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ARSENIC BIOSAND FILTERS IN DEVELOPING COUNTRIES

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Abstract

Arsenic is a common pollutant in many developing countries and has been linked to cancer and cardiovascular disease. In this research, biosand filters (BSFs) were modified with iron filings to remove arsenic from contaminated water. Six BSFs (three with 1 kg of iron filings and three without iron filings) were simultaneously dosed with 20 liters of Muskegon Lake water that contained 100 µg/L of arsenic for 30 days. Arsenic concentrations were determined using a HACH low range arsenic test kit. The mean arsenic removal rate for all 3 BSFs with iron filings was 100% for 13 days, but later was reduced to 60% as one of the unit's flow decreased. Mean arsenic removal in BSFs without iron filings started at 50% and declined to 0% after 14 days as the natural iron in the sand was saturated with arsenic. The arsenic removal rate for all BSFs with iron filings was ~94% and ~22% without. Iron filings are a common waste product and our results suggest they may be useful in removing arsenic from water.

Introduction

Water is the foundation for life and all body systems depend on it. High concentration of arsenic in natural water systems possess a threat to over 200 million people worldwide (Mandal and Suzuki, 2002; Smedley and Kinsburg, 2002; Baig et al., 2013). Approximately 137 million people in 70 countries have been affected by arsenic contaminated drinking water (Chowdhury et al., 1999). In developing countries, natural and readily available waters such as shallow groundwater, surface water, water from boreholes and springs are the main sources of drinking water (Noubactep et al., 2009). In Kenya, majority of the arsenic in the water wells originate

from contaminated post-mining equipment buried close to the water table. Due to the high incidences of cancer in the region, it is speculated that the arsenic concentrations in the water are higher than the World Health Organization (WHO) recommended value of 0.01mg/L (Chen et al., 2008; WHO 1996). Furthermore, WHO has classified arsenic as group 1 carcinogenic element (Cutter, 1998; NRC, 1999; USEPA, 2000), meaning it is known human carcinogen.

According to previous research, arsenic can originate from natural sources such as geochemical reactions and volcanic emissions as well as anthropogenic activities such as mining, industrial waste discharge, and agricultural use of arsenic pesticides (Wang and Tsang, 2013). Arsenic also is abundantly available in the earth's crust (20th most common) sea water (14th most common) and human body (12th most common) of all existing elements (Lyman et al., 1998; Matschullat, 2000). In a similar study, the total amount of arsenic in the global arsenic cycle is 3.7×10^6 kt in the oceans, 9.97×10^5 kt on the earth (land) and 25×10^9 kt in sediments and 8.12 kt in the atmosphere (Mackenzie et al., 1979). In the aqueous environment inorganic arsenic appears in the oxidation states +V as arsenic acid, As (V) and +III as arsenous acid As (III), and their salts.

Inorganic arsenic consist of derivatives such as arsine gas and compounds such as monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) which are methylated by bacteria, fungi, and yeast (M. Bissen et al., 2003). Furthermore, arsenic is also a constituent of more than 245 minerals. Natural sources of arsenic such as volcanic eruptions produce high arsenic concentrations. Anthropogenic sources of arsenic are from the disposal of chemical waste, smelting of arsenic bearing minerals, burning of fossil fuels and application of arsenic compounds in consumer products. However, it should be noted that the toxicity of arsenic

depends on its chemical form in that organic arsenic compounds are less toxic than the inorganic arsenic compounds (M. Bissen et al., 2003).

The total amount of arsenic emitted to the atmosphere include: 17 150 t by volcanoes, 27 t by oceans, and in 125-3 345 t by burning of wood and oil and by naturally occurring forest fires (Matschullat et al., 2000). In areas not influenced by human activities, air contains arsenic concentrations of only a few nanograms per cubic meter (Umweltbundesamt, 2003; M. Bissen et al., 2003). In sea water the concentration of arsenic varies between 0.09 $\mu\text{g/L}$ and 24 $\mu\text{g/L}$ (average: 1.5 $\mu\text{g/L}$), and in freshwater between 0.15 $\mu\text{g/L}$ and 0.45 $\mu\text{g/L}$ (maximum: 1 mg/L) (Leonard, 1991; M. Bissen et al., 2003). In mineral and thermal waters, arsenic was found in concentrations up to a factor of 300 of the mean concentration of arsenic in groundwater (Rude, 1996; M. Bissen et al., 2003). Arsenic exists in multiple oxidation states and each with different toxicities based on solubility in different environments. Arsenate, As (V) and arsenite As (III) are the most common inorganic forms of arsenic in aquatic environments. Arsenate species are considered to be soft acidic mostly present in surface water and stable in aerobic environments while arsenite species are considered hard acidic and stable in moderately anaerobic environments such as underground water (Baig, 2013; Wang and Tsang, 2013). Moreover, As (III) has a higher toxicity and mobility than As (V) therefore needs to be oxidized to form As (V), which is readily adsorbed (Onnby et al., 2012). Long term exposure to arsenic leads to serious carcinogenic effects in mankind which include: skin, cardiovascular, neurological, renal and respiratory diseases (Hotta, 1989; Matschullant, 2000; Bissen and Frimmel, 2003; Sofuogluet al., 2009; Li et al., 2012). The arsenic cycle for both the natural and anthropogenic sources is shown in Figure 1.

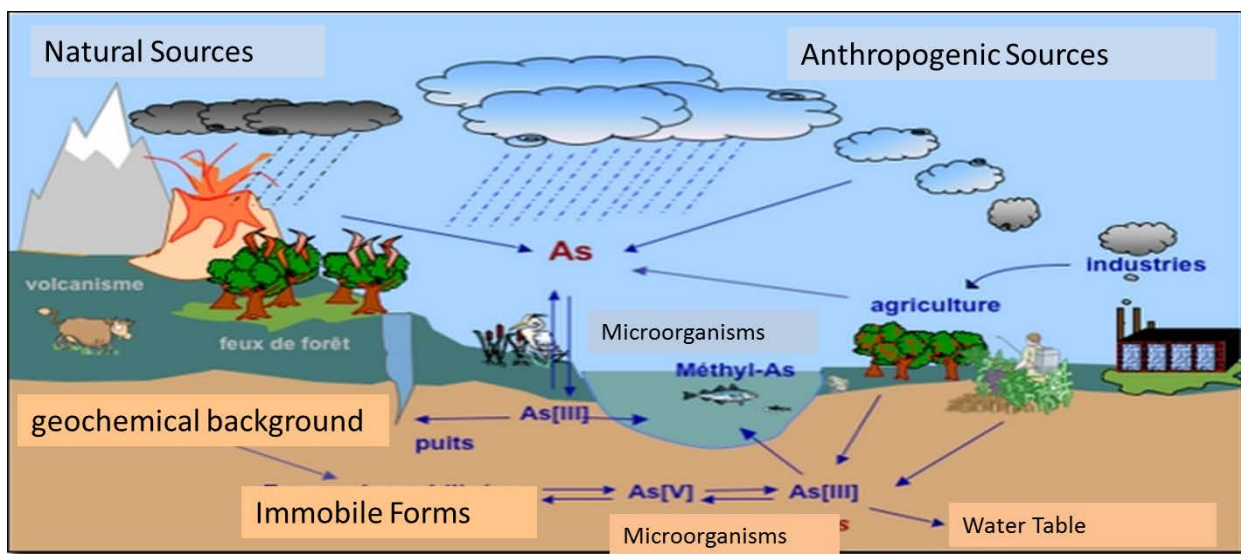


Figure 1. Arsenic cycle for natural and anthropogenic sources
<http://coursenligne.u-strasbg.fr/pages.jsp?idsite=279>

Even though Arsenic is considered to be an essential element, most arsenic compounds are toxic. Furthermore, trivalent arsenic (As (III)) is resorbed faster in biological systems than pentavalent arsenic (As (V)) but both work to inhibit the energy-linked functions of mitochondria in the body. As (III) compounds also have a high affinity to sulfhydryl groups in proteins and cause deactivation of enzymes. As (V) competes with phosphate in cell reactions and can uncouple oxidative phosphorylation so that the high-energy bonds of adenosine triphosphate are not conserved (Squibb and Fowler, 1993; Gorby et al., 1994; Pontius et al., 1994; M. Bissen et al., 2003). In a study by Krishnamohan et al., 2007, mice were exposed to sodium arsenate with the aim of studying urinary arsenic methylation and porphyrin profile. Initially, methylated arsenicals were thought to be less toxic than inorganic arsenic (Moore et al., 1997), however, current studies have shown that monomethylarsonous acid (MMA^{III}), an intermediate metabolite, to be more toxic than inorganic arsenite (As^{III}) and arsenate (As^{V}) (Petrick et al., 2000, Styblo et al., 2000a and Petrick et al., 2001). The percent metabolites found in the human body include: inorganic arsenic 10–15%, monomethylarsonic acid (MMA^{V}) 10–

15%, and dimethylarsinic acid (DMA^{V}) 60–80%. (Tam et al., 1979, Foa and Colombi, 1984 and Vahter et al., 1995). Moreover, latest studies have found monomethylarsonous acid (MMA^{III}) and dimethylarsinous acid (DMA^{III}), both of which are more toxic than inorganic arsenic, have been traced in small quantities in human urine (Aposhian et al., 2000; viz. Petrick et al., 2000 and Petrick et al., 2001; Del Razo et al., 2001 and Mandal et al., 2001).

Biochemically, arsenic has been shown to affect the heme biosynthesis and degradation pathway which coordinates the activity of nearly 200 enzymes (Li and Rossman, 1989). The heme biosynthetic pathway is found in all nucleated cells and it plays an important role in hemoglobin biosynthesis in erythroid cells and also in a variety of other hemoproteins particularly those in the family of cytochrome P450 in the liver (Marks, 1985). Several studies have shown that the interference of arsenic in the heme biosynthesis pathway results to the alteration of urinary porphyrin profiles (Woods and Fowler, 1978, Garcia-Vargas et al., 1995, Wang et al., 2002 and Ng et al., 2005). The results of the experiment by Krishnamohan suggested that urinary As specifically MMA^{III} can be used to determine the onset of cancer in the human body using coproporphyrin I since the porphyrin profile in rodents is a highly sensitive biomarker for both single sub-lethal and chronic arsenic exposure (Ng et al., 2002a). As also interferes with the synthesis of the heme biosynthesis which causes an alteration in the porphyrin profile. Therefore, the levels of total arsenic in the human body was directly proportional to increased incidences of cancer (Bhattacharya et al., 2007; Krishnamohan et al., 2006).

Arsenic toxicity and chronic arsenicosis is of an alarming magnitude around the world particularly in South Asia where it is a major environmental health disaster (Chakraborti et al., 2004; Kapaj et al., 2006). Research has shown that arsenic is among the major human carcinogens that pose a risk by both inhalation and ingestion (Centeno et al., 2002; Chen and

Ahsan, 2004; P. Bhattacharya et al., 2007). Furthermore, most of the ingested As is rapidly excreted via the kidney within a few days (Tam et al., 1979; Buchet et al., 1981; Vahter, 1994; P. Bhattacharya et al., 2007). However, high levels of As are retained for longer periods of time in the bone, skin, hair, and nails of exposed humans (Karagas et al., 2000 and Mandal et al., 2003). That explains a recent report from the HEALS prospective study which found that the risk of skin lesions caused by arsenic did not decrease after reducing exposure until several years later (Argos et al. 2011). The study of Arsenic has not been done extensively in Africa, the only countries covered in a worldwide review of arsenic by Naujokas et al., 2013 were Egypt and Ghana however there is anecdotal evidence in Kenya establishing a correlation between throat and stomach cancer to drinking arsenic contaminated water. In Ghana, most of their arsenic comes from Sulphide minerals, such as arsenopyrite and pyrite, which were found in Biriman basement rocks. The lowest concentrations were found in shallow ground water and increased in greater depths especially when leaching of soils containing kaolinite, muscovite, and laterites occurred (Bowell, 1992). In Kenya, most of the sources of arsenic are anthropogenic and they are mainly from buried mining wastes that have managed to leach to the water tables contaminating water supply for a whole region (KTN, 2013).

Arsenic compounds are excreted in the urine after three to four days (Umweltbundesamt et al., 1983; Fowler, 1994; Pontius, 1994) but the individual sensitivity to arsenic differs depending on exposure level. Humans who are not accustomed to the consumption of arsenic die at an arsenic uptake between 0.1 g/d and 0.3 g/d however chronic arsenic eaters can consume up to 1 g/d H_3AsO_3 without manifestations of acute poisoning (Reichert et al., 1979; Morton and Dunnette 1994). Meaning that the consumption of arsenic from early in life can create some sort of tolerance for in the body therefore the toxic effects might not be severe almost immediately

compared to someone who has not been exposed to arsenic on a regular basis for a long time. Ingestion of elevated arsenic concentrations, $>100\text{ }\mu\text{g/L}$, is associated with numerous health effects hence the importance of it being monitored in food sources and drinking water sources, including private wells (P. Bhattacharya et al., 2007; Naujokas et al., 2013). Among the confirmed health effects of cancer include: the inability to repair damaged DNA, lung cancer when exposed to it by air since species volatilized to the atmosphere are rapidly oxidized to the inorganic species or bladder cancer, renal cancer, liver cancer, and skin cancer when consumed orally which is common in most areas around the world (Roth, 1957; Luchtrath 1972; Yiannis, 2004; P. Bhattacharya et al., 2007). However, Gao and Burau found that the loss of arsenic from soils to the atmosphere can be neglected but can still cause respiratory symptoms such as chronic cough, blood in sputum, and other breathing problems (Varsanyi, 1989); Parvez et al., 2010).

Arsenic has been linked to a lot of cutaneous lesions which are one of the best known clinical manifestations of chronic arsenic exposure and occur within the first several months to years of arsenic exposure. Melanosis is considered an early and more common manifestation whereas keratosis is considered a sensitive marker of more advanced stages of arsenicosis (WHO, 2005; Das and Sengupta 2008; Naujokas et al., 2013). Arsenic-related melanosis can be patchy or exhibit a distinctive “rain drop” pattern which often appears on the trunk of the body. Keratotic lesions tend to appear mainly on the palms and soles. Sudden increases in the size of keratotic lesions, or cracks or bleeding of lesions, suggest malignant transformation—often to squamous cell carcinoma (Naujokas et al., 2013). A recent report from the HEALS prospective study found that the risk of skin lesions did not decrease after reducing exposure for up to several years (Argos et al. 2011). Therefore, lesions can appear several years after exposure diminishes. The vast majority of exposed individuals (even with high levels of chronic exposure) will not

develop skin lesions but are still at risk of arsenic-related skin and internal cancers and other non-cancer diseases (Argos et al. 2010; Chen Y et al. 2011; Parvez et al., 2010); (Naujokas et al., 2013; Figure 2).

Increasing evidence has shown that chronic exposure to arsenic can increase cancer in other regions of the body. In a study of bladder cancer, the results showed that longer exposure periods >40 years and higher drinking water concentrations of >600 µg/L increased the risk of bladder cancer (Chen CJ et al., 1992; Chen CJ et al., 2010b; Chiou et al., 2001; Gibb et al., 2011; Marshall et al., 2007). In a study of kidney cancer in Taiwan, the mortality rate ratio increased with dose of arsenic in drinking water concentrations from 170 to 800 µg/L, however more studies need to be done with larger sample sizes exposed to <100 µg/L of arsenic (Chen CJ et al., 1988a; Smith et al., 1992). A number of studies in Taiwan have also demonstrated that an increase in arsenic concentrations in drinking water has caused liver cancer particularly liver angiosarcoma which has been supported by both rodent and in vitro studies together (Chen CJ et al., 1988a; Wu et al., 1989; Smith et al., 1992; Liu and Waalkes, 2008; Liaw et al., 2008). Arsenic has also caused significant neurological impairments evident in children and adults who have experienced loss in cognitive abilities and motor functions after exposure to it (Wasserman et al., 2004, 2007; Vahidnia et al., 2007; Chen Y et al., 2009; Dong and Su et al., 2009; Gong et al., 2011; Hamadani et al., 2011; Parvez et al. 2011). In children between 6 and 10 years, cognitive impairments were observed and a recent study reported impairments in verbal and full-scale IQ, which were greater in girls than in boys (Wasserman et al., 2004, 2007; Haadani et al., 2011). In adults, chronic exposure to arsenic has been linked to significantly lower scores on tests of cognitive ability as well as lower educational levels and also painful muscle spasms and peripheral neuropathy (Vahidnia et al., 2007; Sengupta et al., 2008; Gong et al., 2011, Figure 2).

Table 3. Arsenic affects a broad range of organs and systems.

Targets	Health effects	References
Skin	Skin lesions	Argos et al. 2011; Haque et al. 2003; Smith et al. 2000a
	Skin cancer	Tseng 1977, 2007; Yu et al. 2006
Developmental processes	Increased infant mortality	Milton et al. 2005; Rahman et al. 2010a
	Reduced birth weight	Rahman et al. 2009
	Altered DNA methylation of tumor promoter regions in cord blood and maternal leukocytes	Intarasunanont et al. 2012; Kile et al. 2012
	Neurological impairments in children	Dong and Su 2009; Hamadani et al. 2011; Wasserman et al. 2004, 2007
Nervous system	Early-life exposure associated with increased cancer risk as adults	Bates et al. 2004; Chen CL et al. 2010b; Liaw et al. 2008; Marshall et al. 2007; Su et al. 2011; Yuan et al. 2010
	Impaired intellectual function in children and adults	Hamadani et al. 2011; Wasserman et al. 2004, 2007; Dong and Su 2009
	Impaired motor function	Gong et al. 2011; Parvez et al. 2011
	Neuropathy	Vahidnia et al. 2007
Respiratory system	Increased mortality from Pulmonary tuberculosis	Smith et al. 2011
	Bronchiectasis	Smith et al. 2006
	Lung cancer	Heck et al. 2009; Marshall et al. 2007; Smith et al. 2009
	Coronary and ischemic heart disease	Chen Y et al. 2011; Gong and O'Bryant 2012
Cardiovascular system	Acute myocardial infarction	Yuan et al. 2007
	Hypertension	Abhyankar et al. 2012; Abir et al. 2012
	Liver cancer	Chen and Ahsan 2004; Chiu et al. 2004; Liaw et al. 2008; Liu and Waalkes 2008
	Kidney cancer	Bates et al. 2004; Yuan et al. 2010
Liver, kidney, and bladder	Bladder and other urinary cancers	Chen et al. 2010b; Chiou et al. 2001; Gibb et al. 2011; Marshall et al. 2007
	Altered immune-related gene expression and cytokine expression	Ahmed et al. 2011; Andrew et al. 2008; Kile et al. 2012
	Inflammation	Ahmed et al. 2011
	Increased infant morbidity from infectious diseases	Rahman et al. 2010b; Spivey 2011
Immune system	Diabetes	Chen et al. 2007; Del Razo et al. 2011; Islam et al. 2012; Jovanovic et al. 2012
	Impaired glucose tolerance in pregnant women	Ettinger et al. 2009
	Disrupted thyroid hormone, retinoic acid, and glucocorticoid receptor pathways in mice and amphibians	Barr et al. 2009; Davey et al. 2007, 2008

The list of references is not intended to be comprehensive but rather to provide examples of health effects across multiple

Figure 2. Table showing a broad range of organs and systems affected with chronic arsenic exposure. The list of references is not intended to be comprehensive but rather to provide examples.

(Naujokas, Marisa F., et al. "The broad scope of health effects from chronic arsenic exposure: update on a worldwide public health problem." *Environmental health perspectives* 121.3 (2013): 295-302.)

Cardiovascular effects include carotid arteriosclerosis and there has also been a speculation on the link between hypertension and arsenic exposure in some studies, however additional studies need to substantiate this association (Yuan et al., 2007; States et al., 2009; Abhyankar et al., 2012; Chen Y et al, 2009, 2011; Abir et al., 2012). In the immune system, arsenic has been related to altering gene expression and cytokine production in lymphocytes in the lung. Moreover, maternal urinary arsenic has significantly been associated with increased inflammation and reduced number of T cells as well as altered cytokine profiles in cord blood, which results to reduced thymic function in infants and increased infant morbidity from infectious diseases (Lantz et al., 2007; Andrew et al., 2008; Ahmed et al., 2011, 2012; Morzadec et al., 2012). In other human and animal studies, chronic arsenic exposure has been linked to multiple endocrine effects which include: affecting hormone regulation via the retinoic acid, thyroid hormone, estrogen receptors and even diabetes in periods >10 years (Chen CJ et al., 2007 Watson and Yager 2009; Barr et al., 2009; Davey et al., 2007, 2008; Ettinger et al., 2009; Smith and Steinmaus 2009; Del Razo et al., 2011; Islam et al., 2012; Jovanovic et al., 2012; Figure 2).

Centralized water treatments systems such as membrane separation and ion exchange tend to be expensive and technical for developing countries therefore it has been important to develop a Point of Use (POU) filtering device that is easy to use and adaptable to different environments (Wang and Tsang, 2013). Accessibility to decentralized house-hold water treatment and safe storage empowers lower income communities to take control of their own water safety (Noubactep et al., 2009). Therefore, low cost removal of arsenic using different granulated adsorbents in filter based treatment is considered an efficient and effective method for low income communities (Baig et al., 2013; Gene-Fhrman et al., 2005; Guo et al., 2007). In this research, we used modified biosand filters (BSFs) with iron filings to remove arsenic from

contaminated water through adsorption. The high surface area, spherical shape, improved porosity, elevated adsorption capacity and least waste generation are some of the advantages of using granular adsorptive technique (Malik et al., 2009). Based on the historic use of the Biosand Filter for POU water treatment, the technology has had high success with efficient pollutants removal, is easy to implement and use, and can be a cost effectiveness and low maintenance solution to improve drinking water quality (Bajpai and Chaudhuri, 1999; Gene-Fuhrman et al., 2007; Mahmood et al., 2011; Ngai et al., 2006). For modified BSFs, a sufficient amount of treatment material in the filter, in this case iron filings, is required to produce satisfactory results in arsenic removal. Whatever the filter amendment used, an adequate flow rate must be maintained in the BSF (Noubactep et al., 2009).

Methods

Arsenic oxide, As_2O_3 , was used to make the stock solution for the experiment using deionized water as a solvent for the reaction. A 0.264g amount of As_2O_3 was put in a 1000ml flask then filled with deionized water to form the spiking solution. Due to the low solubility of the oxide, the solution was left swirling overnight with some low heat applied to the flask to help dissolve the remainder solid. The solution was then removed from the hotplate the next morning and put in brown 1000ml bottles for storage.

During the experiment, 10ml of the stock solution was added to 20 L of Muskegon lake water to make a concentration of 100 $\mu\text{g/L}$, which would then be used as a sample of arsenic water. The iron filings used for the experiment were collected from a local foundry in Muskegon

and they were washed and sieved several times to remove the soot and grease from its surfaces. The arsenic low range test kit was obtained from HACH Companies in Loveland, Colorado, US.

6 BSFs (3 with 1 kg of iron filings in their diffusers and 3 without iron filings) were simultaneously dosed with 20 liters Muskegon Lake water that contained 100 $\mu\text{g/L}$ of Arsenic for 30 days. The control for the experiment included testing a random 20 L bucket of arsenic water then comparing the value to arsenic-free Muskegon lake water. For all the 30 days a 20L bucket of 100 $\mu\text{g/L}$ arsenic water was poured into all the 6 BSF and the output was collected in a clean sample bucket. Arsenic concentrations were determined using a HACH low range arsenic test (Figure 3), which tested positive when a yellowish stain from arsine gas appeared on the mercuric bromide test paper. The color calibration range in the HACH arsenic test kit was used to determine the percent concentration of arsenic in the water.



Figure 3. The HACH Low Range Arsenic Test Kit

Sample bottles from the arsenic test kit marked with 100ml were used to collect the arsenic water sample from the 20L clean sample buckets. The HACH arsenic low range test kit

consisted of five steps which included adding four different reagents and collecting the final sample on a test strip (Figure 4). The four different reagents were: Sodium phosphate dibasic, potassium monopersulfate, mixture of disodium and tetrasodium and zinc. The calibration scale on the bottle containing test strips was changed to fit our experiment since we recorded lower values than those previously assigned. Sodium phosphate dibasic and potassium monopersulfate (Oxone®2) were first added to the sample then swirled. The bottle containing the contents was then left standing for 15 minutes which results in the formation of a strong oxidizing environment that oxidizes sulfides to sulfates which no longer interfere with the reaction (Kroll, 2001). Next, a mixture of disodium and tetrasodium total arsenic was added to the same bottle and swirled before it was let to stand for 15 minutes. The final procedure was to add Zinc to the solution then immediately capping the bottle with an air tight rubber cover containing a test strip then the reaction was left to stand for 30 minutes. After the results were collected, the bottles were rinsed with arsenic-free and iron-free water then the reaction was repeated for the remaining samples.

In the HACH method, hydrogen sulfide is first oxidized to sulfate to prevent interference, then the oxidizing environment is neutralized. Next, sulfamic acid and powdered zinc react to create strong reducing conditions in which inorganic arsenic is reduced to arsine gas. The arsine gas then reacts with mercuric bromide, impregnated onto a test paper to form mixed arsenic/mercury halogenides (e.g. AsH_2HgBr). The mixed halogenides discolor the test strip to a degree proportional to the concentration of arsenic in the sample. The color change is from white to yellow to tan to brown (Kroll, 2001).

The arsenic biosand filter is a regular biosand filter but with iron in the diffuser plate for arsenic removal (Figure 5). The setup of the biosand filter is usually the same for all of them, but in our case 2 cm of iron filings were put in the diffuser plate after the different layers of sand and



Figure 4. Iron Filing Amended and Unmodified Biosand Filters.

gravel were put in the container, which is usually 0.9 m tall with a surface of 0.3 m^2 (Manz 2010). The filter media consists of three layers of material: (1) underdrain gravel, (2) a separation layer of small gravel, and (3) a thick layer of filtration sand over the separation layer (called the filter bed). All three of these layers are traditionally obtained from crushed quarry rock. The process of setting up the filter includes: adding the underdrain gravel to the filter housing, followed by enough water to cover the previous media layer by approximately 20 cm. The small gravel layer is added next, followed by multiple layers of filtration sand until the media surface is 5 cm below the resting water level. The purpose of adding filter media into a small depth of water is to prevent air pockets and preferential flow pathways within the filter bed (Wood, 2013). In the study by Ngai and Walewijk, bacteria is removed from the contaminated

water by physical-chemical means in that they got stuck between sand particles and also biological in that they are predated on by other bacteria in the biolayer (Figure 6).

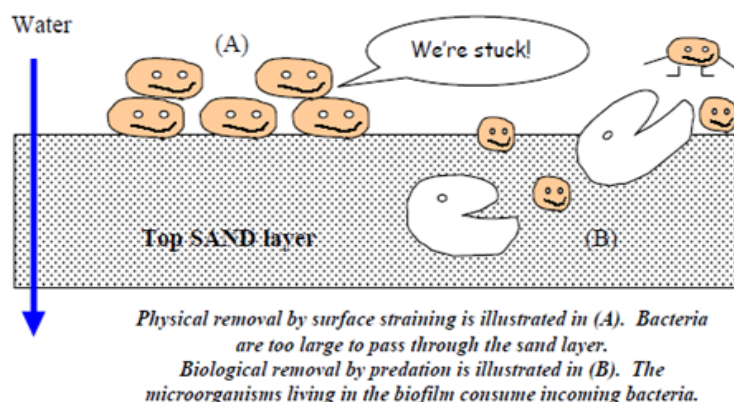


Figure 5. Bacterial removal in the biolayer of a BSF. (Ngai, Tommy, and Sophie Walewijk. "The arsenic biosand filter (ABF) project: Design of an appropriate household drinking water filter for rural Nepal." *Massachusetts Institute of Technology. Cambridge, USA* (2003).

According to the Center of Disease Control and Prevention (CDC), slow sand filter lab effectiveness studies with a mature biolayers have shown 99.98% protozoan, 90-99% bacterial, and variable viral reduction. Field effectiveness studies have documented *E. coli* removal rates of 80-98%. Furthermore, two health impact studies report 44-47% reduction of diarrheal disease incidence in users. However, experience has shown proper filter maintenance is necessary for optimal performance therefore user training and follow-up is critical to filter success. Since the filter is typically used without subsequent chlorination, training users to properly care for and maintain a safe storage container is necessary (CDC, 2014). The following are some of the advantages and disadvantages of slow sand filtration cited by the CDC, the benefits include: proven reduction of protozoa and most bacteria, high flow rate of up to 0.6 liters per minute, simplicity of use and acceptability, visual improvement of the water, production of sufficient quantities of water for all household uses, local production (if clean, appropriate sand is

available), one-time installation with low maintenance requirements, and long life (estimated >10 years) with no recurrent expenses. The disadvantages include: not as effective against viruses, no chlorine residual protection - can lead to recontamination, routine cleaning can harm the biolayer and decrease its effectiveness and finally difficult to transport due to weight - high initial cost. Figure 6 demonstrates how the iron nails and iron filings bind to the arsenic in the water. Ideally the iron is coated with iron (III) oxide which will then adsorb As (V) from the water and enable its removal.

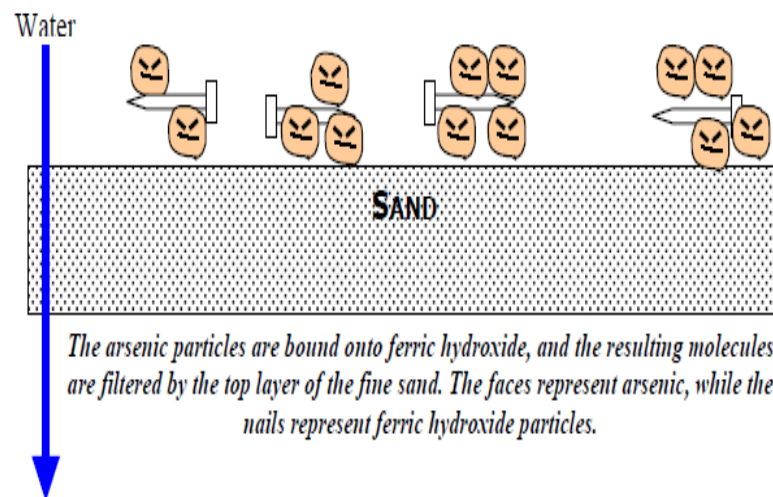


Figure 6. Arsenic Removal Mechanism in Iron nail/filing modified BSF.

(Ngai, Tommy, and Sophie Walewijk. "The arsenic biosand filter (ABF) project: Design of an appropriate household drinking water filter for rural Nepal." *Massachusetts Institute of Technology. Cambridge, USA* (2003).

Results

The average arsenic removal rates for all BSF with iron filings was ~94% and for BSF without iron filings was ~22%. In the first 13 days the arsenic removal rate for all 3 BSF with iron filings was 100%, but later reduced to an average of ~80% since 1 of the BSF filters blocked

but after it was re-packed the percentage removal went back to 100%. As for the BSF without iron filings, their efficiency in the beginning was 50%, but later reduced to 0% after 14 days because the natural levels of iron in the sand had become saturated with arsenic (Figure 7).

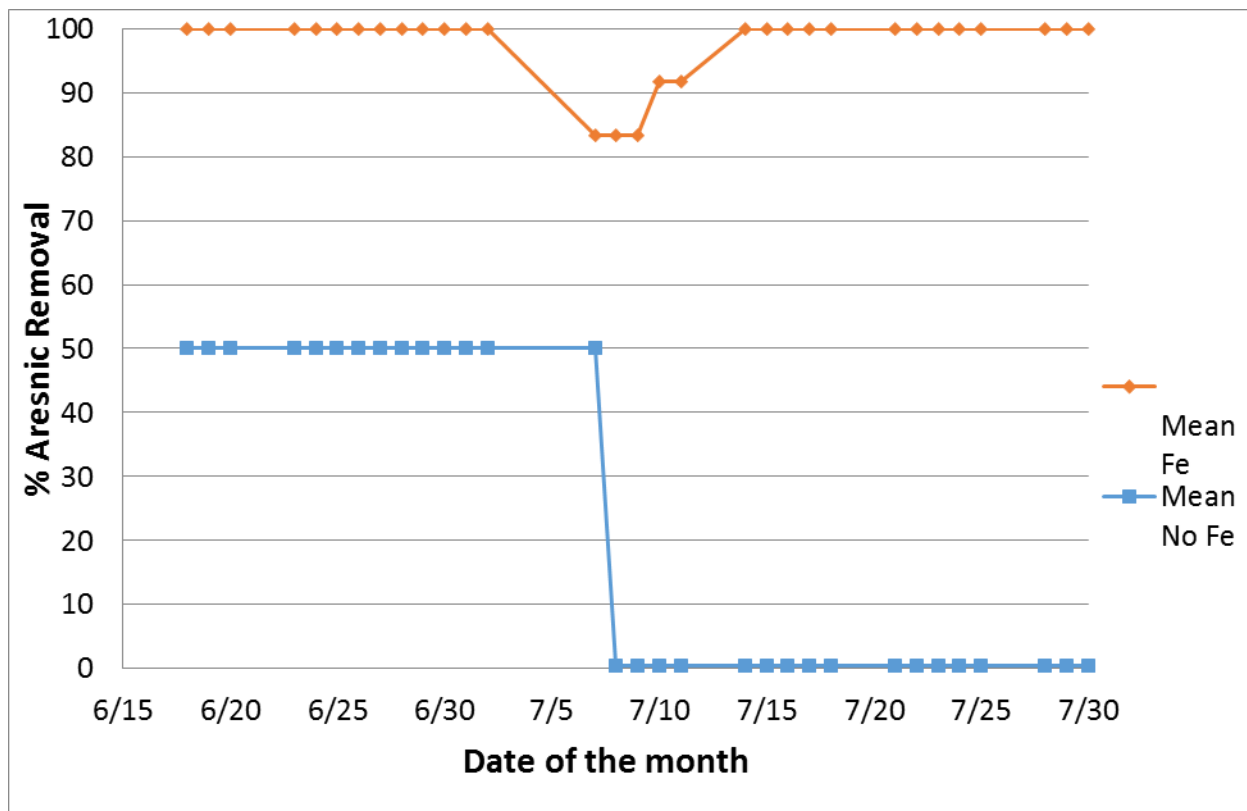


Figure 7. Arsenic removal in iron amended biosand filters and biosand filters without iron.

Figure 8 shows that the percent arsenic removal for the first two biosand filters was 100% throughout the course of the experiment. However, filter 3 decreased in percent arsenic removal to ~50% when it became blocked. After it was re-packed, the percent removal returned to 100%. Figure 9 shows that the percent arsenic removal for all the regular biosand filters was 50% at the beginning of the experiment. However, they all decreased to 0% after a while because the iron in the sand was depleted.

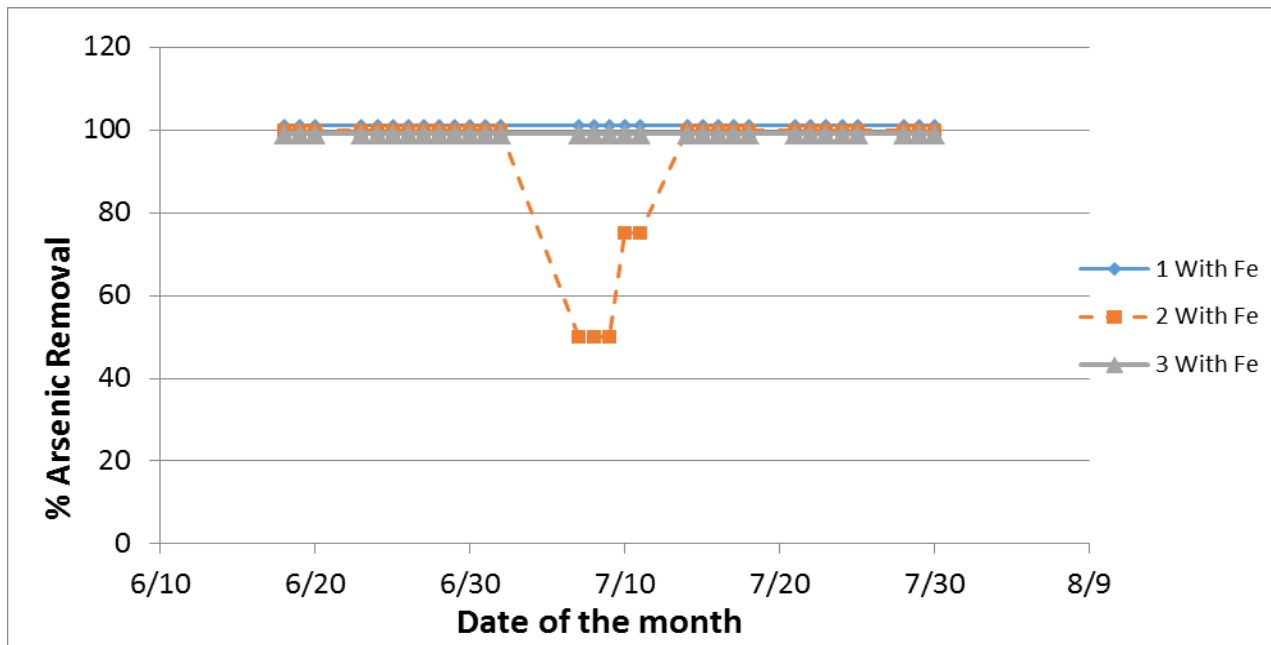


Figure 8. Arsenic removal in the 3 arsenic biosand filters with iron filings.

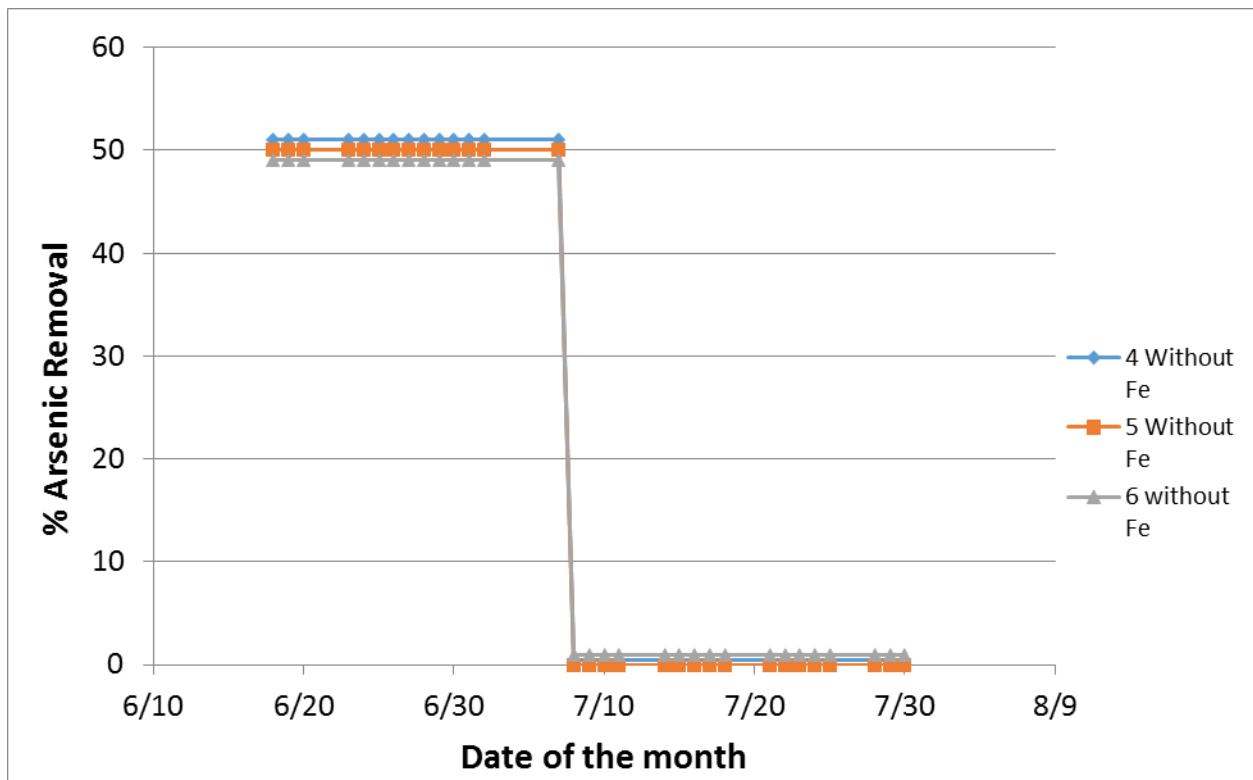


Figure 9. Arsenic removal in the 3 regular biosand filters without iron filings.

Figure 10 shows the test strips used to collect arsine gas which was used to determine the concentration of arsenic in the water. The clear color in test strips (1, 2 & 3) signifies that there was 0 $\mu\text{g/L}$ of arsenic in the water, the yellowish color signifies that there was $\sim 50 \mu\text{g/L}$ of arsenic in the water (test strips 4 & 6) and the orange color from the random arsenic bucket signifies 100 $\mu\text{g/L}$, which was poured down each filter every day.

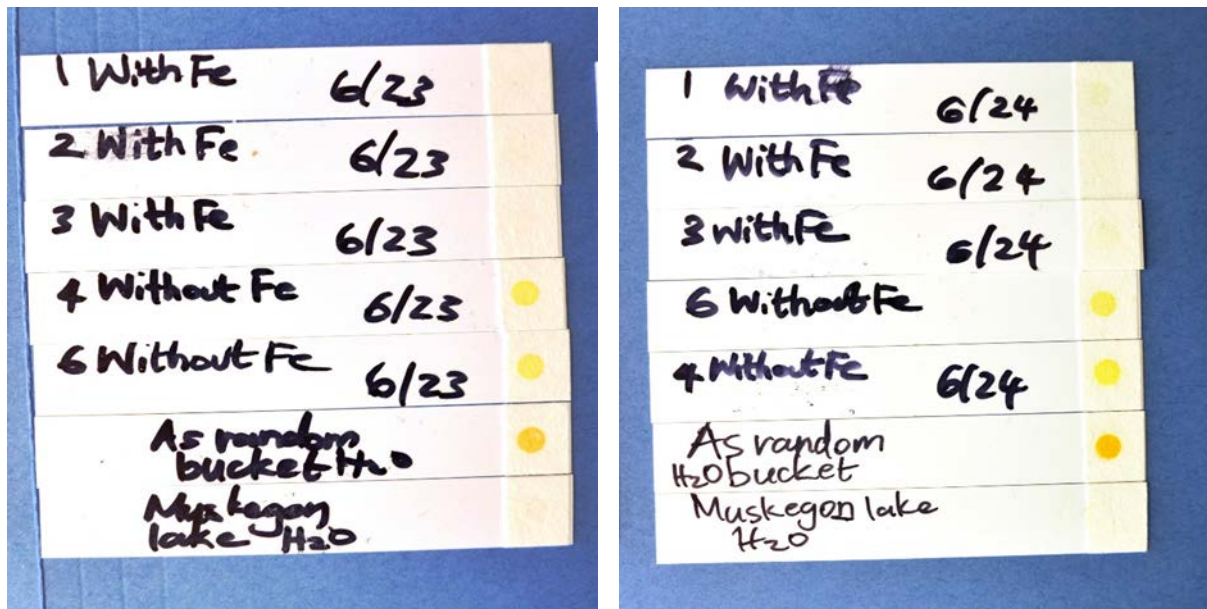


Figure 10. Picture showing the approximate concentration of arsenic in water after filtering through the BSF units with/without iron filings

Discussion

The experiment confirmed that arsenic removal using iron filings was successful with 94% removal in 30 days which was similar to using iron nails as an adsorbent for arsenic (Nagi et al., 2007). The iron filings in the diffuser plate had to be stirred every day before water was

poured down the filter because it would form a hard layer of iron (III) oxide. Before using the iron filings, several washes are required to remove grease of other particles to remove to prevent them from piling on the biolayer since there is limited research on the effects of iron being deposited on the biolayer. However, it was still a better option compared to iron nails because it had a larger surface area to volume ratio which enhanced arsenic removal and also a minimum amount of iron filings was needed for adsorption of arsenic; most studies used 5 kg of iron nails per filter while the iron filings used in this experiment only weighted 2 kg per filter.

Figures 8 & 9 show that the average percent removal for arsenic was ~ 94% since one of the filters blocked resulting to different sand layers mixing in the process of re-packing, therefore some arsenic was deposited at the bottom of the filter. To prevent this constant measuring of the flow rate is required to assess the efficiency of the filter since the minimum required flow rate is 200ml/min and a decrease from that would then require the top sand layer to be stirred to increase aeration and thus flow rate.

Figure 9 shows that there was a decrease in percent arsenic removal for the regular biosand filters since the iron in the sand got depleted. The experiment used sand from Michigan's beaches which naturally contains high levels of iron therefore we would expect that to influence the percent removal of arsenic since iron works as an adsorbent for binding arsenic. Studies have shown that As (III) and As (V) bind to ferric hydroxides by mono- and bi-dentate complex formation (Farrel and Mishra. University of Arizona). Figure 10 shows that the concentration of arsenic in the water can be easily determined using the HACH low range test kit. The darker the color the more concentrated the arsenic was in the solution. The calibrations used to determine the concentration was generated in the factory when they were putting together the test kit, but in

general the lower the concentrations had a clear color to a tint of yellow while the higher concentrations had the darkest colors which appeared orange to brownish.

Conclusion

Iron filings are a common waste product and our results suggest they may be useful in removing arsenic from water in lower income regions. They also have a large surface area to volume ratio for more arsenic to bind and are also environmentally sustainable since recyclable iron can be used. Effective cleaning of the iron filings is important to remove fine particles since some iron leached from the diffuser plate and deposited on the biolayer. The impact of iron on the biolayer needs to be investigated since there is minimal research that shows their co-existence. The regular biosand filter is moderately effective in removing arsenic through adsorption but only for a limited time since there is speculation that the iron in the sand gets depleted. It is also important to practice using the arsenic test kit so as to generate accurate data and also to calibrate the arsenic concentration scale for higher concentrations of arsenic if needed.

Overall, the iron filings in the diffuser plate had to be stirred every day before water was poured down the filter because they would form a hard layer of iron (III) oxide due to the iron filings fine particles congregating. Moreover, the sand was stirred every week when the flow rate went below 200 ml/min in order to prevent packing of the sand particles, which would interfere with the flow rate. Future studies should focus on running the experiments for longer periods of time using different amount of iron filings in arsenic biosand filters, the impact of arsenic removal on bacterial removal by the biolayer and the sand needs to be investigated, and the impact of dissolved oxygen, temperature, pH and other ions on arsenic removal using adsorption.

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