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Rural methods to mitigate arsenic contaminated water



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<p>Consumption of arsenic contaminated water is one of the burning issues in the rural world. Poor public awareness program about health effects of drinking arsenic contaminated water and the rural methods to mitigate this problem poses a great threat of arsenic poisoning many people of the rural world. In this thesis, arsenic removal efficiency and the working mechanism of four rural and economical arsenic mitigation technologies i.e. solar oxidation and reduction of arsenic (SORAS), Bucket treatment unit (BTU), Sono filter and Arsenic bio sand filter (ABF) are described by studying the articles of several researchers. All of these technologies are based on the principal of adsorption, ion exchange, oxidation, co-precipitation and coagulation methods. In SORAS technology, transparent PET bottle containing arsenic contaminated water and natural acids like lemon juice is exposed to the sunlight. Sunlight causes a photochemical oxidation of arsenic, which lowers down the arsenic level of contaminated water by over 80 %. In BTU technology, arsenic was filtered using two buckets. Alum and potassium permanganate were used to enhance the reaction. This technology removed the arsenic contaminated by 90 % of 34 tube wells selected for experiment in 55 days of installation. After 55 days this system required cleaning for efficient removal of arsenic. Similarly, the sono filter removed the arsenic by 90-95 % at the flow rate of 20-30 L/h. Arsenic biosand filter which proved to be the best among all above technologies removed 95-97 % of arsenic concentration from contaminated water and filtered at a rate of 40 L/day. In short, all above mentioned technologies were capable of reducing the arsenic level of contaminated water to WHO permissible limit. In addition, these technologies also removed other contaminants such as bacteria, viruses, turbidity, pathogens. Cleaning the filter in regular interval of time lengthen the life of these filters.</p>	
Keywords	Rural, arsenic, Health problem, Mitigation, POU, Solar oxidation, Coagulation, Co-precipitation, Adsorption, Filtration, Bucket treatment, Sono filter, Biosand filter

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1 Introduction

Safe drinking water is one of the important basic needs of every people of the world to live healthy lives. Safe drinking water should meet all the criteria set to be drinkable. Many people in developed countries are enjoying the good quality water through the centralised water supply system. However, in undeveloped and developing countries safe drinking water is greatly threatened. Every year, millions of people die of drinking polluted water. UNICEF has suggested that about 1.1 billion people in the globe do not have access to safe water [1]. Consumption of poor quality water can exposes humans to bacterial diseases, metal poisoning and other health hazards. However, many people in poor countries consume water from for examples contaminated tube wells, rivers and springs directly leading their health in great risk. The contamination of the water source can be of natural origin or it can be caused by human activities. Natural calamities such as floods, landslides and dissolution of naturally occurring contaminants for example arsenic, boron, uranium and other metals and metalloids in ground or surface water, are some typical examples of natural contamination of water sources. Industrialisation, agricultural activities, mining, poor waste management are examples of human activities that pollute the water sources. To minimise the risk of water pollution, several point-of-use mechanisms (POU) such as boiling, chlorination and solar disinfection are suggested as the cheaper methods to purify the water at household level [2].

Arsenic contamination in drinking water is one of the burning issues in the current world because millions of people are suffering from its hazards. Various technologies such as reverse osmosis and membrane filtration etc are working in arsenic mitigation in developed world, but these technologies are quite expensive for the majority of people in poor countries. Thus, more attention should be paid to technologies suitable for clusters of people who cannot afford the expensive technology and live under the poverty line. The target of this thesis report is to explain some of the cheaper methods of arsenic removal at household level. The technologies described in this thesis are already in practice in many countries, and they are serving well the people living there. All the technologies described here works on the principle of conventional arsenic treatment methods like adsorption, oxidation, co-precipitation and coagulation.

2 Arsenic Chemistry

Arsenic is one of the naturally occurring toxic metalloids located at the earth's crust. Its symbol is As and its atomic number is 33. It ranks as 20th in natural abundances and as 12th in human body [3]. Arsenic occurs in both organic and inorganic form in nature. Dimethylarsinic acid ($C_2H_7AsO_2$) and monomethylarsonic acid (CH_5AsO_3) are examples of the organic form of arsenic in water while arsenic trioxide (As_2O_3) and sodium arsenate (NaH_2AsO_4) are examples of inorganic form of arsenic in water. Arsenic mostly occurs in combination with sulfur, oxygen and iron in nature [4]. Generally, arsenic has four main oxidation states: As (-III), As (0), As (+III) and As (+V). However, in natural waters, the inorganic form of trivalent arsenite As (+III) and pentavalent arsenate As(+V) are the most predominant forms. It is reported that the trivalent form of arsenic is 60 times more toxic than oxidized pentavalent state [5]. This is the reason why it is necessary to convert trivalent state of arsenic to pentavalent state during treatment of arsenic poisoned water. Organic state of arsenic is more predominant in surface water due to biological activity and industrial pollution [4, 6].

The two important factors that control the arsenic speciation are pH and redox potential (Eh). Trivalent and pentavalent species of arsenic occur in different forms at different pH levels. Under the oxidizing condition ($pH < 6.2$), $H_2AsO_4^-$ is more predominant while at the higher oxidizing condition, $HAsO_4^{2-}$ is more abundant. At the reducing condition ($pH < 9.2$), the uncharged H_3AsO_3 is dominant. Research shows that more trivalent species of arsenic are found in the reducing condition of ground water than the pentavalent forms, whereas the case is vice-versa in oxidizing ground water conditions. As pH increases the oxy anions including pentavalent arsenate (As^{5+}) become more soluble in ground water. Even at near neutral pH, arsenic, unlike other elements, is soluble in ground water in higher concentrations. This is the reason why groundwater is easily contaminated with arsenic [4, 5]. The stabilities of arsenic species under different pH and redox conditions are shown in Figure 1 below:

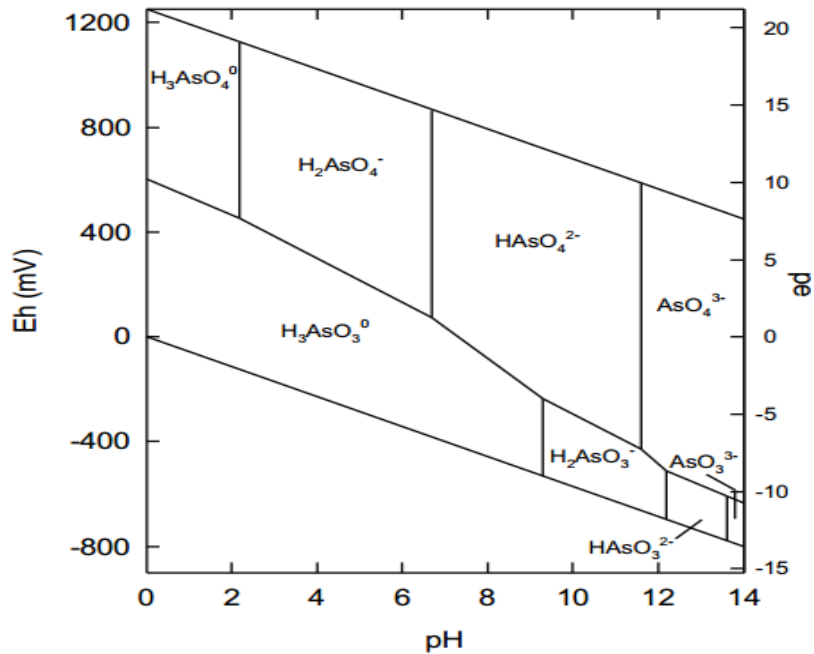


Figure1. Arsenic species at different pH and redox conditions [4].

3 Sources of arsenic in ground water

The source of arsenic in natural water varies according to the nature of geographical location, biological activities and the industrial activities in that area. Generally, a high concentration of arsenic is found in oxidizing environments like arid or semi arid areas and in strongly reducing aquifers [5]. Ground water pollution by arsenic is mostly a natural phenomenon (tectonic activities or geochemical erosion) and is abundant in those areas where the sediments and rocks contain arsenic. In nature, the arsenic stays fixed in the rocks or sediments till the ground water has sufficient dissolved oxygen, and it is released when the sediments come in contact with oxygen-depleted groundwater. Oxygen depletion is generally caused by the decomposition of organic materials. Ground water in river delta and Bengal delta are caused by this type of phenomenon [7]. The sand and gravels deposited in these areas are the deposits of Holocene age interlocked with alluvial flood plains carried by the Siwalik Hills [3]. Studies conducted in several parts of the globe have suggested that ground water contamination by arsenic is found mostly in shallow wells, very old wells and the wells from where the large amount water is extracted.

Human activities like mining of the ore can lead to heavy arsenic contamination of natural waters. Since most of the valuable ores, for example copper, gold, lead and zinc contain traces of arsenic. Hence, if the proper care is not taken during the extraction of those metals, there is a high chance that they mix with natural water sources through runoff. Also, the use of insecticides, pesticides or herbicides which are made by using arsenic components can lead to soil contamination, which ultimately leads for arsenic poisoning in natural waters [8]. Irrigation by using the arsenic-polluted water can lead to the soil being polluted by arsenic, and arsenic can also be deposited into the crops, which human consumes later, thus getting exposed to arsenic [9].

3.1 Mechanism of ground water pollution by arsenic

Currently, there are two well explained mechanisms of ground water pollution by arsenic. They are oxidation theory and oxy-hydroxide theory [10, 11]. The oxidation theory is more accepted than oxy-hydroxide theory. The oxidation theory (also called as pyrite oxidation) explains that arsenic is released due to the oxidation of the sulphide minerals (e.g. arsenic pyrite) in shallow aquifers. As the water table decreases due to heavy scale extraction of ground water for several purposes, there is a chance of oxygen diffusion in the pores of sediments and an increase of the dissolved oxygen in the upper part of the water table resulting to the oxidation of arsenic pyrite forming a water-soluble hydrated iron arsenate compound. When this arsenic-bearing compound (e.g. Arsenic pyrite) is broken down by light pressure, it easily mixes with water and emerges during the extraction via tube wells [11]. The oxy-hydroxide theory explains that the arsenic is adsorbed to the oxy-hydroxide of iron and manganese buried in the sedimentary columns. This adsorbed arsenic is released to the ground water by the natural reductive process developed in the sediments and ground water [12].

4 Arsenic Contamination in the world

Millions of people around the globe are suffering from arsenic contamination. A considerable number of reports about the health hazards caused by arsenic poisoning has come from many developing countries such as Bangladesh, China, Myanmar, Vietnam, Nepal, India, Mexico and Argentina including the developed world, for example USA and Japan (see Figure 2 and Figure3). Figure 4 shows that mainly in South Asia and south-east Asia a large number of people are suffering from a high level of arsenic poisoning in soil and ground water, Bangladesh being in the highest risk zone of arsenic

contamination [13]. Only in Bangladesh, 75 million people are at risk of arsenic contamination, and 24 million people are exposed to arsenic contamination affected [11]. In Nepal, about half a million people living in the Terai belt (low land area bordering with India) are at high risk of arsenic contamination, and the same problem affects other south Asian and southeast Asian countries [3].



Figure 2. Dark areas representing the countries affected by arsenic contamination [14].

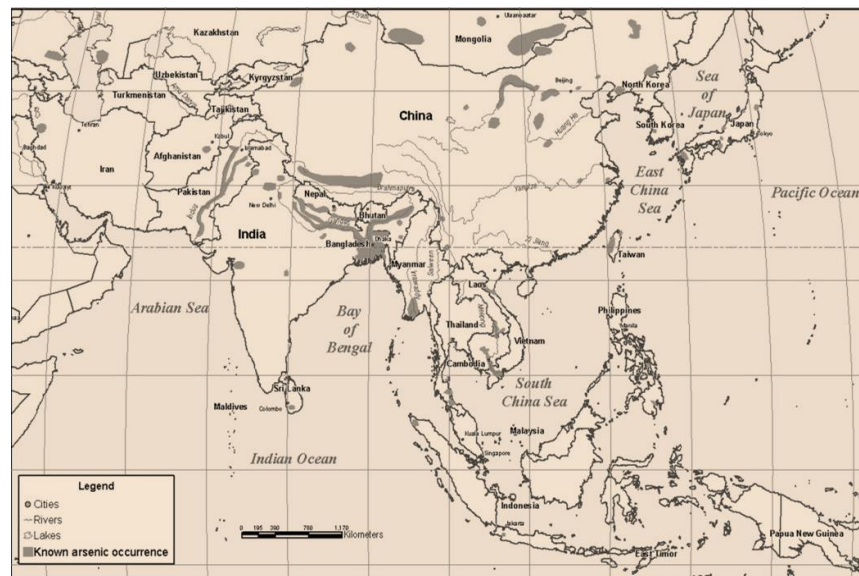


Figure 3. Ground water Arsenic contamination in south and Southeast Asia [15].

5 Permissible level of arsenic consumption

To fight the severe effects of the arsenic poisoning around the world, the World Health Organisation (WHO) has set the standard for arsenic contamination in drinking water at 0.01 mg/l [16]. The maximum permissible standard for arsenic is 0.5 mg/l, which is adopted by many countries as their national standard. United States and the European Union follows the WHO standard, but a major concern is in those countries which are facing difficulties in maintaining their National standard of 0.05 mg/l. Table 1 illustrates the national drinking water standards for arsenic of some countries.

Table 1. Limit values of arsenic in water [17].

Countries / Organisation	Limit of Arsenic in Water (in ppb)
US: New Jersey	5
Australia	7
WHO, EU, Canada, Japan, US, Taiwan	10
Mexico	35
Argentina, Bangladesh, China, Nepal ,India, Ghana, Thailand, Thailand, Vietnam etc	50

6 Health and social effects of arsenic poisoning

Arsenic poisoning has been a great threat in the current world. A significant number of health-related problems caused by consumption of arsenic affected water have been reported by many countries around the globe. The people living in Bangladesh and west Bengal are in the highest risk of arsenic poisoning in the world. The effects can be chronic or acute. Chronic effects can be seen after a few years of exposure, while the acute ones can be seen if a large dose is taken at one time. The common effects of acute arsenic poisoning are muscular pain and weakness, diarrhea and abdominal pain, which in severe cases can lead to a coma or death, while in chronic effect, the hypo pigmentation and hyper pigmentation can be seen in the skin. It can lead to keratosis, hardening of skin in hands and feet, which can cause skin lesions. [18] It also attacks the keratin protein of the hair, which results for hair loss [19]. The American National academy of sciences has suggested that the arsenic in drinking water causes cancer in lungs, bladders, skin, kidney and liver, harms in the nervous system, heart

and blood vessels and can cause birth defects and reproductive problems [8]. Some effects of arsenic poisoning are illustrated in Figure 4 and Figure 5 below.



Figure 4. Feet of person suffering from hyperkeratosis [18].



Figure 5. Skin lesions in hand due to arsenic poisoning [19].

Arsenic contamination not only causes the toxic problems, but it is also one of the major causes of the social problems in many parts of the world. Especially in Bangladesh, people suffering from arsenic poisoning are forced to live miserable lives. In most cases they are avoided or discouraged to appear in public places and in their work places as well. In some schools of Bangladesh, the children suffering from arsenic contamination are not allowed to attend classes. In the worst case, the women suffering from arsenic poisoning remain unmarried and if a woman gets arsenic poisoning after the marriage she is sent back to the father's home [20].

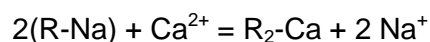
7 Conventional technologies for ground water arsenic treatment

There are several technologies developed for the mitigation of ground water arsenic. However, the most common and conventional methods are Ion exchange methods, membrane process, chemical precipitation/coagulation, oxidation and adsorption methods [5] are described below.

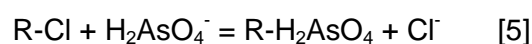
7.1 Ion exchange methods

An ion exchange method is a physical-chemical process where the ions are exchanged between solution phase and solid resin phase of similar charge. This process is not suitable as a POU method to be used in private tube wells but is mostly used in large scale purposes for water softening and removal of nitrate, arsenate and chromate from municipal waste water. This process is used to remove As(V) but not As(III). The exchange affinity of anion of As(V) depends on the concentration of other anions like sulphate and nitrate anions [21]. In this method, water from a source (especially contaminated ground water) is passed through the ion exchange resin beds, which remove the arsenate and other anions, especially sulphate anions, and the unwanted contaminant effluent is left at the bed. The bed is then regenerated or rinsed with a brine solution (chlorine exchange) for the preparation of another cycle [22]. The chemistry for the anion exchange for arsenic removal and cation exchange for the softening of water is given below.

- Cation exchange for water softening (R= Resin site)



- Anion exchange for arsenic removal



7.2 Membrane process

Membrane process is a technique which uses the semi-permeable membrane to separate the dissolved solids and as well as arsenic from the water. It is a physical barrier which blocks some particles from passing through but allows an easy movement of other particles through the membrane, depending upon the physical and chemical properties of the particles. The potential difference between the two sides of membrane is a driving force for the movement of particles [23].

This mechanism removes the arsenic through the mechanism of filtration, electric repulsion and adsorption of arsenic bearing compounds. Shape, size and chemical properties of arsenic components are the major factors that affect the rate of membrane separation. For example, if the size of the particulate arsenic compounds is larger than the membrane, it is prevented from passing through the membrane [23]. There is several membrane processes developed for the arsenic removal from the feed water which are divided in two broad categories: low pressure membrane filtration and high pressure membrane filtration [24]. Low pressure membrane filtration (10-30 psi) includes microfiltration and ultrafiltration, while high pressure membrane filtration (75-250 psi pressure) includes reverse osmosis and nano-filtration [24, 25]. All these mechanisms are quite expensive for single household purposes; thus, they can be adopted for small village water supply schemes.

7.3 Coagulation

The coagulation method has been practiced for a long time to remove suspended and dissolved solids from the surface or ground water. Alum (hydrated potassium aluminium sulphate) and iron (III) salts are used as coagulants to remove arsenic in this process. The arsenic removal mechanism occurs in two stages: adsorption and occlusion. During adsorption, the dissolved arsenic is attached to the surface of a particle, and during occlusion the dissolved contaminant is adsorbed to a particle and then entrapped as the particle continues to agglomerate. Several factors such as pH, dosage of coagulants, turbidity, natural organic matter, anions and cations in solution and temperature are the key parameters that can affect the rate of coagulation. Basically, this method is applied to remove As (V) than As (III) species because at the same parameter condition, a better result can be obtained for As (V) than for As (III). However, As (III) can be converted to As (V) by using a strong oxidant like chlorine [26].

7.4 Adsorption methods

Adsorption is a method through which the atoms, ions or molecules are attached to the surface. This adsorption mechanism is also widely used to remove the arsenic species from the contaminated water. In this process, the contaminated water is passed through adsorption media which are usually packed into a column. The arsenic present in contaminated water is then adsorbed in adsorbents and removed from the water. The adsorbents used for this process are, for example, activated alumina, ion exchange resin and iron compounds. The efficiency of these media depends on the types of oxidising agent used for the sorption of arsenic. These adsorption media are capable of removing the arsenic below the WHO permissible limit [27].

7.5 Oxidation

Oxidation is one of the conventional methods to treat arsenic contaminated water. Mostly, As (III) is oxidised to As (V) using several oxidants, such as chlorine, potassium permanganate, ozone and hydrogen peroxide. However, the harmful effects of the by-product of oxidant should be taken into consideration while choosing the oxidant for arsenic removal [28]. Aeration or natural oxidation of arsenic is one of the cheaper methods to oxidise As (III) to As (V) but it is very slow in nature. Addition of strong reagents like KMnO_4 can make the reaction faster [29]. Not only chemical oxidation, but these days' also solar oxidation and biological oxidation are commonly used to remove the arsenic from the water [27]. The description of the solar oxidation (SORAS) technology is presented in section 8.2.1 below.

8 Rural technologies for arsenic removal

There are several rural technologies to treat the contaminated water. These technologies are either community based or household treatment systems. The household treatment methods are also called as point-of-use (POU) methods as they are less expensive and quicker methods. Boiling, aeration, chlorine disinfection, sand filters, ceramic filters and solar oxidation are typical examples of POU methods of water treatment where the water is collected from single tap or source and is used for a specific purpose like cooking and drinking [30]. In community systems, many households in a society invest money and make a single treatment unit for common use.

The advanced and expensive methods for treatment for arsenic contaminated water are not affordable to many people in the world. To solve this problem, several house-

hold and inexpensive methods of arsenic treatment are identified. These methods are in practice in many parts of the globe. The rural method of arsenic removal technology can also be both community based and household based. However, this thesis describes the working mechanism and arsenic removal efficiency of only some of the widely practiced household arsenic treatment units.

8.1 Community based removal technology

Many people in the rural villages consume the water from common hand pumps or tube wells. If the groundwater contains arsenic, there is a high chance that most of the people living in those areas are affected by arsenic poisoning. Thus, the arsenic treatment unit is established in hand pumps or in tube wells in many rural villages where the ground water is arsenic contaminated.

Normally, the arsenic treatment unit attached to tube wells operates in intermittent flow of water. There are four stages of treatments which are mixing, flocculation, sedimentation and filtration. Sodium hypochlorite is added for the oxidation and alum for coagulation in the first stage; then there is mixing and flocculation followed by sedimentation and filtration of the water. The treated water is carried manually using a bucket or a jar [31]. The arsenic removal plant (Figure 6) developed by All India Institute of Hygiene and Public health by following this principle was found to be effective. It removed 90 % of the arsenic in tube well water having an initial concentration 300 $\mu\text{g/L}$ [30, 27].

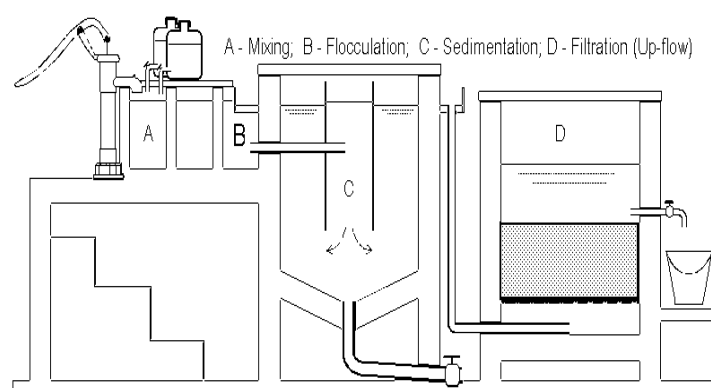


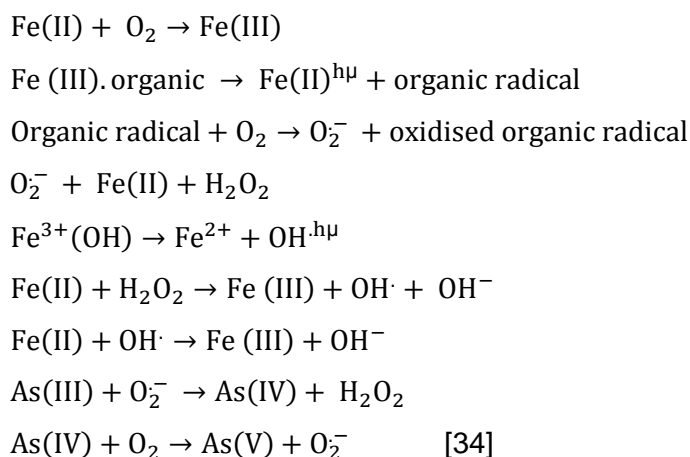
Figure 6. Arsenic treatment unit at tube wells [29]

8.2 Household technology

The concept of designing household arsenic treatment technology is to facilitate the poor people to consume arsenic-free water. Many poor countries cannot afford the centralised treatment methods for arsenic. As a result, many different types of economical arsenic treatment units are developed in the world. However, this thesis deals with only some common technologies that are practiced in highly arsenic-affected areas of South Asian zones. Solar oxidation and removal of arsenic, Arsenic bio sand filter, Sono filter, Bucket treatment units are some common POU methods of arsenic treatment that are described in this thesis. All these technologies are developed utilising the locally available materials and no fuel is used to operate them.

8.2.1 SORAS

SORAS stand for solar oxidation and removal of arsenic. It is one of the most economical methods of arsenic removal technology. A small transparent bottle, sunlight, lemon juice and the iron components in the water are necessary for this process. The bottle should be PET (Polyethylene Terephthalate) and transparent so that it would have good transmittance rate of UV-A light which is necessary for proper solar oxidation. Coloured bottle is not recommended as there is a chance of poor transmittance of light and the reaction of paint used to colour the material with UV can be hazardous. [32] In this technology, the irradiation of water uses sunlight to reduce the arsenic level in water by the photo oxidation method. To perform the SORAS action, the sample water should contain iron components, i.e. Fe (II). The SORAS process takes place in two stages; in the first stage, the As(III) is oxidised to As (V), and in second stage As(V) is then adsorbed into Fe(III) oxides which settles at the bottom of the container [33]. Lemon juice or tamarind extract is used as a natural source of acid to increase the rate of photo-chemical oxidation of As (III) and to reduce the arsenic concentration below 0.05 mg/l. The basic Chemistry of the SORAS process is given below:



Several experiments have already been performed to find out the efficiency of SORAS technology in many labs of the world. Majumder Ayan et.al. [34] had performed an experiment to find out the efficiency of SORAS technology at household level. They filled the 1 L PET bottle with 750 ml of ground water of A.G. Colony. The arsenic content measured was [As (III) = 235 µg/L and As (V) =25 µg/L] and after that 5 ml of tamarind extract (tartaric acid) was added to the water. After adding the extract, the bottle was shaken manually for 30 s and left in sunlight for 6-8 h. After illuminating in sunlight, the water was filtered using the fine cotton cloths and the filtrate was analysed for the total arsenic remained in the residual. The results are shown in Table 2 below.

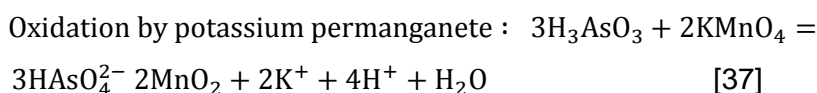
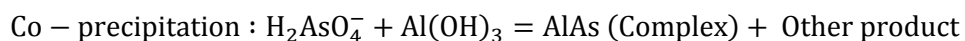
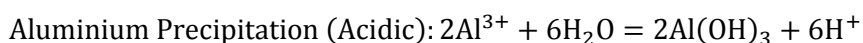
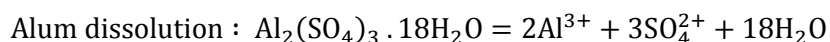
Table 2. Residual total arsenic in A.G. Colony ground water after an experiment in a closed PET bottle using tamarind extract of raw water with initial concentration of As (III) = 235 µg/L and As (V) = 25µg/L [34].

Experiment Number	Solar Intensity (kW/m ²)	pH		Residual total Arsenic in filtrate after 6-8 h of treatment (µg/L)
		Initial	Final	
1	0.3-0.7	Initial	Final	40
		7.4	8.1	
2		7.3	8.2	47

Table 2 shows that the arsenic removal by SORAS method in a closed PET bottle is actually possible. The bottle chosen should be transparent in nature. This method can be used as a household method of arsenic treatment. This is one of the cheapest and mobile methods of arsenic treatment. This method is equally effective for killing the viruses, bacteria and parasites present in water [35].

8.2.2 Bucket treatment unit

Bucket treatment unit (BTU) method of arsenic-contaminated water treatment is based on the coagulation, co-precipitation and adsorption process. This technology was developed by the DPHE-Danida Project. This unit consists of two buckets of 20 L which are placed one above another (See Figure 8). The arsenic contaminated water is poured on the top bucket and after that the chemicals containing 4 g of alum and 0.04 g of powered potassium permanganate is added in the raw water. The mixture is then stirred rapidly for a couple of minutes and allowed to settle after stirring. The settled water is then passed to the lower bucket with a pipe attached to the lower end of the upper bucket. The lower bucket has sand for sand filtration of the microflocks that come together with water from the upper bucket. The water that is filtered at lower level is collected through the tap connected at the bottom of the lower bucket. Here, in this process, the trivalent arsenic compound present in the raw water is oxidised to the pentavalent compound using potassium permanganate followed by co-precipitation, coagulation, flocculation (alum is used as flocculent) and finally sand filtration at the lower bucket [29]. The Potassium permanganate in the solution enables further oxidation of the trivalent arsenic compounds to pentavalent one. The Al-As complex obtained at the last stage is removed by the sedimentations filtration process. The system should be cleaned at least once a week. The chemistry behind the process is presented below and the schematic diagram of the process is shown in figure 7.



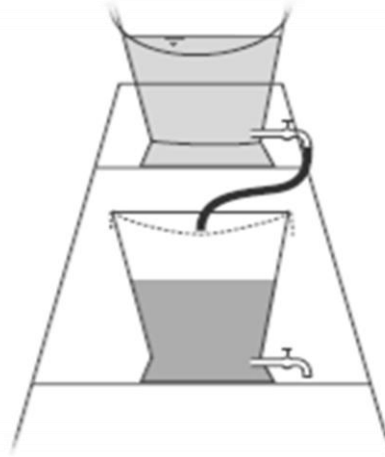


Figure 7 : Schematic diagram of bucket system of arsenic treatment [31].

To determine the arsenic removal capacity of the BTU system, Tauhara et.al. did a laboratory test (July – December 2000) of the 60 different samples of the raw water taken from 34 tube wells [36]. The samples were taken from 60 different households where the BTU systems were installed. The arsenic level was not uniform in all the samples; consequently, they divided the samples in 3 different samples i.e. 50-100 ppb, 101-200 ppb and >201 ppb (see Table 3). The arsenic level was measured after 30, 55 and 75 days. The result showed that 91.7 % (55) of households had less than 50 ppb of arsenic after 30 days, 100 % after 55 days and 93.3 % after 78 days (see Table 4). The result slowly declined after 55 days as the system required cleaning and as the sand should be boiled and washed in regular intervals. To improve the working efficiency of the system, the researchers suggested making the system stronger in structure and upgrading the quality of the bucket to be used. Table 3 and Table 4 below give the test results.

Table 3. Arsenic concentration in raw water [36].

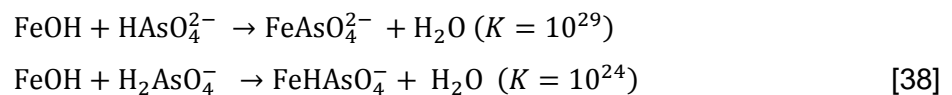
As (ppb)	Number of Selected Tube wells	Number of Families selected	Minimum Arsenic in raw water (ppb)	Maximum Arsenic in raw water (ppb)	Mean Arsenic in raw water (ppb)
50-100	18	29	50	98	74
101-200	9	21	109	192	149
>200	7	10	250	580	353
Total	34	60			

Table 4. Arsenic concentration in sample water after installation of a BTU system [36]

Arsenic concentration (ppb)	Number of households		
	30 days	55 days	75 days
0-50 ppb	55 (91.67 %)	60 (100 %)	58 (96.67 %)
More than 50 ppb	5 (8.33 %)	0 (0.00)	2 (3.33 %)
Total	60 (100 %)	60 (100 %)	60 (100 %)

8.2.3 Sono filter

This method is another simpler home-based method of arsenic treatment which uses the methods of oxidation, precipitation, adsorption and filtration for the arsenic removal from the drinking water. A Similar system is named as 3-Kalsi system in Bangladesh and 3-gargri system in Nepal. This filter is supplied to many households in Bangladesh and Nepal. The outlook of the system is very simple: three clay pots are put vertically above one another with small holes in the top and middle pot. The top and middle pots are reactor pots and the lower one is storage for the treated water. The top layer consists of polyester cloth at the bottom, 2 kg of coarse sand above it and 2 kg of iron chips (Composite iron matrix) covering the coarse sand. The middle bucket consists of polyester cloth at the bottom, 2 kg of fine sand above the polyester cloth and the 1 kg of charcoal above the fine sand. The system clears the water by the principles of adsorption and mechanical straining. Studies show that this method works efficiently in the pH range between 6.5-7.5 and can remove 90-95 % of the arsenic from water [4, 28]. This method is a surface complexation reaction. The primary chemical reaction of the system is as follows.



The schematic diagram and the possible chemical reactions in all the stages of the process are given in Figure 8 and Table 5 below.

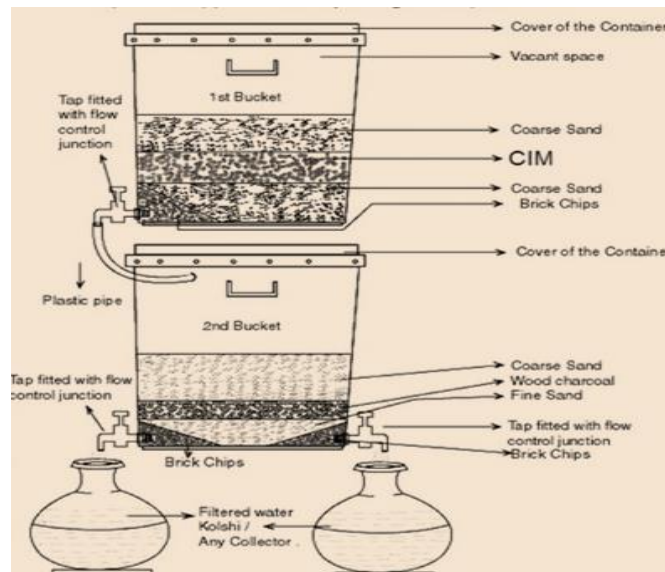


Figure 8. Schematic diagram of the Sono filter [38].

Table 5. Possible chemistry in Sono filters [38].

Reaction Location	Reaction
a. Oxidation of As(III) in top layer	$\text{As(III)} + \text{O}_2^- \rightarrow \text{As(IV)} + \text{H}_2\text{O}_2$ $\text{As(III)} + \text{CO}_3^- \rightarrow \text{As(IV)} + \text{HCO}_3^-$ $\text{As(III)OH}^- \rightarrow \text{As(IV)}$ $\text{As(IV)} + \text{O}_2^- \rightarrow \text{As(V)} + \text{O}_2^-$
b. Top bucket : Oxidation of soluble iron (ferrous to ferric)	$\text{Fe(II)} + \text{O}_2 \rightarrow \text{O}_2^- + \text{Fe(III)OH}_2^+$ $\text{Fe(II)} + \text{O}_2^- \rightarrow \text{Fe(III)} + \text{H}_2\text{O}_2$ $\text{Fe(II)} + \text{CO}_3^- \rightarrow \text{Fe(III)} + \text{HCO}_3^-$
c. CIM hydrous ferric oxide (HFO) [Fe(III) complexation and precipitation]	$\text{FeOH} + \text{Fe(III)} + 3\text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 \text{ (s, HFO)} + = \text{FeOH} + 3\text{H}^+$ <p>[FeOH is a surface hydrated iron]</p>
d. CIM –HFO surface (surface complexation and precipitation of As(V))	$\text{FeOH} + \text{AsO}_4^{3-} + 3\text{H}^+ \rightarrow = \text{FeH}_2\text{AsO}_4 + \text{H}_2\text{O}$ $= \text{FeOH} + \text{AsO}_4^{3-} + 2\text{H}^+ \rightarrow = \text{FeHAsO}_4 + \text{H}_2\text{O}$ $= \text{FeOH} + \text{AsO}_4^{3-} + \text{H}^+ \rightarrow = \text{FeAsO}_4^{2-} + \text{H}_2\text{O} = \text{FeOH} + \text{AsO}_4^{3-} \rightarrow = \text{FeOHAsO}_4^{3-}$
e. Top two buckets : precipitation of other metals [Bulk precipitation of arsenate with soluble metal ions]	$\text{M(II)} + \text{HAsO}_4^{2-} \rightarrow \text{M}_2(\text{HAsO}_4)_3 \text{ (s), M} = \text{Fe, Al, M(II)} + \text{HAsO}_4^{2-} \rightarrow \text{M}(\text{HAsO}_4) \text{ (s) and other arsenates}$ <p>M = Ba, Ca, Cd, Pb, Cu, Zn & other trace metals</p>

<p>f. CIM and sand interface [reaction with iron surface and sand can produce a porous solid structure with extremely good mechanical stability for the filter known as solid CIM]</p>	$\text{FeOH} + \text{Si}(\text{OH})_4 \rightarrow = \text{FeSiO}(\text{OH})_3 (\text{s}) + \text{H}_2\text{O}$ $\text{FeOH} + \text{Si}_2\text{O}_2(\text{OH})_5^- + \text{H}^+ \rightarrow = \text{FeSi}_2\text{O}_2(\text{OH})_5 (\text{s}) + \text{H}_2\text{O}$ $\text{H}_2 \text{FeOH} + \text{Si}_2\text{O}_2(\text{OH})_5^- \rightarrow = \text{FeSi}_2\text{O}_3(\text{OH})_4^- (\text{s}) + \text{H}_2\text{O}$ $\text{FeOHAsO}_4^{3-} + \text{Al}(\text{III}) \rightarrow = \text{FeOHAsO}_4\text{Al} (\text{s})$ $\text{FeOHAsO}_4^{3-} + \text{Fe}(\text{III}) \rightarrow = \text{FeOHAsO}_4\text{Fe}(\text{s})$ $\text{FeOH} \cdot \text{HAsO}_4^{2-} + \text{Ca}(\text{II}) \rightarrow = \text{FeOH} \cdot \text{HAsO}_4\text{Ca} (\text{s})$
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Hussaam et. al. [38] had performed a test to determine the total arsenic concentration in six different tube wells of six different household in Bangladesh. A Sono arsenic filter was installed in all houses, and a test was also performed to determine the arsenic removal capacity of the filter. The test period was 2000-2005, and all the filters were actively used for 2.3 -4.5 years by the householders. The flow rate of the filter was 20-30 L/hr. Total arsenic was measured by using anodic stripping voltametry (ASV) on thin film gold electrode and graphite furnace atomic absorption (AA). The result obtained showed that all the filters were capable of filtering the arsenic below the level of 10 µg/L even if the input range was much higher, from 32 µg/L -2423 µg/L. The filter was equally capable of removing the excess iron as well. The data shows that the cost of treated water decreases by increasing the amount of water to be treated. Test results are given in Table 6 below.

Table 5. Result of six Sono filters monitored in Bangladesh [38].

Parameters	Filter 1 (Fatic village)	Filter 2 (Courtpa- ra village)	Filter 3 (Zia village)	Filter 4 (Alarmpur Village)	Filter 5 (Ka- liskhnpur village)	Filter 6(Juniadah village)
Years in use	2.32	4.5	2.66	3.6	4.44	2.5
Number of Measurements	10	110	12	14	56	8
As concentra- tion in raw wa- ter (µg/L)	32 ± 7	155 ± 7	243 ± 7	410 ± 15	1139 - 1600	2423 ± 87
As concentra- tion in filtered water (µg/L)	<2	7 ± 1	7 ± 1	8 ± 2	7 ± 2	8 ± 4

8.2.4 Arsenic biosand filter

Arsenic biosand filter (ABF) is one of the most economical and effective rural technologies to remove the arsenic from the drinking water. This filter is a developed version of the conventional biosand filter developed by Canadian Professor Dr. David Manz of University of Calgary in late 90s [39]. Many countries of the world, for example Nepal, Bangladesh, India, Vietnam, Brazil and Nicaragua are practicing this system to mitigate the arsenic problem. The major differences between the conventional biosand filter and arsenic biosand filter is that the ABF contains iron nails, while the conventional does not and that the diffuser basin is introduced in the biosand filter as an arsenic removal unit. This filter not only removes arsenic but also removes the pathogens, colloids, viruses and turbidity from the water [3, 40, and 41].

The arsenic biosand filter has two layers in general i.e. pathogen removal unit and arsenic removal unit. The lower part is a pathogen removal unit and the upper part is an arsenic removal unit. It is made by using the locally available materials, such as iron nails, coarse sands, polyester cloth, gravels and fine sand. The dimensions of the filters can be adjusted according to the need. The arsenic removal unit is made up of iron nails, a metal diffuser box and a polyester cloth, while the pathogen removal unit has fine sand, coarse sand and gravels. The brick chips help to keep the iron nails stable when the water is poured through the top of the filter. The nails also work as iron oxide sand which helps to absorb some arsenic contaminants [41]. The schematic layout of the ABF is presented in figure 9 below.

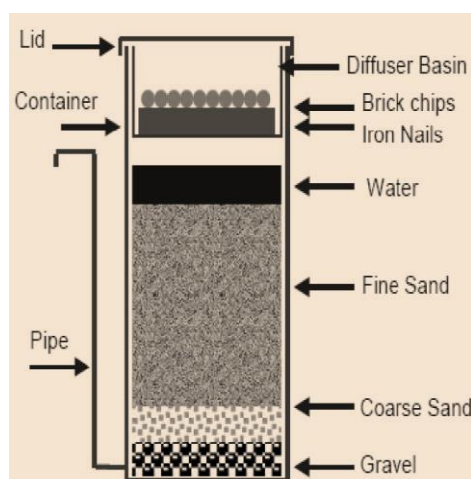
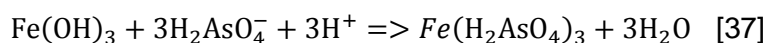


Figure 9. Kanchan arsenic biosand filter [42].

The arsenic biosand filter works on the principle of iron hydroxide adsorption and the slow sand filtration mechanism. The contaminated water is passed through the top of the filter which percolates slowly down to the diffuser layer and pathogen removal layer and the clean water appears from the outlet [43].

The iron nails in ABF are exposed to air and water, which makes it easier for them to rust quickly forming ferric hydroxide particles. Thus, when the arsenic contaminated water is passed into the filter, the arsenic species comes in contact with the ferric hydroxide particles. Since Ferric hydroxide is an excellent adsorbent of the arsenic, they come in contact with the iron rust for surface complexation reaction. Due to this reaction, the arsenic species are absorbed into the rusted iron nails. The arsenic loaded iron particles are then flushed on to the underlying fine sand layer and settle on top of the fine sand layer and only the arsenic free water goes below the fine sand layer [44]. This is how the arsenic is removed from the water in arsenic biosand filter. The possible chemical reaction is given below.



To evaluate the potentiality of the ABF, Ngai et.al had performed a research in Cambodia by installing 10 Kanchan Arsenic Filters in 5 different configurations (42). The test was conducted for 30 weeks (Feb 3 –August24 2008) by filtering 40 L/day by each filter. The average arsenic concentration of raw water was 637 µg/L. The samples were collected every week and tested on site and in ITC's laboratory. After the careful observation for 30 weeks, it was discovered that the entire configuration filter was capable of removing 95-97 % of the arsenic concentration. The graph that illustrates the arsenic concentration of raw water and filtered water by KAF in the original design is given in Figure 11. Filter 1 and Filter 2 are two different filters of same configuration with 5 kg of new iron nails in diffuser.

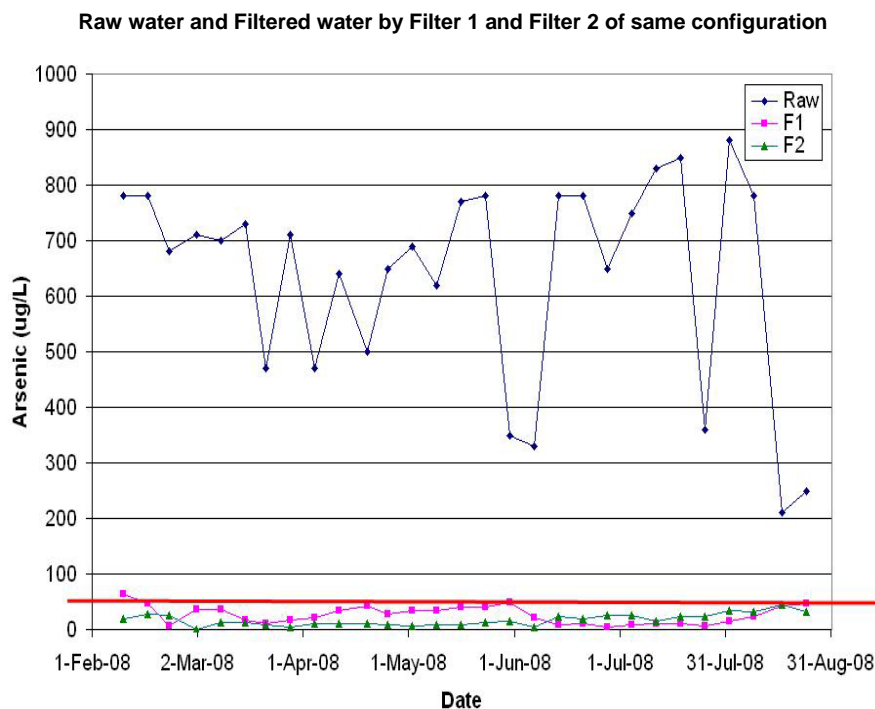


Figure 10. Arsenic filter capacity of KAF [42].

The blue line in Figure 10 shows the variation of arsenic concentration in the ground water of different areas during the test period. The straight brown line is a threshold value of consumable arsenic concentration in Cambodia, which is 50 $\mu\text{g/L}$. The pink dotted line is for Filter 1 of the original KAF design and the green one is for Filter 2 of the original KAF design. This test proves that the KAF is one of the fantastic home based technologies to treat the arsenic-contaminated water.

Apart from Arsenic removal, the ABF can also remove pathogens from the water. The pathogen removal unit (bio layer) is the major component for the pathogen removal from the water. During the filtration process, foreign particles like dust, dirt, organic substances and iron particles start to settle on the top of the fine sand layer forming a cake. This cake later on changes into biofilm layer when there is sufficient nutrients, organic carbons, dissolved oxygen for the growth of microbes like algae, bacteria n protozoa which come via the polluted water to be treated. Depending upon the quality of water and the intensity of use of the filter it may take up to 30 days for the formation of the biofilm. When the biofilm is ready, the incoming pathogens from the polluted water are trapped and eaten by the already existing predator organisms in the biofilm layer. The filter is cleaned by scrapping off the biofilm [45]. Thus, in short, the pathogens are removed by four steps, i.e. mechanical trapping (sediments and pathogens are

physically trapped in the space between the grains), predation (pathogens are consumed by the already existing microbes in the biofilm layer), adsorption (pathogens attached to sediments and each other) and natural death due to lack of food [44, 45].

9 Comparison of above mentioned rural methods of Arsenic Treatment

All the above described rural technologies are practiced in many countries of South Asia. Most of the rural technologies to treat arsenic should be easy to construct, cheaper in nature and user friendly. No chemicals or easily available materials (can be chemicals as well) are used in all above mentioned technologies. However there are some differences in the arsenic removal efficiency, sustainability and in other aspects. Some major differences that are to be noticed while selecting the options are presented in Table 7.

Table 6. Differences between the rural technologies to treat arsenic contaminated water.

S No	Evaluation table	SORAS	BTU	SONO	Biosand Filter
1	Working Mechanism	Solar Oxidation	Coagulation, co-precipitation and adsorption	Oxidation, precipitation, adsorption and filtration	Iron hydroxide adsorption and slow sand filtration
2	Raw materials needed	Sunlight, transparent bottle, natural acid like lemon juice or tartaric acid	2 buckets, alum powder, potassium permanganate powder, fine sand	3 clay pots, coarse and fine sand, iron chips, charcoal	Iron nails, metal diffuser box, polyester cloth, brick chips, fine sand, gravel and coarse sand
3	Arsenic removal efficiency	Over 80 %	Over 90 %	90-95 %	95-97 %
4	Other contaminants removal	Viruse, pathogens, bacteria and parasites	Viruses, pathogens, bacteria and parasites	Iron, pathogens, bacteria	Pathogens, colloids, viruses and turbidity
5.	Overall evaluation	4 th	3 rd	2 nd	Best

10 Other approaches for arsenic mitigation

Most of the arsenic contaminated wells are reported to be shallow in nature. Also, there is high risk of other pollution if the water is taken from the sources with shallow aquifers. Hence, the construction of deep wells can be one approach to mitigate the arsenic problem on a long term basis [46]. No approaches can be effective if the person who uses the source does not know much about the effect of arsenic poisoning and the idea to get the arsenic-free water for their daily consumption. Therefore, the public awareness about being safe from the arsenic contamination should be promoted. Pokhrel et.al suggests that one of the best methods to mitigate the arsenic poisoning is to change the source and explore the safe sources rather than investing for contaminated sources [3]. Properly stored rain water can be another good source of drinking water to the people residing in the location where there is high concentration of arsenic in the sources [47]. Industrialisation activities, mining activities and solid waste disposal near the source area also contaminate the water with arsenic and other chemicals. Rainwater is the major transporter of these contaminants to the source. Therefore, all those activities are should be carried out far away from the residential area. The practice of community treatment systems can also be one of the economical methods of long-term mitigation of the arsenic problem as the cost can be shared by all the houses in the area and other donors.

11 Conclusion

Millions of people in the world are suffering from arsenic contamination by consuming t arsenic-polluted water. To solve this problem, various high-tech mitigation approaches as well as rural methods are identified. Most of the people suffering from arsenic contamination are from poor backgrounds. Therefore, the mitigation approaches should be focused on the rural and household level. Several economical and effective POU mechanisms like SORAS, BTU, Sono filter and arsenic biosand filter are used in many rural parts of the globe as arsenic mitigation approaches.

After studying and analyzing the experiments published in several journals, it was easier to claim that all of the above mentioned technologies are excellent home-based rural technologies to reduce the arsenic level below the WHO standards. SORAS technology can remove over 80 % of arsenic from the contaminated water. Similarly, BTU and Sono filters were reported to remove 90 % of the arsenic contamination. The ABF

technology, which is the best among all these household mitigation methods, can remove over 95 % of the arsenic in the contaminated water. To remove arsenic efficiently for a long period, the filters are supposed to be cleaned at regular intervals. These methods are easy to operate and handle; thus, a small demonstration about maintaining the filter in good condition can be enough. In addition to arsenic, these technologies are also capable of removing viruses, bacteria, pathogens and colloids, for example. Apart from these technologies, other mitigation approaches such as Rain water harvesting, proper industrial and mining activities are other activities to mitigate the arsenic poisoning. However, without proper coordination of locals and other helping bodies, the mitigation approaches cannot be successful. Therefore, the first priority should be to public awareness.

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