIN *et al.*, 2006). At pH 7 and for a $100 \text{ mg} \cdot \text{L}^{-1}$ to $125 \text{ mg} \cdot \text{L}^{-1}$ dose of alum, the removal efficiency of arsenic and iron is around 82 to 86% and 92 to 95% respectively and the optimum removal of arsenic and iron is around 90 to 93% and 97 to 100% respectively at pH 7 for a $200 \text{ mg} \cdot \text{L}^{-1}$ of ferric chloride salt (KHAN *et al.*, 2002).

3.1.3 Ion exchange

In this process, arsenic-contaminated water passes through an anion exchange resin bed. Chloride ions are exchanged for the arsenic ions, so that the water exiting the bed can be lower in arsenic but higher in chloride than the water entering the bed (RAHMAN and AL-MUYEED, 2009). However, ion exchange does not remove arsenite [As(III)] because it occurs predominantly as an uncharged species (H_3AsO_3) in water with a pH value of less than 9.0 (PETRUSEVSKI *et al.*, 2007). The predominant species of As (V), H_2AsO_4^- and $\text{HA}_2\text{O}_4^{2-}$, are negatively charged, and thus are removable by ion exchange (PETRUSEVSKI *et al.*, 2007). If arsenite is present, it must be oxidised to arsenate before removal (PETRUSEVSKI *et al.*, 2007).

3.1.4 Membrane

Reverse osmosis (RO) and nano-filtration (NF) membrane processes have an excellent removal efficiency of arsenic; RO especially can obtain over 95% arsenic removal efficiency (SHIH, 2005). However, traditional RO and NF membrane technologies consume more energy (SHIH, 2005) and produce a larger volume of residuals and thus tend to be more expensive than other arsenic treatment technologies (PETRUSEVSKI *et al.*, 2007).

3.2 Arsenic removal technologies in Bangladesh

3.2.1 Arsenic and iron removal plants (AIRPs)

In conventional small community type arsenic and iron removal plants (AIRPs) (Figure 4), groundwater drawn by hand from tubewell drops into a storage (aeration / sedimentation) chamber for oxidation of iron and arsenic with air to co-precipitate them (RAHMAN and AL-MUYEED, 2009). Water from the storage chamber passes through a filtration chamber (composed of brick chips, charcoal and sands) due to the pressure head of aeration / sedimentation chamber and is subsequently collected into a storage tank for public

use (RAHMAN and AL-MUYEED, 2009). Iron and arsenic removal efficiencies of these AIRPs are 84-98% and 66-90% respectively (RAHMAN and AL-MUYEED, 2009). It is evident from a field survey that these AIRPs are well accepted by the communities (RAHMAN and AL-MUYEED, 2009). The Bangladesh DPHE, with support from the Dutch Government, constructed three AIRPs for piped water supply in small municipalities where arsenic co-exists with iron in groundwater. In these plants, groundwater is pumped over a series of cascades (see Figure 6) to aerate water, then passes through a filtration unit, which removes iron and arsenic precipitates (RAHMAN and AL-MUYEED, 2009).

3.2.2 Bucket treatment unit

In a modified bucket treatment unit, chemicals ($100 \text{ mg} \cdot \text{L}^{-1}$ of ferric chloride and $1.4 \text{ mg} \cdot \text{L}^{-1}$ of potassium permanganate) are mixed manually with arsenic contaminated water in one bucket by vigorous stirring with a wooden stick for about 30-60 seconds and then flocculation by gentle stirring is undertaken for about 90 seconds (RAHMAN *et al.*, 2003). Mixed water is further allowed to settle for about 1-2 hours and the top supernatant is allowed to flow into the lower bucket via a plastic pipe. A sand filter is installed in the lower bucket (Figure 5) (RAHMAN *et al.*, 2003). This process removes arsenic up to 94% (RAHMAN *et al.*, 2003).

3.2.3 Three pitcher filter

In a three-pitcher filter (Figure 6), the top pitcher contains coarse sand, locally collected iron chips and grade-A red brick chips; the middle pitcher contains grade-A red brick chips, charcoal and fine sand (MILTON *et al.*, 2007). Tubewell water is poured slowly into the top pitcher and the filtered water, with reduced arsenic levels, is collected in the bottom pitcher. In this filter, arsenic is mainly removed by the process of adsorption onto the sand and zero-valent iron chips (MILTON *et al.*, 2007). Arsenic removal technologies such as three-pitcher filters are an effective option as a short-term measure but are not an effective option for a year if not maintained properly (MILTON *et al.*, 2007). Recently the three-pitcher filter has been substantially modified as the "Sono filter" (MILTON *et al.*, 2007).

3.2.4 Steven Institute technology

One packet of reagent (reported to be iron sulfate and calcium hypochloride) is mixed with arsenic contaminated water in one bucket and the mixture is transferred to another bucket (Figure 7) to separate flocs by the processes of sedimentation and filtration (RAHMAN and AL-MUYEED, 2009). This technology was effective in reducing arsenic levels to less than $50 \mu\text{g} \cdot \text{L}^{-1}$ in 80% to 95% of the samples tested. However, the sand bed used for filtration is quickly clogged and requires backwashing at least twice a week (RAHMAN and AL-MUYEED, 2009).

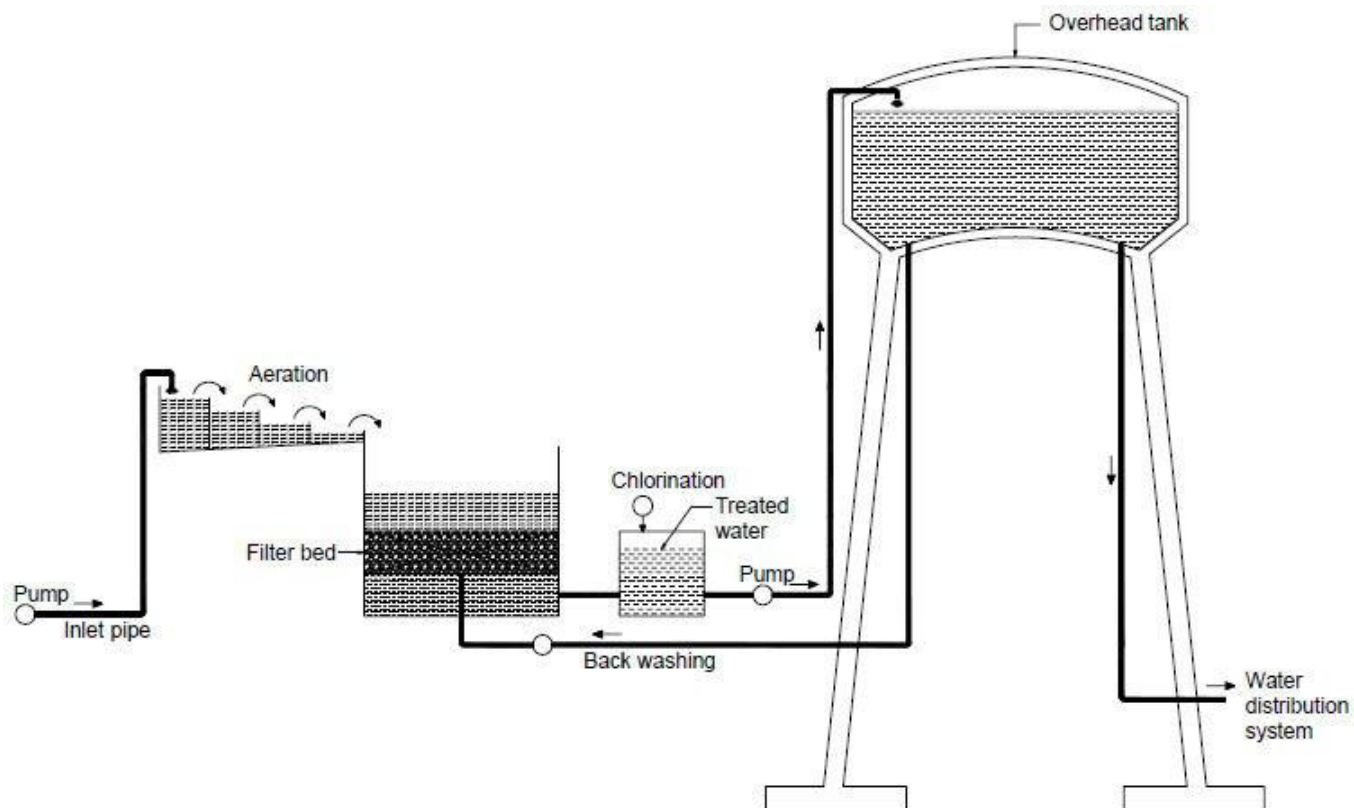


Figure 4. Arsenic and iron removal plant (RAHMAN and AL-MUYEED, 2009, p. 235).
Usine d'enlèvement de l'arsenic et du fer (RAHMAN et AL-MUYEED, 2009, p. 235).

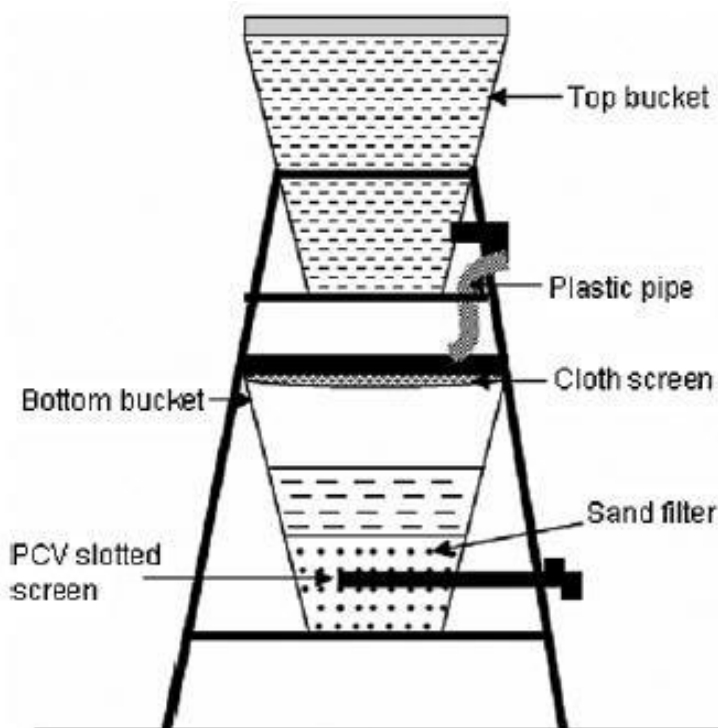


Figure 5. Double bucket unit (RAHMAN and AL-MUYEED, 2009, p. 36).
Unité à double compartiments (RAHMAN et AL-MUYEED, 2009, p. 236).

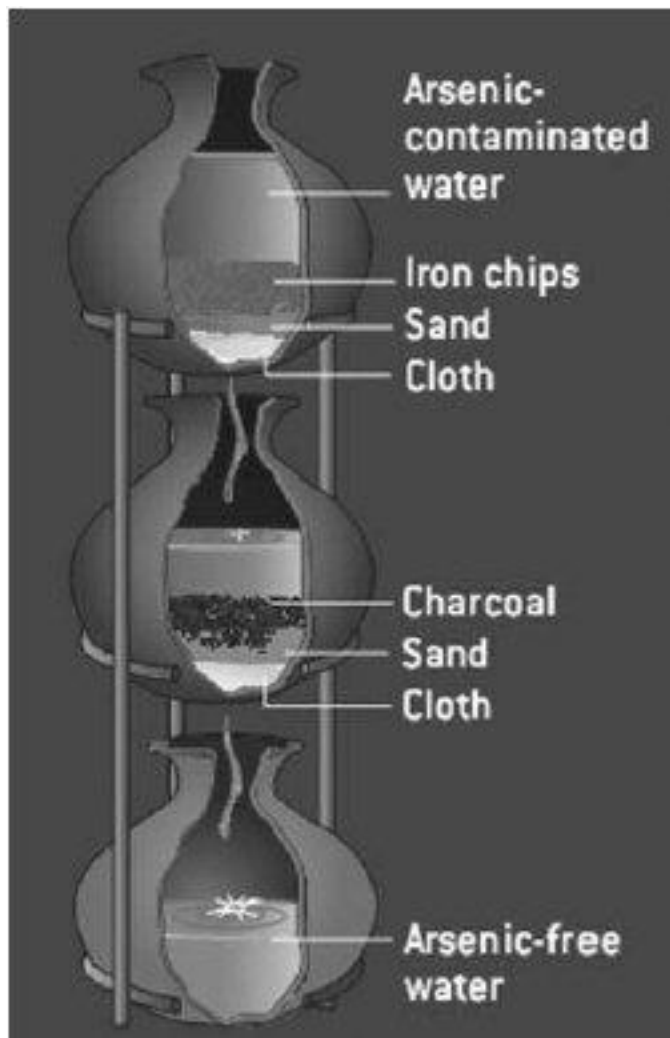


Figure 6. Three pitchers system (CHOWDHURY, 2004, p. 91).
 Système à trois compartiments (CHOWDHURY, 2004, p 91).

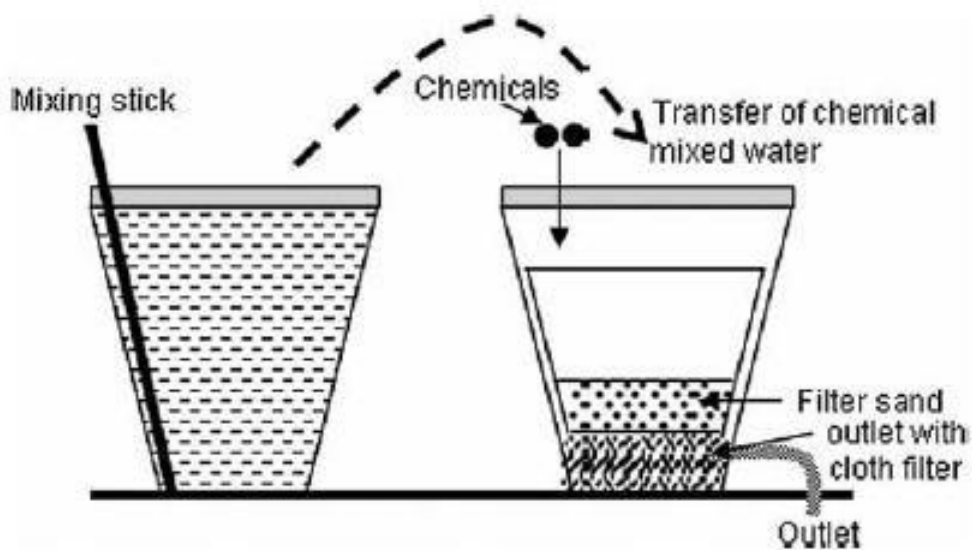


Figure 7. Steven technology (RAHMAN and AL-MUYEED, 2009, p. 236).
 Technologie de Steven (RAHMAN et AL-MUYEED, 2009, p. 236).

3.2.5 DPHE-Danida fill and draw unit

This is a tank having an effective capacity of 600 litres with a slightly tapered bottom for collection and withdrawal of settled sludge (Figure 8) (RAHMAN and AL-MUYEED, 2009). The tank is filled with arsenic contaminated water and the required quantities of oxidant and coagulant are added to water which is further mixed for 30 seconds by a propeller at the rate of 60 revolutions per minute and left overnight for sedimentation (RAHMAN and AL-MUYEED, 2009). The sludge is withdrawn and the settled water is collected through a tap.

3.2.6 GARNET home made filter (GHM)

This consists of two containers one after another, each filled with brick chips, sand layers of more than six inches depth separated by a synthetic cloth (HOQUE *et al.*, 2000). Its removal efficiency is 90-100% up to about 1.0 mg•L⁻¹ of arsenic content and the bacteriological quality is acceptable (HOQUE *et al.*, 2000).

3.2.7 Other arsenic removal technologies

A number of organizations and industries have been trying to develop indigenous arsenic removal systems and chemicals. These include the Bangladesh Council of Scientific and Industrial Research (BCSIR) Filter Unit, Sapla Filter, Shafi Filter, Adarsha Filter, Bijoypur Clay Filter, several cartridge filters, Iron coated sand, Tourmaline mineral, and others (RAHMAN and AL-MUYEED, 2009). Besides these, granular ferric hydroxide, passive sedimentation, *in situ* oxidation, solar oxidation, read-F removal unit, activated alumina, ion exchange and membrane techniques are also available (RAHMAN and AL-MUYEED, 2009).

3.3 Alternative water supply options

3.3.1 Deep tubewells

The aquifers in Bangladesh are stratified and the deep aquifers are separated from the shallow ones by impermeable layers. Thus arsenic free groundwater is found in the deep

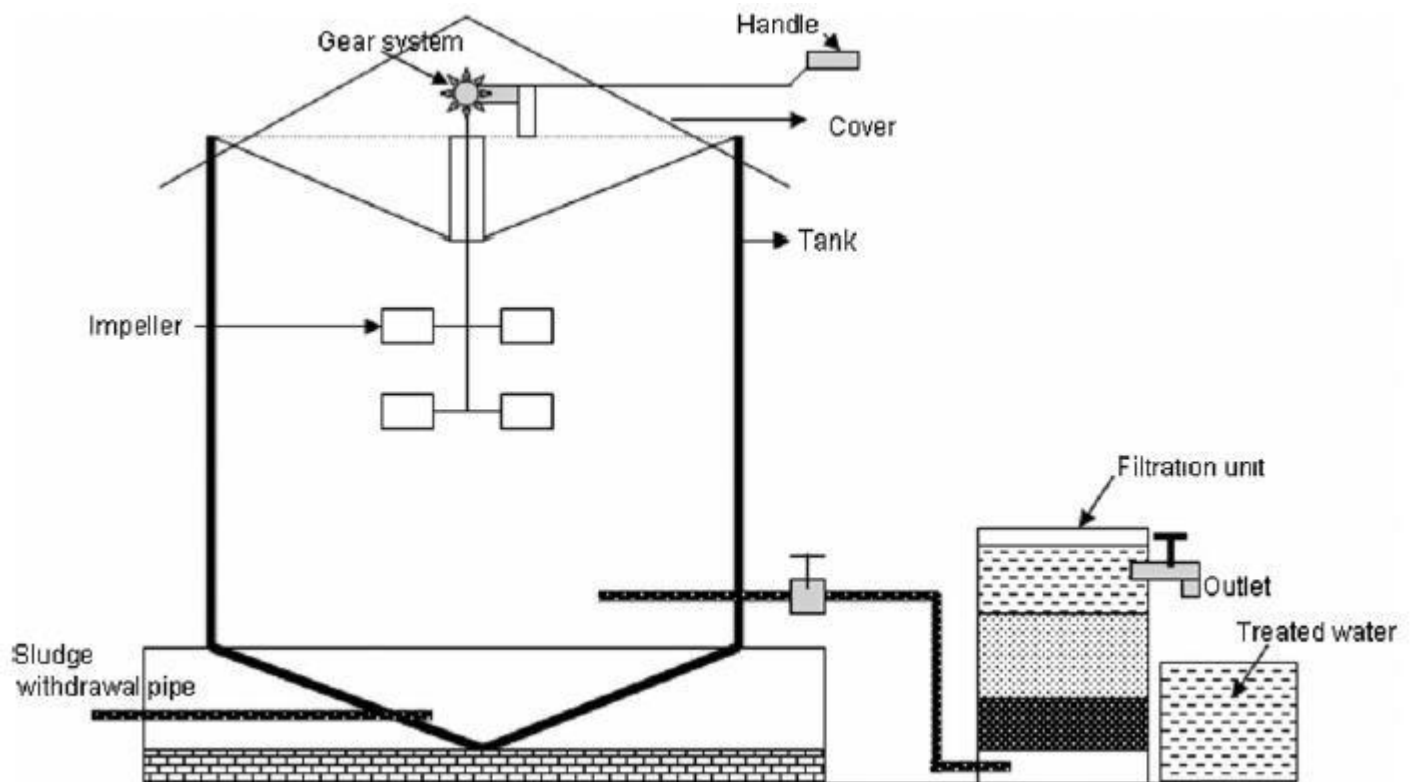


Figure 8. DPHE-Danida fill and draw unit (RAHMAN and AL-MUYEED, 2009, p. 238).

Unité de soutirage et remplissage DPHE-Danida (RAHMAN et AL-MUYEED, 2009, p. 238).

aquifers with the exception of a very few places in the North-Western region (RAHMAN and AL-MUYEED, 2009). It is found that approximately 70% of shallow hand-pumped tubewells (HTWs) comply with the Bangladesh national limit for drinking water ($50 \text{ mg}\cdot\text{L}^{-1}$) whereas less than 1% of deep tubewells (DTWs) exceed the $50 \text{ mg}\cdot\text{L}^{-1}$ As limit (BURGESS *et al.*, 2007). However, DWTs are expensive to drill in comparison with HTWs.

3.3.2 Shallow and very shallow shrouded tubewell

In many areas of Bangladesh, groundwater with low arsenic content is available in shallow or very shallow aquifers composed of fine sand (RAHMAN and AL-MUYEED, 2009). The particle sizes of the soil are not suitable for installing a normal tubewell. Thus to get water through these very fine-grained aquifers, an artificial sand packing around the screen of the tubewell is required, which is called shrouding (Figure 9) (RAHMAN and AL-MUYEED, 2009). Shrouding increases the yield of the tubewell and prevents entry of fine sand into the screen (RAHMAN and AL-MUYEED, 2009).

3.3.3 Infiltration gallery

In this process water is allowed to infiltrate through a layer of soil or sand in order to get water free of suspended impurities including microorganisms (RAHMAN and AL-MUYEED, 2009). This infrastructure is constructed near perennial surface water sources (RAHMAN and AL-MUYEED, 2009). However, it requires disinfection by chlorination before the water can be used (RAHMAN and AL-MUYEED, 2009).

3.3.4 Dugwell

Dugwell (Figure 10) is the most traditional method of withdrawal of groundwater in Bangladesh. Arsenic contamination level is rarely observed above the standard (HOQUE *et al.*, 2000). Drawbacks are insufficient water (KABIR and HOWARD, 2007), unacceptable bacteriological contamination and highly unacceptable water for drinking purposes (HOQUE *et al.*, 2000). However, when a handpump is installed on a covered dugwell and regular chlorination at an acceptable level is maintained, bacteriological quality is improved, though there are complaints about the chlorine smell immediately after chlorination (HOQUE *et al.*, 2000).

3.3.5 Pond sand filters

Ponds are available all over the country and pond sand filters (PSF) (Figure 11) are used as a water supply system to purify water from ponds (YOKOTA *et al.*, 2001). They produce a good quality of water (YOKOTA *et al.*, 2001) and their acceptance is high in absence of other safe options within the neighbourhood (HOQUE *et al.*, 2000). However, acceptable bacteriological quality of the water is only achieved with regular and timely maintenance (HOQUE *et al.*, 2000). Though the quality of water varies with seasons, it can be

improved by further addition of bleaching powder (HOQUE *et al.*, 2000).

3.3.6 Conventional surface water treatment:

Surface water is normally free of arsenic. If treated surface water can be distributed among arsenic-affected communities, it will be highly appreciated. However, the drawback is that it requires a very high initial investment.

3.3.7 Solar disinfection (SODIS) in plastic bottles

Pond and dugwell water can be disinfected by solar radiation in plastic bottles. Unfortunately, people do not appreciate this disinfection workload on a daily basis in small amounts (HOQUE *et al.*, 2000). However, experiments in Bangladesh showed that this process could reduce the arsenic content of water to about one-third. Removal efficiency can be increased by about 45-78% when $50 \mu\text{L}$ citrate or $100\text{-}200 \mu\text{L}$ (4-8 drops) of lemon juice per litre is added (RAHMAN, 2003).

3.3.8 Rainwater harvesting

Rainwater harvesting can be an alternate option in arsenic-affected areas in Bangladesh. The quality of water is almost acceptable and this system can be easily maintained at the home level (HOQUE *et al.*, 2000). However, the shortcomings are: quantity is limited by rainfall and the storage system is expensive.

The performance of all these treatment measures is compared in Table 2.

3.4 Strategic measures of arsenic mitigation

3.4.1 Awareness/Education

Arsenic contamination is largely a natural phenomenon and no preventive measures can usually be taken. Communities become helpless when an arsenic problem breaks out. Hence awareness by the people regarding arsenic contamination of groundwater, associated health effects, symptoms, possible places to seek help, and alternative sources of safe water needs to be ensured. Mass media such as radio, television, popular local media, like folk theatre in rural areas and separate local meetings for women and men, can play an important role in disseminating the awareness message to every person every corner of the country. Once people are convinced that the affliction is spreading through contaminated drinking water and can be countered by switching to arsenic-free water, the next step is to familiarize them with sharing arsenic-free sources, arsenic removal at the household level and community-based removal systems.

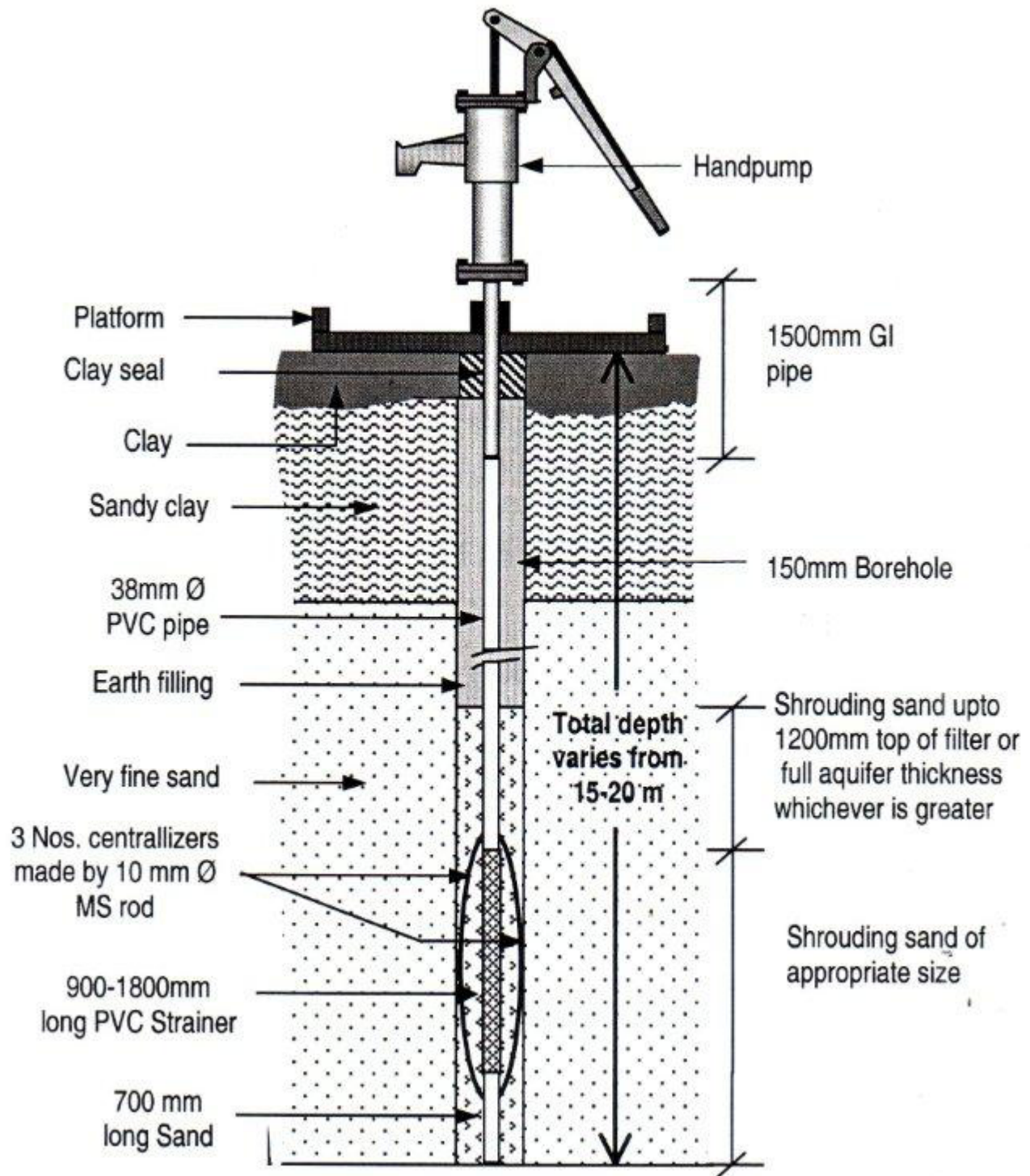


Figure 9. Shallow and very shallow shrouded tubewell (AHMED and RAHMAN, 2000, p. 426).
Puits tubulaires enveloppés peu profonds (AHMED et RAHMAN, 2000, p. 426).

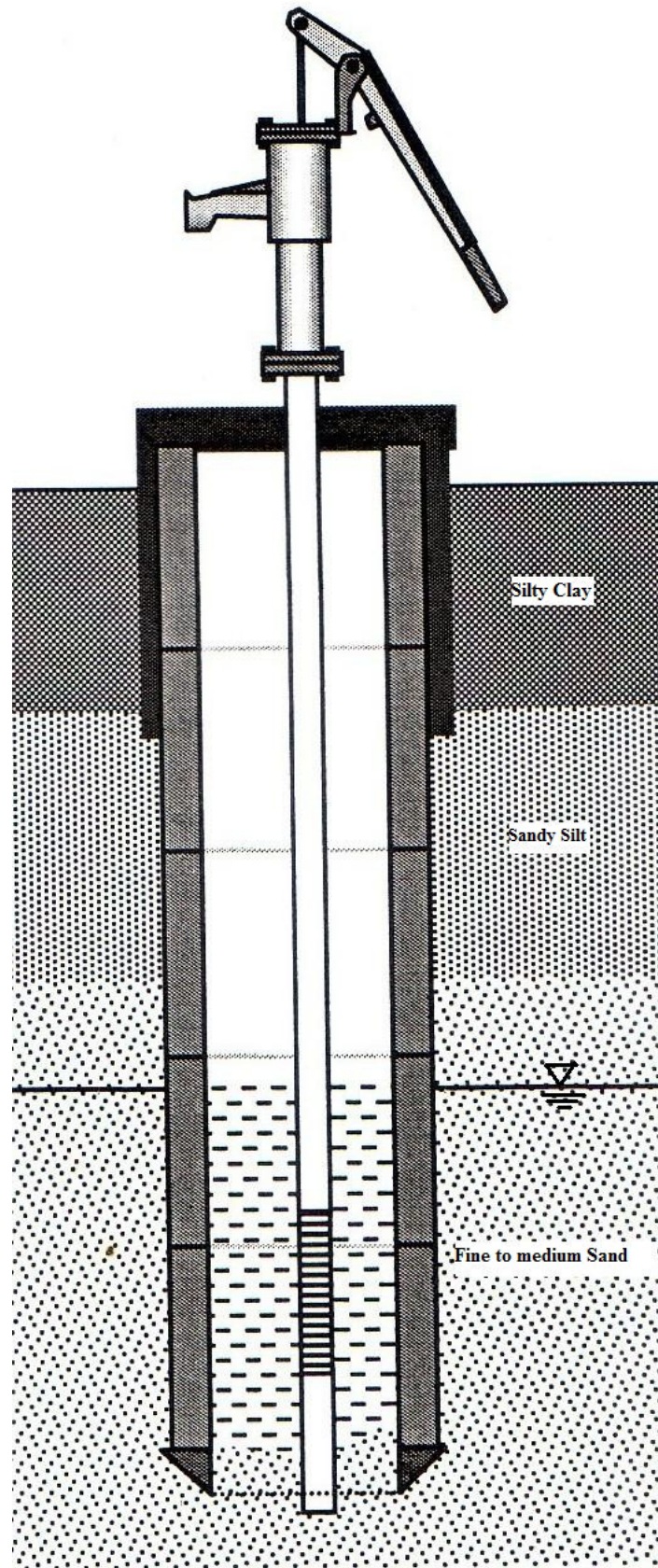


Figure 10. Dugwell (AHMED and RAHMAN, 2000, p. 409).
Puits creusé (AHMED et RAHMAN, 2000, p. 409).

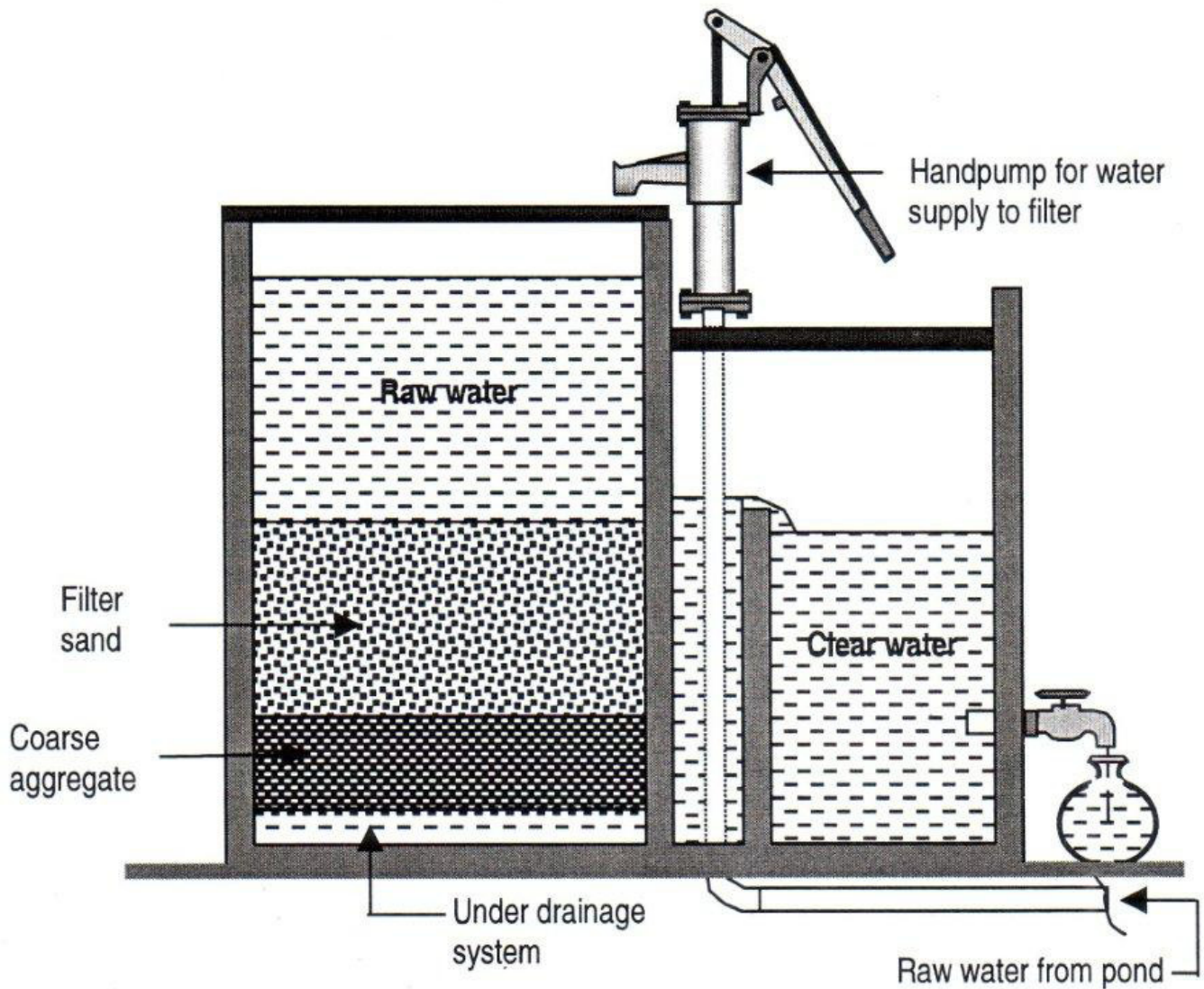


Figure 11. Pond sand filter (PSF) (AHMED and RAHMAN, 2000, p. 428).
Filtre de sable d'étang (PSF) (AHMED et RAHMAN, 2000, p. 428).

3.4.2 Strengthening water quality surveillance and monitoring capabilities:

Arsenic contamination of groundwater appears to be in a dynamic state and may propagate over long distances within a short time in aquifers with high transmissibility and under conditions of regular abstraction of water through production wells (AL-MUYEED and ZAHER, 2004). The water quality of a tubewell may change within a short time-span and a safe tubewell identified by water quality tests may not remain safe in the future (AL-MUYEED and ZAHER, 2004). Hence continuous monitoring of water quality according to national water quality guidelines is needed.

3.4.3 Capacity building through training:

Comprehensive training programmes are to be arranged to develop the skills of doctors and health workers to diagnose cases of arsenic poisoning reliably as well as enhance the knowledge and potential of engineers, hydrogeologists and NGO workers to develop and implement alternative safe water supply systems (AL-MUYEED and ZAHER, 2004).

3.4.4 Concerted effort:

Government itself cannot handle such a complex issue like arsenic contamination in Bangladesh. Community (people,

Table 2. Performance summary of arsenic treatment units and alternate water supply options. Sources: (KHAN *et al.*, 2002; PETRUSEVSKI *et al.*, 2007; RAHMAN and AL-MUYEED, 2009; RAHMAN *et al.*, 2003; WICKRAMASINGHE *et al.*, 2004).
 Tableau 2. Résumé des performances des systèmes d'élimination de l'arsenic et des options d'alimentation en eau. Sources : (KHAN *et al.*, 2002; PETRUSEVSKI *et al.*, 2007; RAHMAN *et al.*, 2009; RAHMAN *et al.*, 2003; WICKRAMASINGHE *et al.*, 2004).

Type of unit	Advantage	Disadvantage	Type/ Population served	Unit cost in US\$	Operation/ maintenance in US\$	Arsenic removal efficiency
Adsorption	Good removal efficiency, low cost adsorbents are available	Regeneration of adsorbents is required	Community/ household level	Small system requires lower operating and maintenance cost		90-93%
Coagulation	Simple operation, low cost, available chemicals	Toxic sludge, not applicable to water containing phosphate	Community/ household level	Low cost		95%
Ion exchange, activated alumina, read-F, granular ferric hydroxide,	Simple, available	Clumsy maintenance, not applicable to water containing phosphate	Community/ household level	Ion exchange is costly		About 50%
Membrane technology	High removal, applicable to large scale treatment, disinfects other impurities	Costly, membrane fouling	Community/ household level	Costly		More than 95%
Arsenic and iron removal plant (AIRP)	Simple, removes iron, well accepted by the community	Critical maintenance, sludge generation	Community (10 households)	200	1/person/yr	About 60-75%
Bucket filter	Simple technique	Good maintenance is required	Household level	6-8	25/family/yr	More than 90%
Steven technology	Easy method to remove arsenic	Sand bed requires backwashing at least twice a week	Household level	-	-	90%
Sono/pitcher filter	Simple and cheap technique	System clogs quickly if ground water contains excessive iron	Household level	13	0.5-1.5/family/yr	More than 90%
GARNET filter	Good bacteriological quality	Good maintenance is required	Household level	-	-	90-100%
Fill and draw unit	Simple procedure	Sludge handling	Household/ community level	250	15	-
Passive sedimentation, <i>in situ</i> /solar	Simple, easy maintenance	Slow and low removal efficiency	-	-	-	50-60%
Alternative water supply options						
Deep tubewell	Highly acceptable by the community	More expensive than shallow tubewell	250-300 persons	775	0.05/person/yr	-
Shallow shrouded tubewell	Arsenic is usually below threshold limit	Only suitable for those areas where arsenic level is very low in shallow/very shallow aquifer	100-120 persons	175	0.01/person/yr	-
Dugwell	Rarely arsenic contaminated	Microbial contamination	120-150 persons	560	0.01/person/yr	-
Pond sand filter (PSF)	Bacteriologically safe	Regular and timely maintenance is required	150-200 persons	560	0.04/person/yr	-
Solar disinfection	Easy and cheap	Less quantity of water, not good acceptance	-	-	-	45-78%
Rainwater harvesting	Acceptable by the community	Dependent on rainfall	5 persons	106	0.34/person/yr	-

social leaders and elected representatives) and multi-partners (such as DPHE, Administration, Education, Health and NGOs) should be involved in every stage of arsenic mitigation (HOQUE *et al.*, 2000). Moreover, international collaboration and cooperation are needed to exchange experience, expand research work and to implement programmes in addressing arsenic issues. This will assist in explaining sustainable solutions to the arsenic catastrophe.

3.4.5 Provision of treatment and medical care:

So far there is no effective treatment for arsenic poisoning (AL-MUYEED and ZAHER, 2004). However, withdrawal of further intake of arsenic-contaminated water brings about improvement in the victims. Moreover, chelation therapy and vitamins (vitamins A, E and C) and a nutritious diet, especially protein and vitamin rich food, enhance the recovery (ALAM *et al.*, 2002). Furthermore, recently introduced *d*-penicillamines, DMSA (dimercaptosuccinic acid) and DMPS (dimercaptopropane sulfonate), known arsenic-chelating agents, are being prescribed by the National Institute of Preventive, Social and Occupational Medicine (NIPSOM) for treating patients with arsenicism (ALAM *et al.*, 2002).

3.4.6 Development of a GIS aided national database

No option is found as convenient as getting water from a shallow hand pumped tubewell. Moreover, the government has already taken some initiatives in identifying safe and unsafe tubewells by green and red marks, respectively (AL-MUYEED and ZAHER, 2004). In addition, a huge number of alternate safe water options is distributed by government and non-government organizations all over the country. Geographic Information System (GIS) based spatial mapping identifying contaminated and uncontaminated tubewells, existing secured water options and safe buffer zones will help in the rational distribution of safe water in the country (JAKARIYA and BHATTACHARYA, 2007).

4. CONCLUDING REMARKS

Bangladesh is the most arsenic-prone country in the world. Studies regarding arsenic contamination in this single country elucidate the health hazard through ingestion of drinking water, and through food chains and at the same time probe the social implications. However, the sources, causes, occurrences and distribution of arsenic in the groundwater of Bangladesh are still a matter of debate. Arsenic-tainted drinking water is the major and direct source of devastating public health problems such as skin manifestations, cardiovascular disease, hepatomegaly, neuropathy, gangrene of the distal organs, skin cancer, kidney and liver failure, diabetes mellitus, hypertension, respiratory problems, DNA alteration, endocrine system disruption,

adverse pregnancy outcomes and impaired child development. Moreover, it is evident that not only “soil-water-human” but also “plant-human” and “plant-animal-human” pathways may be involved in arsenic accumulation in the human body. The extent and time frame of the arsenic ingestion period and nutritional status and immune response of the individual can contribute to arsenicosis. Accordingly, the drinking of arsenic-safe water is the principal aim of both preventive and treatment perspectives. Besides treating arsenic-contaminated water, the Bangladesh government and NGOs are currently promoting alternate options mainly based on surface water. Indeed, no single option can serve the whole cross-section of the arsenic-affected population in Bangladesh. This population spans diverse social and economic backgrounds, which complicate the issue. Deep tubewells, which have been well accepted by the communities during the past few decades in Bangladesh, have emerged to be a suitable mitigation. Moreover, some filters for the household level seem very promising if proper maintenance can be carried out on regular basis. However, not only research on mitigation technology and desktop analyses but also proper strategic plans, orientation of works, proper scheduling and distribution of duties and finally review and monitoring of the overall works are needed. While reviewing different papers, it is observed that many findings are limited to the study of a single area or very few areas. This is a common weak point since arsenic contamination is a very complicated issue in Bangladesh. Therefore, an extensive study is required to find out the cause of arsenic pollution in Bangladesh, establish the relationship between arsenic ingestion and the manifestation of symptoms of arsenic-related diseases, the efficacy of drugs and other methods of treatment, and the deployment of cost-effective, efficient and socially acceptable treatment technologies.

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