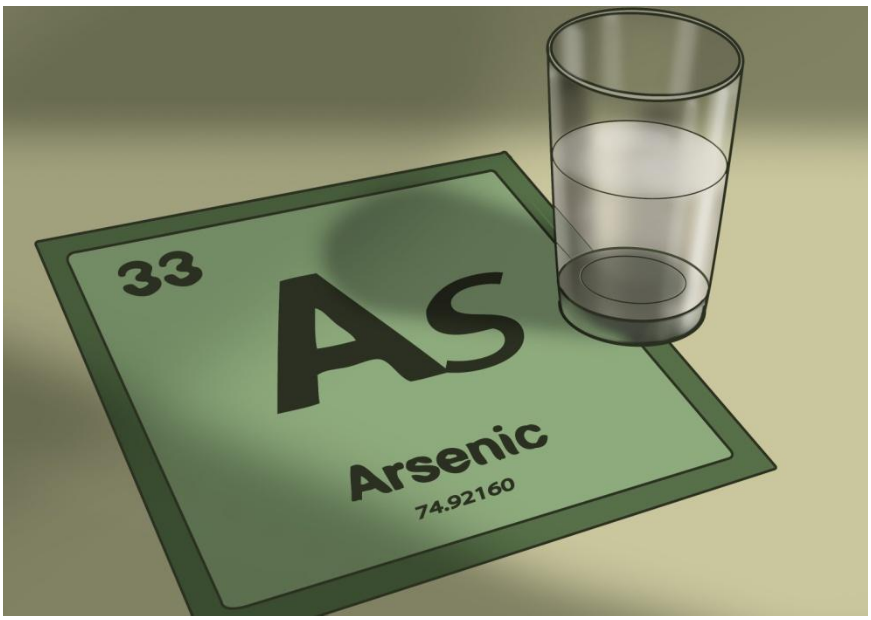

Use surface water, stop digging

Chapter

7

〖Providing Arsenic Safe Drinking Water〗

"Arsenic mitigation solutions showed significant microbial contamination and none can provide 'safe' drinking-water."

M. Feroze Ahmed, Bangladesh University of Engineeringand Technology

The first choice of treating non-malignant skin manifestations of arsenicosis is to provide arsenic safe drinking water if it is due to drinking arsenic contaminated water. Arsenicosis due to inhalation of arsenic polluted air is not effective using this measure.

Four questions must be considered before thinking to provide arsenic safe drinking water (Ravencroft et al., 2009): a) who will be the user? (household, rural community or municipality); b) who will implement it? (household, commercial level, non-government organization or government); c) who will finance?; d) is the water be able to free from any chemical or microbial?

We have to find out the simplest, cheapest, and quickest solution of providing arsenic safe drinking water.

The first step is the screening of arsenic contaminated tube wells. Even in arsenic endemic area, all the hand pump tube wells are not equally contaminated with arsenic. After identification, hand pump tube wells are colored with red (>50 ppb) or green (<50 ppb) marking ("traffic light" colors; Figure 7.1). However, red marked (high arsenic containing) tube well water may be used safely for washing laundry. The simplest and most immediately achievable option is the sharing of green marked hand pump tubewells or red marked tube wells that contain relatively low concentration of arsenic. The latter option is particularly applicable where 70-100% hand pump tube wells are contaminated with high concentration of arsenic. The number of people per green-marked tube wells has increased many times without facing any practical difficulties to share (van Geen et al., 2002). The red or green color coding should be monitored time to time, as tube well with previously safe test result may be later found to contain increased level of arsenic.

The available options for arsenic safe drinking water are: surface water, groundwater and rainwater. We give emphasis on two terminologies applicable to provide arsenic safe drinking water: mitigation and remediation. Mitigation means the provision of alternative arsenic-free water whereas remediation means arsenic removal from extracted water (Garelick et al., 2005).

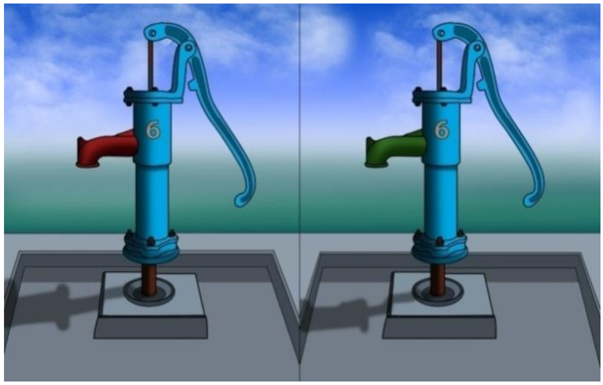

Figure 7.1 *Red (left) and green (right) marking of hand pump tube wells.*

Mitigation

Mitigation includes pond sand filter, rain water harvesting, dug well, and supply of tap water collected by deep tube well. Detail discussion on this topic has been done in a book (Ahmed and Ahmed, 2002).

7.1 Pond Sand Filter

Principle: Pond sand filter consists of a tank containing the bed of filter materials and a storage chamber. Water is pumped into the pond sand filter tank using a hand pump tube well head connected to a pipe which intakes water from the pond (Figure 7.2). It then flows vertically through the sand bed. At the bottom of the tank an under drain system (the 'filter bottom') is placed to support the filter bed. The bed is composed of fine sand, usually free from clay, loam and other organic matters. The filter bed normally is 1.0-1.5 m thick, and the water to be treated stands to a depth of 0.3-0.5 m above the filter bed. From the base of the filter bed the water is discharged into a storage chamber.

Advantage: This system is preferable where there is an abundance of surface water, for example, in Bangladesh. There is no need of chemical treatment. One pond sand filter can supply the daily requirement of drinking and cooking water for about 40-60 families.

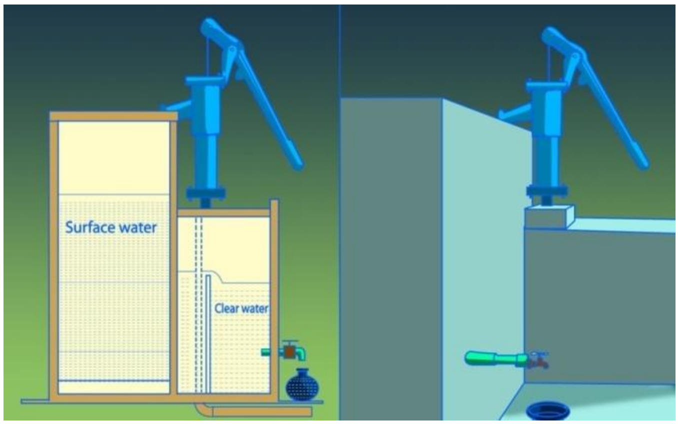

Figure 7.2 *Schematic diagram of pond sand filter.*

Disadvantage: This method is not applicable where there is no pond. The use of pond sand filter may be sometimes interuppted for maintenance. The suspended matter present in the raw water is largely retained in the upper 0.5-2.0 cm of the filter bed. This allows the filter to be cleaned by scraping away the top layer of sand. The filter cleaning operation takes one day. But after cleaning, one or two more days are required for the filter bed to again become fully effective. Trained caretaker is needed for maintaining the pond sand filter. Pond which is used for fish culture, agricultural and domestic runoff, latrine discharges, and washing livestock is not suitable. So, it is sometimes difficult to get such pond in arsenic endemic area. Owner of the pond will not restrict its use only for the supply of drinking water considering commercial point of view.

Some of the pond sand filters are abundant after implementation (BRAC, 2000). This type of pond sand filter is not feasible.

7.2 Rain Water Harvester

Rainwater harvesting technique is practiced in many parts of the world for more than 4,000 years. There is a long-established tradition of rainwater collection in some parts of Bangladesh, where groundwater is heavily contaminated with arsenic, iron, and salinity.

The success of rainfall harvesting depends upon the frequency and amount of rainfall. It is not a dependable water source during dry season or prolonged drought. The total annual rainfall in India is 400 million hectare meters (area x height) whereas the total area of India is 329 million hectares. This gives us an example, how much rainwater we can use properly with good planning. The desert receives less than 200 mm of raining annually whereas Cherrapunji (India) receives 11,400 mm annually. The use of umbrella can protect you from raining. In addition, it can be used to collect rain water for drinking purpose in order to avoid the use of arsenic contaminated drinking water (Figure 7.3). This motivates you but the process is difficult to implement.

Figure 7.3 *Dual use of umbrella.*

Principle: A rain water harvester is constructed using pre-cast concrete blocks. Water is channeled from collection pipes on the roof into the rain water harvester through a funnel with a mesh filter (Figure 7.4). The rain water harvester is covered with a lid. The first collected rainwater may carry significant amounts of contaminant (debris, dirt, dust) which accumulate on the roof and in the gutters. It is, therefore, recommended not to collect the first flush of rainwater. A cover for the intake is provided and users are instructed to remove these 5/10 minutes after the rainfall started.

Advantage: Initial investment and maintenance are not costly. A large number of families can be benifited if properly maintained in an area where the amount of rainfall is large like India or Bangladesh. Good quality water can be stored if collected properly. It is an effective method of supplying drinking water in coastal areas where salanity is a problem. This method of water collection is suitable for tin-roof houses. Alternative arrangement can be made by using polythene or thick clothes on the roof of house to collect water.

Figure 7.4 *Rain water harvesting.*

Disadvantage: Its success also depends on communities that consider water supply a priority. The quality of the collected water can be improved by proper maintenance of the roof and gutters and careful cleaning at the beginning of each wet season. There is shortage of water during the dry season. As the water is mineral-free, some people may dislike it due to its tasteless.

7.3 Dug Well

Dug well is the oldest method of collection of potable water from the ground. The use of dug wells in Bangladesh has declined since the 1960s following the introduction of the hand pump tube wells.

Principle: Dug well may be converted into hand pump sanitary dug well. The well is covered and water is drawn from the well using a hand pump (Figure 7.5). An apron is constructed around the well to prevent contamina-tion from the surface. Following digging/excavation the well is lined with local materials, either concrete or clay rings to prevent the walls from collapsing. Proper lining and a well-designed apron are crucial for prevention of surface water contamination.

Advantage: In Bangladesh, the water of dug well water contains safe concentration of arsenic. The wells are cheaper and easier to construct. Usually no special equipment or skill is required for the construction of dug well.

Disadvantage: Percolation of contaminated surface water is the most common route of pollution of well water. It is, sometimes, difficult to protect the water from bacterial contamination.

It may be possible to combine dug well with home-based surface water filter to provide a socially acceptable, bacteriologically safe water source for rural household.

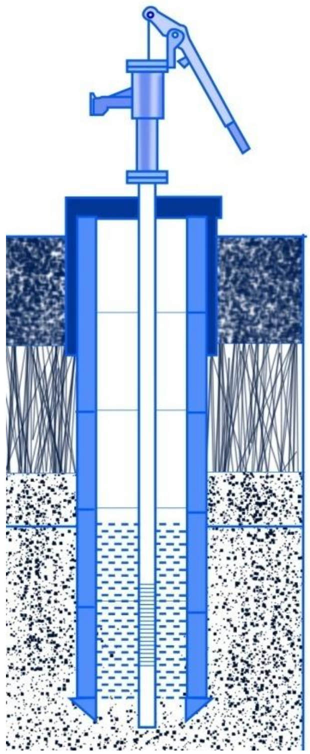

Figure 7.5 *Schematic diagram of dug well with sanitary protection.*

7.4 Community Water Supply

Principle: Like urban area, surface water with treatment or groundwater with safe level of arsenic are directly pumped into a water tank and then supplied to the houses by pipe line (Figure 7.6).

Advantage: This has contributed significantly to both the reduction and control of water-related diseases. It reduces the burden of water collection, which is borne especially by women and children.

Disadvantage: The total cost of a piped water scheme depends on the type that is, household or stand post type connection, size and distribution of the settlements, etc. The construction cost may vary from US$ 25,000 and above. It needs regular operation and maintenance cost.

Figure 7.6 *Community water supply.*

7.4.1 Remediation

Several physico-chemical techniques are recommened for the removal of arsenic from arsenic contaminated drinking water, both on-site and off-site, especially in the area where most of the tube wells are contaminated. The most commonly used technologies are oxidation, co-precipitation followed by adsorption onto coagulated flocks, lime treatment, ion exchange, adsorption onto various solid media and membrane filtration. They may be used alone or in combination. Remediation also includes household filters, phytoremediation and solar-light assisted arsenic removal**.**

7.5 Oxidation

Principle: Oxidation is a required step to transform As^{III} species in more easily removable As^{V} species by chemicals like gaseous chlorine, hypochlorite, ozone, permanganate, hydrogen peroxide, manganese oxides and Fenton's reagent (H_2O_2/Fe^{2+}). This reaction process is very fast for permanganate, chlorine and ozone in comparison to hydrogen peroxide and chloroamine.

Advantages: Among them gaseous chlorine is a rapid and effective oxidant, but it reacts with organic matter, producing toxic and carcinogenic trihalomethanes. Potassium permanganate effectively oxidizes As^{III}, and it is inexpensive and suitable for developing countries. Hydrogen peroxide is an effective oxidant if the untreated water contains dissolved iron, which occurs in conjunction with arsenic contamination, allowing the occurrence of Fenton reactions. It is a simple process with low operation cost. It can be applicable for large volume of arsenic contaminated water.

Disadvantages: An adequate selection of oxidants in relation with aquatic chemistry and water composition is a pertinent step to achieve a high removal efficiency of aqueous arsenic by oxidation. Toxic chemicals and carcinogens are produced as by-products. Interfering substances may decrease the arsenic removal efficacy. Due to several drawbacks, oxidation alone is not an effective method for removal of arsenic. Another method must be included (precipitation of As^{V}). As^{V} adsorbs more easily onto the solid surfaces than As^{III}.

7.6 Coagulation and Filtration

Compared with aluminum coagulants, Fe^{III} salts have been found to be more effective for arsenic removal. Although the coagulation process is a simple and economically sound one, it produces a wet bulky sludge.

Principle: Chemicals such as aluminum sulfate, ferric chloride and ferrous sulfate, iron salts are used to remove arsenic (As^{V}), which adsorbs onto coagulated flocs and then can be removed by filtration. As^{III} is at first oxidized with chlorine. Iron chloride generates relatively large flocs, while smaller ones are formed with ferrous sulfate. Filtration is a necessary step.

Advantages: It is a simple, most common, effective and low cost method acting over wide range of pH. Removal of As^{V} from water is high. Installation cost is small and it can be easily applied to large volume of water.

Disadvantages: Very high amount of coagulant is needed. Additional separation step is necessary. Without filtration, As^{V} removal is around 30%, but using a 0.1 or 1.0 mm filter, As^{V} removal improves to more than 96%. Further environmental pollution occurs due to improper disposal of contaminated sludge.

7.7 Adsorption

Because of the ease of handling, sludge-free operation, and possibility of regeneration, the adsorption process appears to be the most promising one. Activated alumina has long been the most often used adsorbent for arsenic removal. The problems including the need for pH adjustment, the relatively low adsorption capacity, and aluminum dissolution have prevented activated alumina from wider applications.

Cerium: An iron based inorganic adsorbent, developed by doping cerium ions into iron ions, is used for As^{V} removal. In terms of adsorption pH range and adsorption capacity, the new adsorbent demonstrated a much better performance than activated alumina (Zhang et al., 2003).

Advantages: It is comparatively cheaper and available commercially.

Disadvantages: It interferes from competitive anions (PO_4^{3-}, HCO_3^{-}, SiO_3^{2-}, SO_4^{2-}). Further environmental pollution occurs due to improper disposal of contaminated sludge.

7.8 Ion-exchange

Advantages: The removal of arsenic is not depending on pH and concentration of the influent. It is moderately effective.

Disadvantages: The removal of As^{III} is not possible and prior oxidation is necessary. Other anions interfere the process. Iron may be clogg. It produces large volume of toxic brine during regeneration of resins.

7.9 Membrane

Advantages: The removal of As^{V} from water is good with no toxic waste product.

Disadvantages: Very low amount of As^{III} is removed. Pretreatment is often required. High initial and maintenance cost are required. It is not an effective method when water is highly contaminated with arsenic.

7.10 House-hold Filter

There are several house-hold filters: Safi filter, sono file, pitcher filter, etc (Figure 7.7). The three- or four-pitcher filter is based on an indigenous method of filtration, which has been used in Bangladesh for ages to remove excess iron and calcium from drinking water. The household level filtration device was designed to remove both arsenic and pathogenic bacteria.

Principle: The Safi filter consists of two concrete buckets (20 liter). One buchet is placed on the top of another bucket. The upper bucket is filled with arsenic contaminated tube well water, which then flows through a permeable 'candle' and is collected in the lower bucket where it is stored. When needed it is drawn off with a tap. The Safi filter candle is prepared from a chemical mixture of laterite soil, ferric oxide, manganese di-oxide, aluminum hydroxide and meso-porous silica. These materials adsorb arsenic as the water passes through the candle and thus the contamination is removed.

Two local clay pitchers are used to filter water. The top pitcher is partially filled with sand and charcoal, and a small hole is made in the bottom. A piece of synthetic cloth is placed over the hole to prevent sand from spilling out. Water is passed through this pitcher to remove suspended matter from the surface water and arsenic as well as iron from tube well water. After passing through the top pitcher, filtered water is stored in the bottom pitcher. It is modified by adding a third pitcher above the sand/charcoal pitcher, which is filled with iron filings to provide an additional source of iron oxide to adsorb more arsenic.

Advantage: This filter can supply approximately 40 liters of water per day. The cost of such filter is approximately US$ 15. The candle eliminates pathogenic bacteria from the contaminated water. After two years of continuous use, the candle should be replaced with a fresh one. Each new candle costs around US$ 4. The total cost for developing pitcher filter is less than US$ 5. The three-pitcher system has enormous potential to provide an emergency drinking water source for the arsenic-affected rural area. It is based on an indigenous technology, cheap, and can be constructed with locally available materials.

The removal efficiency of arsenic by sono filter is high (up to 300 ppb). Each filter lasts for up to 5 years. Spent materials are non-toxic. This filter can supply approximately 80 liters of water per day which is sufficient for a family of 5.

Disadvantage: The filter has problem like flow rate and arsenic removal efficiency (BRAC, 2000). Sono filter is not as successful with extremely high concentration of arsenic. Regular cleaning is required to prevent bacteriological contamination.

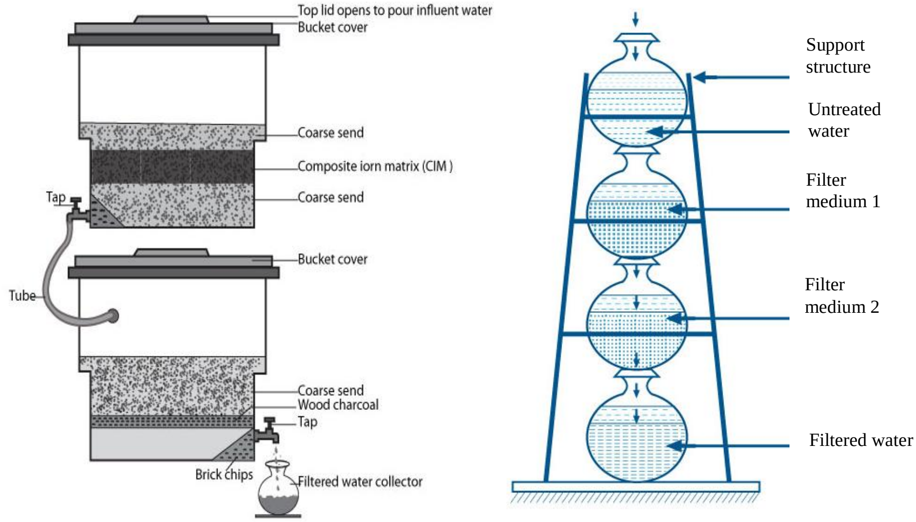

Figure 7.7 *Pitcher filter.*

7.11 Bishuddhya Filter

Principle: This is a plastic non-chemical based filter that does not remove arsenic, but instead is designed to remove bacteria from arsenic free surface water. The filtration and purification technique used in this system are similar to pond sand filter. The principal material used in this filter is different mesh sizes of locally available rocks. The water passes from the bottom through different layers to remove bacteria before it arrives at a storage chamber.

Advantage: Bishuddhya filter is relatively cheap. The cost for this household-based device is around US$ 45 with virtually no operation and maintenance cost, except for washing the materials after a certain interval depending on the suspended loads of arsenic contaminated water.

Disadvantage: The only precautionary measure that needs to be ensured here is that surface water must be obtained from a protected source to ensure no contamination with chemicals, fertilizers, etc.

7.12 Activated Alumina Filter (ALCAN Filter)

Principle: The term 'activated' refers to the capacity of the alumina to enter into adsorption and/or catalytic reactions, and is determined largely by such variables as crystal structure, pore size and distribution, and the chemical nature of the surface. In this system there is adsorption of arsenic by activated alumina. The arsenic contaminated water passes through the activated alumina media and the treated water becomes arsenic free. Activated alumina is formed by the thermal dehydration (250-1150 ℃) of an aluminum hydroxide such as, gibbsite, bayerite, etc. Its principle characteristics are high surface area (>200 m^2/g) and associated porosity.

Advantage: Activated alumina is able to remove cations and anions by chemisorptions. This involves an ion exchange mechanism with the hydroxylated surface. It is able to remove a wide range of anions and cations such as arsenic, fluoride, chromium, zinc, iron, phosphates and organic materials. Arsenic removal efficiency is high. It is available to both community and household levels. There is no need to add any chemical. Each can provide 3,600 L of arsenic safe water per 12 hours for more than 100 families.

Disadvantage: The regeneration of saturated alumina is required once column is totally saturated. However, the efficiency of activated alumina decreases after regeneration. This method is pH sensitive and is high possibility of media getting fouled or clogged by precipitated iron. The initial cost is high for both type of units: US$ 260 per unit (unit plus media), and US$ 52 (unit plus media) for the household based unit. Running cost is required because the activated alumina needs to be changed periodically. The replacement cost of media for community-based units is US$140 to treat 80,000 liters of water, and for household based unit it is US$ 12 to treat 11,000 liters of water. Apart from the cost which seems to discourage villagers, disposal of used material is also another issue of concern not only for this filter but also for all other arsenic removal filters.

7.13 Phytoremediation

Water hyacinth *(Eichhornia crassipes)* removes arsenic from arsenic-contaminated drinking water (Misbahuddin & Fariduddin, 2002). This effect depends on factors like the amount of water hyacinth, amount of arsenic present in the water, duration of exposure, and presence of sunlight and air. It provides a natural means of removing arsenic from drinking water at the household level without monetary cost. However, it is not clear where water hyacinth may influence bacterial contamination.

7.14 Solar-light Assisted Technology

Principle: Lemon juice (citrate) is added to a transparent bottle containing arsenic-contaminated waters, and left in the open air exposed to direct sun light for several hours (Figure 7.8). Iron should be added, if the required concentration is not naturally present. Due to the nature of the reaction, oxygen, iron, the irradiation source and an organic Fe^{III}-chelating compound are crucial to promote the reaction. After standing overnight, the Fe^{III} oxide precipitate is separated by filtration (Hug et al., 2001). The optimum molar ratio for arsenic, citrate and iron is 1:4.5:18.7, respectively, over 90% of arsenic being eliminated after 4 hours of irradiation by visible light (black light, 360 nm) (Lara et al., 2006).

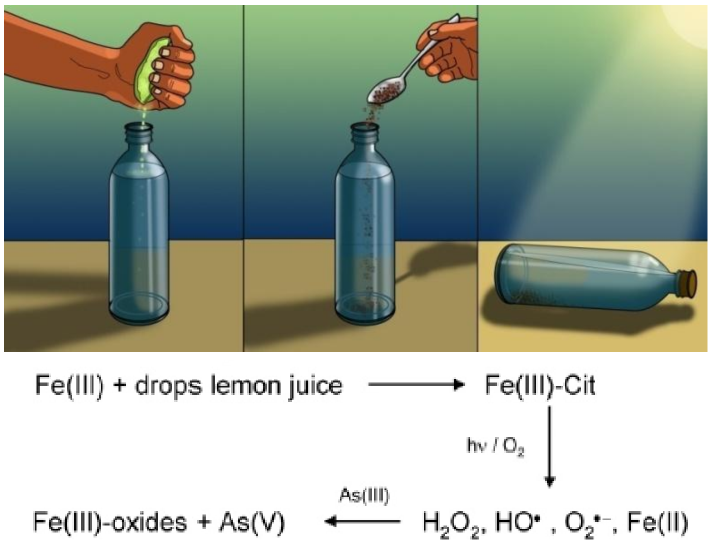

Figure 7.8 *Solar-light assisted arsenic removal (Litter et al., 2010).*

Advantage: The comparison between the As^{III} and As^{V} co-precipitation rates indicates that almost 80% of As^{III} is removed after 1 hour of irradiation, while As^{V} required 4 hours of irradiation to reach the same value. When natural water containing approximately 1 mg/L of arsenic, only as As^{V}, is irradiated with solar light under optimized conditions, approximately 95% of the arsenic is removed after 1 hours of irradiation.

Disadvantage: This procedure requires optimum concentration of arsenic, citrate and iron.

7.15 Overall Impression

All the options have advantages and disadvantages. Different methods are tried in different countries (Table 7.1). Arsenic removal from waters is not an easy task. The selection of method depends on the economical aspect, size of the population, incidence of chronic illness, and lack of safe water. Sophisticated and expensive techniques cannot be applied in populations with low economic condition. In addition, these methods require continuous monitoring and maintenance cost. It needs awareness campaign by different stakeholders, villagers to understand the urgency of drinking arsenic safe water and re-sinking/reinstalling tube wells within 50-100 m depths. Periodic checkup of arsenic level in water is also vital.

Table 7.1 *Use of different options in Asian countries for removing arsenic from drinking water.*

Country	Dug well	Pond sand filter	Rainwater harvesting	Household water treatment	Community water treatment	Deep tube well
Bangladesh	√	√	√	√	√	√
Cambodia			√	√	√	
China					√	
India	√			√		√
Myanmar	√		√	√		√
Nepal	√			√	√	√
Pakistan	√			√		
Taiwan			√		√	
Vietnam			√	√	√	√

In some arsenic endemic areas of Bangladesh, more than 90% of hand pump tube wells are contaminated with high concentration of arsenic. In that case, the effectiveness of alternate water options are questionable. The affordability is also considered. Therefore, patient may consider the shifting of highly contaminated hand pump tube wells to low contaminated tube wells.

Proving arsenic safe drinking water is possible in Taiwan due to small number of people is affected whereas it is almost impossible in Bangladesh or India where millions of people are affected.

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✶ Myth 1

Use of green marked hand pump tube well water by the neighbor might decrease the amount of water. So, it should not be shared by other people who are using red marked hand pumped tube well water.

✶ Myth 2

Arsenic can be removed from water by boiling or filtering.