Removal of Poisonous Arsenic from Groundwater in South and East Asian Countries

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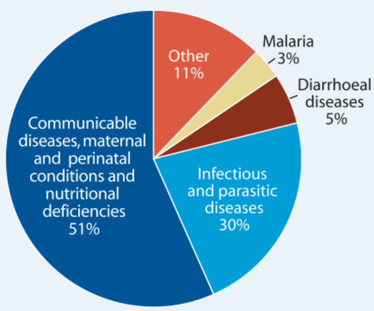
Abstract

Arsenic is used in many forms of pesticides, herbicides, crop desiccants, and additives in livestock feed, particularly for poultry [1]. The environmental exposure to arsenic can have drastic effects due to its carcinogenic properties, ranging from skin lesions to death from internal cancer. In 1993, The World Health Organization (WHO) has reduced the guideline arsenic concentration value (ACV) from 50 $\mu g\ L^{-1}$ to 10 $\mu g\ L^{-1}$ because of the increased evidence of its toxic effects on humans; however, most developing countries are using the former ACV due to economic constraints and the lack of tools and techniques [1]. Many international agencies and nongovernmental organizations, including the United Nations Children's Fund (UNICEF) and World Vision International, have carried out screening programs necessary for measuring arsenic concentration of the groundwater in regions of Bangladesh, China, India, Nepal, Taiwan, Myanmar, Cambodia, and Pakistan. Additionally, scientists have analyzed the hydrogeochemistry of arsenic better to understand their mobility with other minerals present in groundwater and to determine those removal processes that are highly effective.

Background

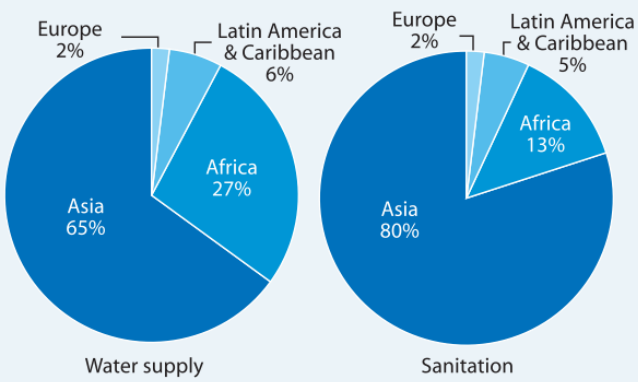
In South and East Asia, over 60 million people are at risk from arsenic contamination in groundwater and at least 700,000 people have been affected by arsenicosis [1]. This is mainly due to natural occurrence through desorption from iron and other metal oxides, but human activities have increased the level of arsenic into the environment. Farmers use arsenic for preservation purposes, especially for feedstock and wood. The countries that are affected with this chronic issue include Bangladesh, China, India, Nepal, Taiwan, Myanmar, Cambodia, and Pakistan. China and India are currently the leading countries with the most identified arsenicosis patients with numbers at 500,000 and 200,000, respectively [1]. The health effects of high concentrations of arsenic can be fatal; the common ones include skin and internal cancer, Blackfoot disease, diabetes, and cerebrovascular disease [1]. In 2000, all 191 United Nations (UN) Member states, including the United States of America, agreed to establish the Millennium Development Goals, that "set specific targets for reducing poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women by 2015 [2]." For the environmental issues concerning clean water, the UN has created the Water for Life Decade (2005-2015), a proposed plan to improve water sanitation in developing countries. Figure 1 displays the types of deaths associated with unsanitary water. Based on the world's population, Figure 2 shows that Asia is the primary continent unserved by water sanitation. WHO and UNICEF have been working together in the Joint Monitoring Program for Water Supply and Sanitation to provide pertinent data and household surveys every two years in developing countries around the world. A milestone has already been achieved in 2010 before the UN's Water for Life Decade; the proportion of the population without sustainable access to safe drinking water between 1990 and 2015 has been halved [3]. In Asia, WHO,



Deaths from water-associated diseases, estimates for 2001
This chart shows the breakdown of deaths caused by water-related diseases, the majority of which result from communicable diseases, maternal and perinatal conditions and nutritional deficiencies. Other causes include infectious and parasitic diseases; diarrhoeal diseases; and malaria.

Source: WHO, 2002.

Figure 1 [2]



Water supply and sanitation— distribution of unserved population
The vast majority of the world's people who are unserved by either water supply or sanitation live in Asia. Yet it is important to note that within Africa the proportion of people without these services is higher than within Asia.

Source: WHO/UNICEF Joint Monitoring Programme, 2002.

Figure 2 [2]

UNICEF, and other NGOs concluded that the high concentration of arsenic present in the groundwater and aquifers is primarily due to mining as arsenic is present in many sulfide and oxide minerals. With the large degrees of spatial and temporal variability, measurements can be time consuming and costly. The method for field-testing, adopted by UNICEF and other NGOs, is called blanket testing that involves randomly testing wells of equal distances apart. Depending on the availability of resources, either field test kits or sophisticated laboratory instruments, such as the hydride generation-atomic absorption spectrometry (HG-AAS), were used to measure the groundwater present in aquifers of dug wells, deep tube wells, alluvial, deltaic, and lacustrine plains [1]. Testing a well can provide important information regarding the water supply in that given area. As a result of this process, many pumps that draw groundwater from aquifers have been marked unsafe, leaving fewer water stations open for the communities.

This report encompasses the World Bank's report on several types of purification systems that scientists consider effective for removing arsenic from groundwater for the developing countries in South and East Asia.

Methods for Remediation

There are four types of removal techniques for the purification tanks: oxidation and sedimentation, coagulation and filtration, sorptive filtration, and membrane filtration.

Oxidation and Sedimentation

The oxidation-sedimentation process converts noncharged arsenite (As_2O_3) into arsenate (AsO_4^{3-}) that can be easily removed from water. Air oxidation can be achieved through catalysis, by bacteria, strong acidic or alkali solutions, copper, power activated carbon, and high temperature. This allows the arsenic to be adsorbed and therefore precipitate; however, this method cannot reduce the concentration to the recommended level when the content is high.

Coagulation and Filtration

The coagulation-sedimentation-filtration process consists of three mechanisms: precipitation, coprecipitation, and adsorption. As insoluble compounds precipitate, arsenic is then incorporated into a growing metal hydroxide phase. This allows them to bind to the surfaces of insoluble metal hydroxides and therefore filtered from the groundwater. This process has been proven to be effective and there are currently five types of purification units being used in several communities: the bucket treatment unit, the unit by Stevens Institute of Technology, the fill and draw treatment unit, the tube well-attached arsenic treatment unit, and the iron-arsenic treatment unit. Figure 3 shows the layout of the double bucket household arsenic treatment unit. It consists of two buckets placed one on top of the other. The chemicals are mixed with the arsenic-contaminated water, which allows flocculation. Then the water is poured into the bottom bucket, where sand filtration is used. The Stevens Institute of Technology also uses two buckets, one to mix the chemicals and the other to separate; however, the second bucked has an inner container with slits to help the sedimentation process and keep the sand bed in place (Figure 4). The fill and draw system, by the DPHE-Danida Project, is a community-level treatment unit with a tank size of 600 liters with manually operated blade impellers. The tank is filled with arsenic-contaminated water and oxidants and coagulants are added as well. The water is then mixed and then left overnight for sedimentation. The settled water is then drawn through a pipe into a filtration unit where treated water is finally collected (Figure 5). Figure 6 shows the tube well-attached arsenic removal unit designed by the All India Institute of Hygiene and Public Health (AIIH&PH). This treatment system involves the addition of sodium hypochloride and aluminum alum as coagulants during the mixing process. The filtration process in this system is up flowing after the sedimentation process, depicted as D on the figure.

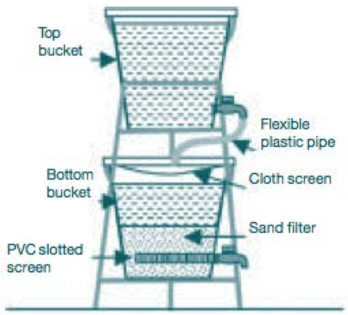


Figure 3: Double Bucket Household Arsenic Treatment Unit [1]

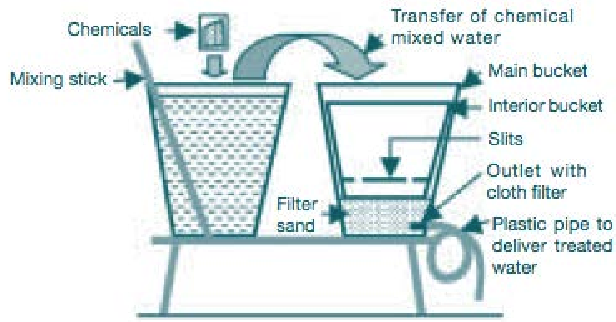


Figure 4: Stevens Institute of Technology Unit [1]

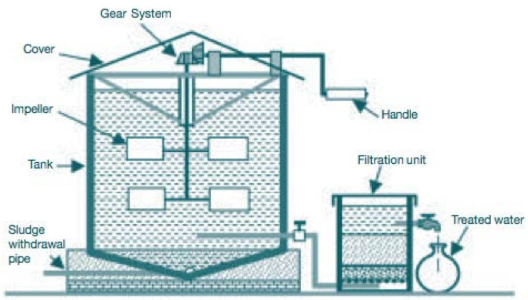


Figure 5: DPHE-Danida Fill and Draw Arsenic Removal Unit [1]

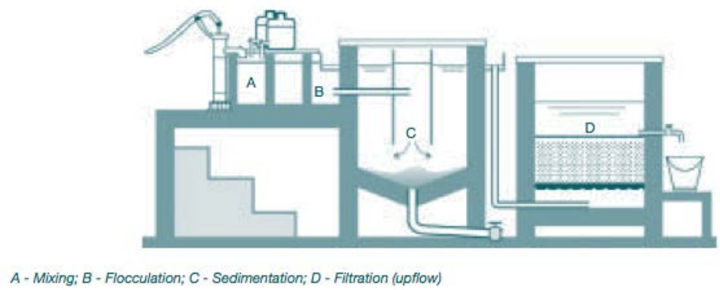


Figure 6: Tube well-Attached Arsenic Removal Unit designed by All India Institute of Hygiene and Public Health [1]

Sorptive Filtration

The sorptive-filtration system is composed of media, pre-injected with an oxidizing agent that causes arsenic to adsorb. The efficiency of this system depends of the media and the oxidizing agent. The most commonly used media for arsenic removal include: activated alumina, granulated ferric oxide and hydroxide, metallic iron, iron-coated sand or brick dust, cerium oxide, and ion exchange media. The medium can be saturated and exhausted after a period of time; the medium can no longer remove the impurities and must be replaced. There are five units that follow the sorptive filtration process: the Alcan enhanced activated alumina unit, the granular ferric hydroxide-based arsenic removal unit, the three kalshi filter for arsenic removal, the Shapla filter for arsenic removal at household level, and the tetrahedron arsenic removal technology.

In the Alcan enhanced activated-alumina unit (Figure 7), no chemicals are added during the process and solely relies on the media to adsorb the arsenic. This unit can produce more than 3,600 liters of clean water before the media is saturated with impurities [1]. The granular ferric hydroxide (Figure 8) has the capacity to remove 45 grams of arsenic and 16 grams of phosphorous per kilogram of dry ferric hydroxide. The setup of this unit requires a pretreatment that oxidizes water and removes iron flocs in the gravel filter bed. The effluent travels to another filtration system, the adsorption bed, which contains the activated media to adsorb the arsenic. The three-kalshi filtration unit (Figure 9) is composed of two small filter mediums in burned clay pots. The raw water travels through the first medium containing 2 kg sand on top and 3 kg of iron fillings on the bottom. Then, the water travels through the second medium, which includes 2 kg more of sand, then 1 kg of charcoal, and then 2 kg of brick chips. Finally, the third clay pot collects the filtered water. In the Shapla household level filtration unit (Figure 10), developed by the International Development Enterprises (IDE), Bangladesh, raw water travels through a media composed of brick chips that are coated with ferrous sulfate. A cloth filter covers the exit stream after the filtration to prevent the brick chips from traveling through. A pipe connected to the bottom of the tank releases the treated water in a bucket. Tetrahedron, United States and Water System International (WSI), India partnered together to develop a unit that uses the ion exchange process (Figure 11). First the raw water is treated with chlorine to kill bacteria and oxidize arsenic and iron. After the water passes through the stone chips, it is piped to a resin column with a column head tap. The resin column has three layers: the first layer oxidizes As(III) to As(V), the second layer removes As(V), and the bottom layer contains activated alumina to further extract more arsenic from the treated water.

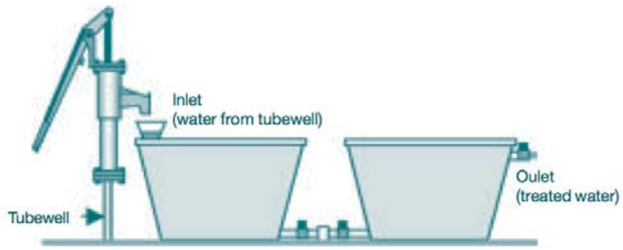


Figure 7: Alcan enhanced activated-alumina unit [1]

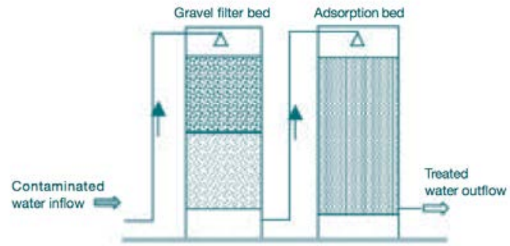


Figure 8: Granular Ferric Hydroxide-Based Arsenic Removal Unit [1]

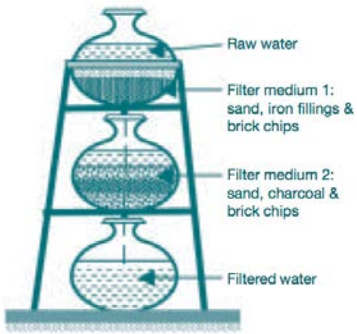


Figure 9: Three Kalshi Filter for Arsenic Removal [1]

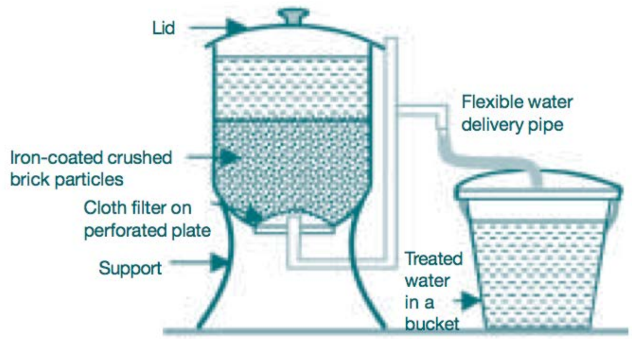


Figure 10: Shapla Filter for Arsenic Removal at Household Level by IDE [1]

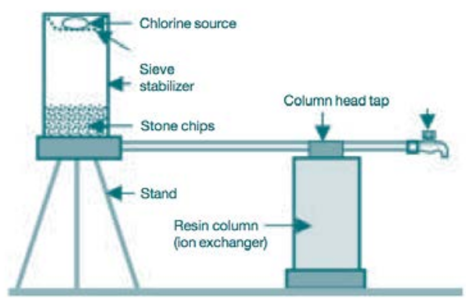


Figure 11: Tetrahedron Arsenic Removal Technology [1]

Membrane Filtration

Another process uses membrane filtration. Synthetic membranes can remove impurities from water, including bacteria, viruses, salts, and various metal ions. There are two types of membrane filtration systems: low-pressure membranes, used in microfiltration and ultrafiltration; and high-pressure membranes, used in nanofiltration and reverse osmosis. The latter have pore sizes appropriate to the removal of arsenic [1]. Membrane filtration is special because this process is independent of pH; however, a pretreatment unit, usually containing chlorine or iodine to kill bacteria and viruses, is required before pumping the contaminated water through the membrane.

Results

Table 1 lists the results with the four-filtration processes for arsenic-contaminated water.

Technology	Advantages	Disadvantages
Oxidation and sedimentation: air oxidation, chemical oxidation	• Relatively simple, low cost, but slow process (air) • Relatively simple and rapid process (chemical) • Oxidizes other impurities and kills microbes	• Processes remove only some of the arsenic • Used as pretreatment for other processes
Coagulation and filtration: alum coagulation, iron coagulation	• Relatively low capital cost • Relatively simple in operation • Common chemicals available	• Not ideal for anion-rich water treatment (e.g. containing phosphates) • Produces toxic sludge • Low removal of As(III) • Preoxidation is required • Efficiencies may be inadequate to meet strict standards
Sorption techniques: activated alumina, iron-coated sand, ion exchange resin, other sorbents	• Relatively well known and commercially available • Well-defined technique • Many possibilities and scope for development	• Not ideal for anion-rich water treatment (e.g. containing phosphates) • Produces arsenic-rich liquid and solid wastes • Replacement/regeneration is required • High-tech operation and maintenance • Relatively high cost
Membrane techniques: nanofiltration, reverse osmosis	• Well-defined and high removal efficiency • No toxic solid wastes produced • Capable of removal of other contaminants	• High capital and running costs • High-tech operation and maintenance • Arsenic-rich rejected water is produced

Table 1: Comparison of Main Arsenic Removal Technologies [1]

Conclusion

Arsenic is a severe poison. Even low concentrations of arsenic in water can cause serious illness and death. As a result of efforts from the United Nations (UN), World Health

Organization (WHO), and many Non-governmental organizations (NGOs), the number of deaths caused by unsanitary water has decreased substantially. In the 2012 update from the United Nations Children's Fund (UNICEF) and WHO, the percent of the population suffering from unsanitary water has decreased more than half, from 24 to 11 from 1990 to 2010, respectively [3]. Many wells and pumps have been marked unsafe as they exceed the recommended consumption of arsenic in water. Therefore, many companies and research institutes have been creating filtration systems to help account for the loss of contaminated wells and pumps. The types of filtration systems depend on the size of a community. Although these systems have been producing good results, there are disadvantages for developing countries, such as high cost or high-tech. Some purification tanks require extensive maintenance that may be too difficult for the community to sustain. The oxidation and sedimentation filtration process is very simple and cost-effective; however, this process only removes some arsenic from the water. At present, for developing countries, this process is likely to be more effective than other methods for remediation.

References

This report gives an overview and summary of the original volumes from the staff of the International Bank for Reconstruction and Development/The World Bank and of the Water and Sanitation Program. The findings, interpretations, and conclusions expressed in this paper do not necessarily reflect the views of the Executive Directors of the World Bank or the governments they represent.

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[1] "Arsenic Contamination of Groundwater in South and East Asian Countries." *Worldbank.org*. Web. 20 Mar. 2012. <http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:22392781~pagePK:146736~piPK:146830~theSitePK:223547,00.html>.

[2] "International Decade for Action Water for Life 2005-2015: Homepage." *UN News Center*. UN. Web. 10 Apr. 2012. <http://www.un.org/waterforlifedecade/>.

[3] "Progress on Drinking Water and Sanitation." *WHO*. Web. 10 Apr. 2012. <http://www.who.int/water_sanitation_health/publications/2012/jmp_report/en/index.html>.