VALIDATION OF THE TWO-BUCKET TREATMENT UNIT (BTU), AN ARSENIC REMEDIATION TECHNOLOGY

BY

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Abstract

The largest mass poisoning in history was arsenic contamination of well water in Bangladesh (Mori et al., 2018). Arsenic is a naturally occurring compound found in the environment, but elevated levels are toxic to humans (Mori et al., 2018). Arsenic affects millions each year and poisoning leads to a plethora of adverse health effects (Mori et al., 2018). Some of the effects are cancer of the lung, kidney, and bladder, neurologic disorders, hypertension, pulmonary disease, cardiovascular disease, peripheral vascular disease, and diabetes mellitus (Mori et al., 2018). Following the Bangladesh incident, the most widely implemented arsenic removal technology in the region was a two-bucket treatment unit (BTU) developed by DPHE-Danida Project (Study, n.d.). However, extensive research into the efficacy of this treatment method showed mixed results (Ahmed, n.d.). The objective of this study is to evaluate the BTU's arsenic removal capacity. Known levels of contaminated water were filtered through the BTU and their post-treatment concentrations were assessed to evaluate the effectiveness of the filtration system. Findings reveal that all arsenic-contaminated samples (n=12) were remediated to levels below the U.S. EPA's Maximum Contaminant Level set by the Safe Drinking Act, 10 μg/L (*Drinking water arsenic rule history*, 2015).

Introduction

The widespread contamination of water by arsenic is a major concern. Millions of people are at risk of contamination but may be unaware considering arsenic is colorless, odorless, and tasteless (Saraban et al., n.d.). There is no known medicine for treating arsenic poisoning (Ahmed, n.d.). Hence, access to arsenic-free water is urgently needed to protect human health. One approach is by remediating arsenic-contaminated water.

Materials & Methods

Materials and Methods were informed by (Saraban et al., n.d.).

Materials

- 20-liter plastic bucket with spigot (2)
- 20-liter plastic lid with hole and cap (2)
- Flexible plastic PVC tube
- Bucket stand that holds 2 buckets
- #30 wire screen
- 10 liters of coarse sand
- Stirring rod
- 4 g of Iron (III) fluoride trihydrate
- 0.04 g of $KMnO_4$ (powdered potassium permanganate)
- Hach EZ Arsenic Low Range Test Kit (PN: 2800000, Hach Loveland, Colorado)

Methods

Spiked sample creation. To determine the efficacy of the methodology, solutions were prepared with known concentrations of arsenic. These samples were prepared by adding an arsenic solution to Nanopure water. 1 L of 18 ug/L of arsenic solution was created by adding 180 uL of 100 ug/mL ICPMS calibration standard with 992.82 g of Nanopure water. 1 L of 175 ug/L of arsenic solution was created by adding 1,750 uL of 100 ug/mL ICPMS calibration standard with 998.25 g of Nanopure water. 1 L of 375 ug/L of arsenic solution was created by adding 3,750 uL of 100 ug/mL ICPMS calibration standard with 996.25 g of Nanopure water.

To determine the arsenic concentrations after the solutions passed through the BTU, a do-it-yourself arsenic test kit was used. Specifically, the Hach EZ Arsenic Low Range Test Kit (PN: 2800000, Hach Loveland, Colorado). This analysis was chosen for two, primary reasons. First, time constraints prevented analysis using inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer ELAN). ICP-MS is an elemental analysis technology capable of detecting arsenic at levels up to nanograms per liter (*Inductively coupled plasma mass spectrometry (ICP-MS) information*, n.d.). Second, the Hach kit has been previously tested and confirmed for providing reliable readings (Geen et al., 2005).

The arsenic color chart from the Hach kit provided a range of 0-500 ug/L. Thus, 18 ug/L, 175 ug/L, and 375 ug/L were the median arsenic concentrations for low, medium, and high ranges on this chart. It was important to analyze a broad range of arsenic concentrations to ensure the unit's remediation capacity did not depend on this factor.

Unit Assembly. Two, 20 L buckets with spigots were placed above one another using a bucket holder (Figure 1). The #30 wire screen was cut into a small circle to fit in the bottom bucket's spigot (Figure 2). This was a final measure to ensure no grains of sand or precipitated arsenic entered the treated water samples. Then, the bottom bucket was filled halfway with 15 kg of washed, coarse sand. The #30 screen was then placed on top of the sand (Figure 3). Both buckets were secured with lids. Lastly, a plastic PVC tube was attached to the spigot of the top bucket and placed in the opening of the bottom bucket's lid (Figure 4).

Water treatment. The BTU relies on the processes of coagulation, co-precipitation, and adsorption (Sutherland, 2001). 4 g of Iron (III) fluoride trihydrate and 0.04 g of $KMnO_4$ (powdered potassium permanganate) were added to the top bucket and stirred into the contaminated water for 25 seconds. Originally, the protocol called for 4 g of $KAl(SO_4)_2 12H_2O$

(powdered aluminum potassium sulfate coagulant) but this was replaced with Iron (III) fluoride trihydrate based upon recommendation from a peer-reviewed article evaluating the BTU (Saraban et al., n.d.). They recommend this substitution to increase public acceptance, given studies linking excess aluminum in drinking water and Alzheimer diseases (Saraban et al., n.d.). The water was allowed to settle for at least 3 hours while arsenic adsorbed to flocs and a sludge is created. This sludge settled at the bottom of the pre-filtration bucket (Figure 5). while the remainder of the water passes through to the bottom bucket. In the bottom bucket, the wire screen and sand layer filtered out remaining arsenic floccules. Treated water samples were then collected from the spigot of the bottom bucket.

Post-treatment Sample Analysis. Four, 50 mL water samples were collected from the BTU and analyzed for each spiked arsenic concentration (18 ug/L, 175 ug/L, and 375 ug/L) (n=12) (Figure 6). A paper test strip with an embedded mercuric bromide color-changing pad was inserted into a flip-top cap. Then, prepackaged sulfamic acid and zinc powder from the Hach EZ Arsenic Low Range Test Kit (PN: 2800000, Hach Loveland, Colorado) were added. The bottle was capped and gently swirled for one minute. Afterward, the bottle was swirled for 10 seconds every 5-minutes for a total of 40 minutes. This continual agitation allowed the arsenic became gaseous (Figure 7), which in turn caused a color reading on the test strip (Geen et al., 2005). The color on the test strip was then compared to a color chart to reveal the arsenic concentration range observed in the sample, as shown in Figure 8.

Results

All arsenic-contaminated samples were remediated to a range of 0-10 μg/L of arsenic (*Drinking water arsenic rule history,* 2015) (Figure 9).

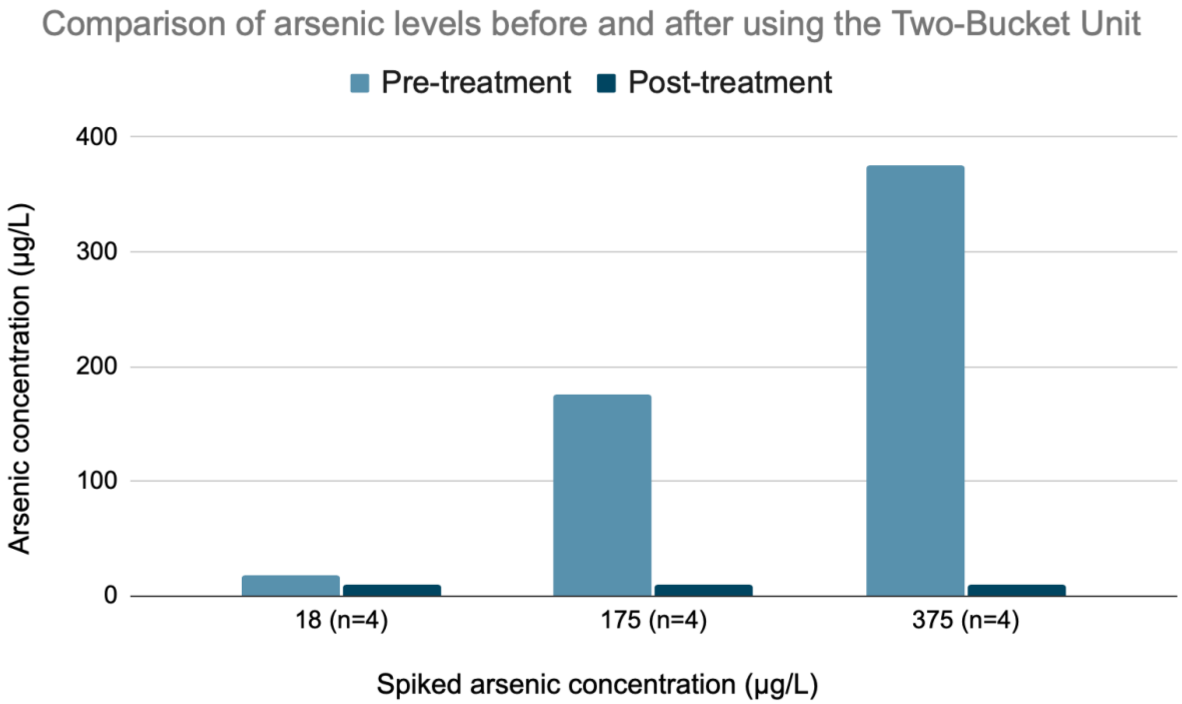

Figure 9. Summary of all samples before and after running through the BTU (n=12)

Four samples of water with 18 µg/L of arsenic produced DIY test strips with arsenic concentrations in the 0-10 µg/L range (Figure 10).

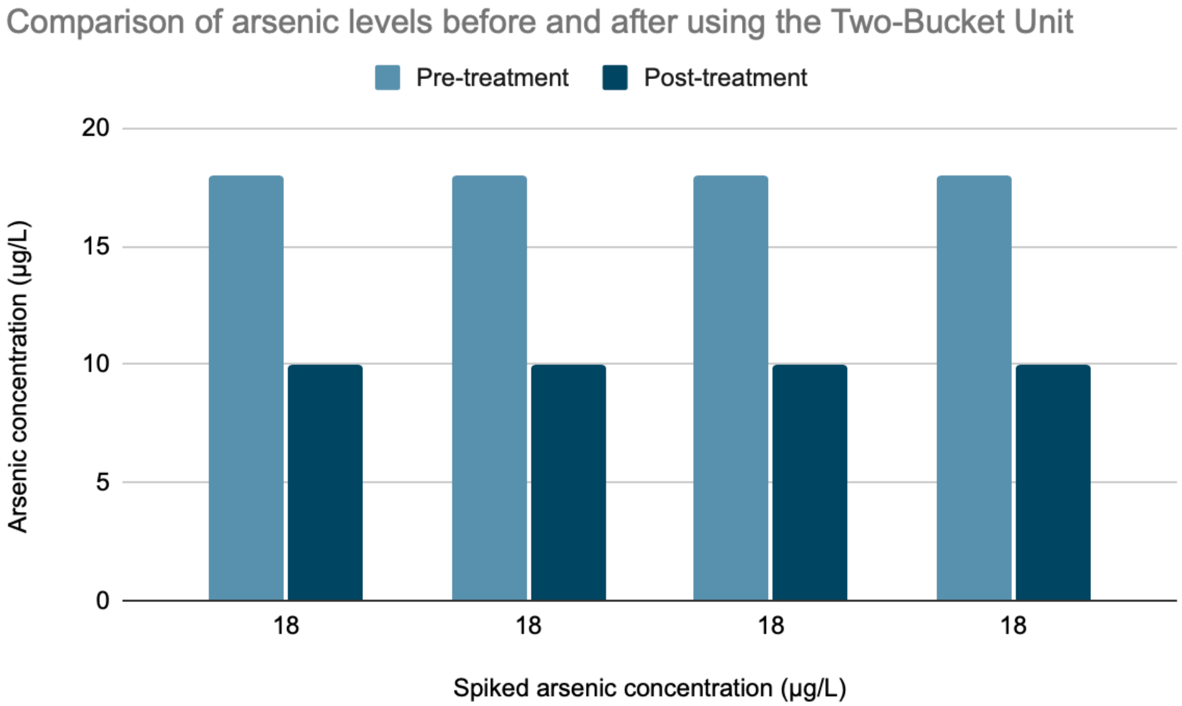

Figure 10. Summary of four, 18 µg/L spiked arsenic samples before and after running through the BTU

Four samples of water with 175 µg/L of arsenic produced DIY test strips with arsenic concentrations in the 0-10 µg/L range (Figure 11).

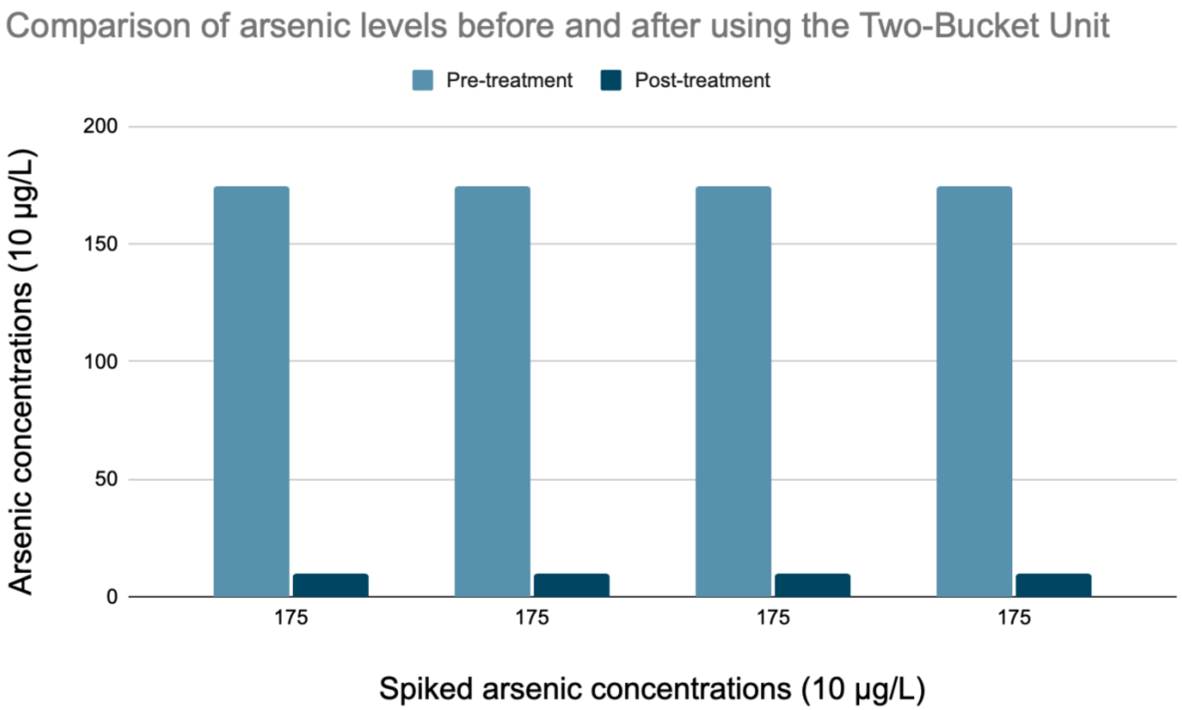

Figure 11. Summary of four, 175 µg/L spiked arsenic samples before and after running through the BTU

Four samples of water with 375 µg/L of arsenic produced DIY test strips with arsenic concentrations in the 0-10 µg/L range (Figure 12).

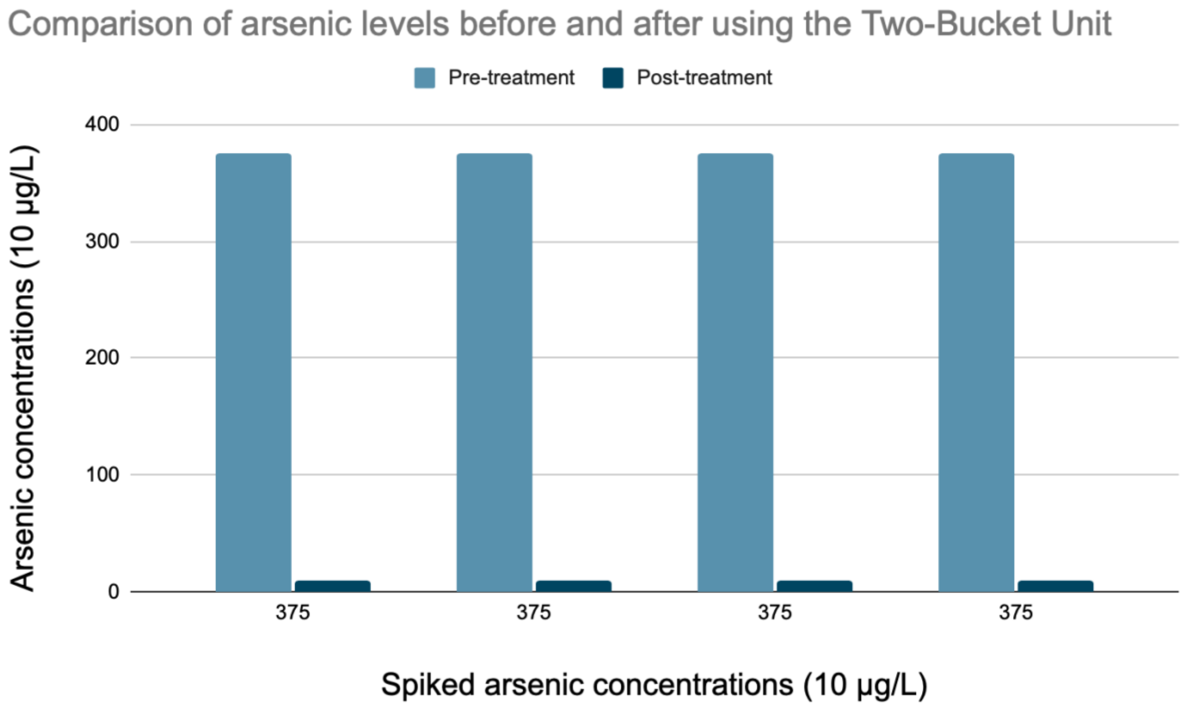

Figure 12. Summary of four, 375 µg/L spiked arsenic samples before and after running through the BTU

Conclusion

The Two-Bucket treatment Unit removed arsenic to levels at or below 10 ug/L for all concentrations of arsenic (18, 175, 375 ug/L). Water purification was consistent over the entire range of known arsenic concentrations.

A discrepancy was that samples were pink post-treatment. This was likely due to the use of excess powdered potassium permanganate (which was also pink). Thus, this was an error. Samples noticeably transitioned from pink to clear when running the DIY test, however. This is attributed to the zinc and sulfamic acid from the kit which changed the pH levels and, thus, color of the water.

Limitations & Next Steps

The limitations of this study include small sample size, non-laboratory analysis methods, and high cost.

First, twelve samples cannot be used to provide statistical significance and further tests are required. Second, while the Hach kit has confirmed reliability, it is not the gold standard for determining arsenic concentrations in water. Still, it serves as an accessible screening tool for community members to use due to its low-cost. Additionally, it provides an arsenic concentration range rather than a precise reading. If more time had been allocated to this project, samples would have also been analyzed via ICP-MS for precision.

The total cost for building the BTU was ~$300. In the year 2000, the unit was $7 (Study, n.d.). Perhaps this cost would have been lower if materials were ordered in bulk. Furthermore, hazardous waste disposal can present an extra cost. In Tucson, however, city residents can safely dispose of their household hazardous waste for free through the Household Hazardous Waste Program (Household Hazardous Waste (HHW) Program, 2014).

Next steps include expanding the sample size, analyzing samples via ICP-MS, and conducting an updated cost-estimate of the unit. Adjusting the chemical masses in accordance with the volume of water being remediated will also avoid creating pink water samples. Thus, checking the mass balance to ensure accuracy is another critical next step.

Final comments

Overall, the Two-Bucket treatment Unit effectively remediated the water samples to achieve arsenic levels that met the U.S. EPA's Maximum Contaminant Level set by the Safe Drinking Act. Additionally, the system's efficiency was not dependent on the arsenic concentrations of the water samples. More tests are required to determine statistical significance of the unit’s capacity to remediate arsenic, but the results support the efficacy of the technology thus far.

Figure 1. Two, 20 L buckets vertically stacked via bucket holder

Figure 2. Spigot with screen

Figure 3. Screen on top of coarse sand in bottom bucket

Figure 4. PVC tube facilitating flow of water into the bottom bucket

Figure 5. Settled arsenic sludge in pre-filtration bucket

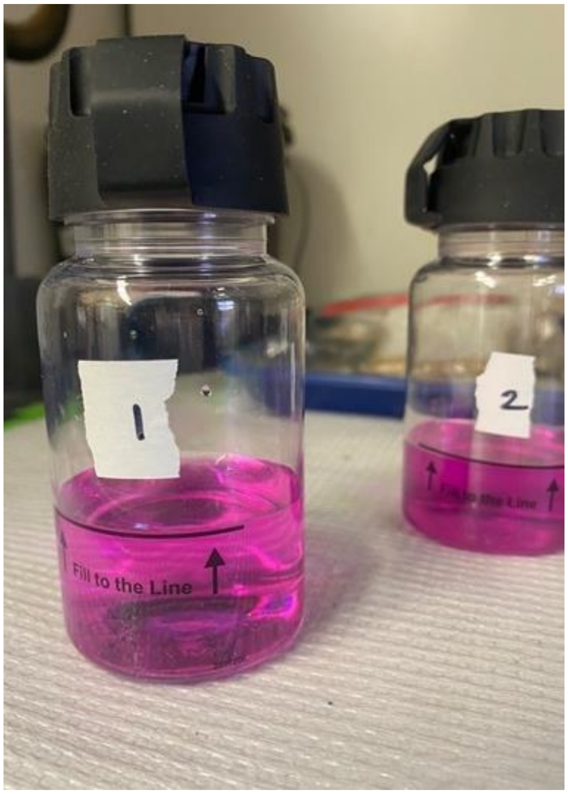

Figure 6. Post-treatment water sample

Figure 7. Sulfamic acid and Zinc volatilizing arsenic

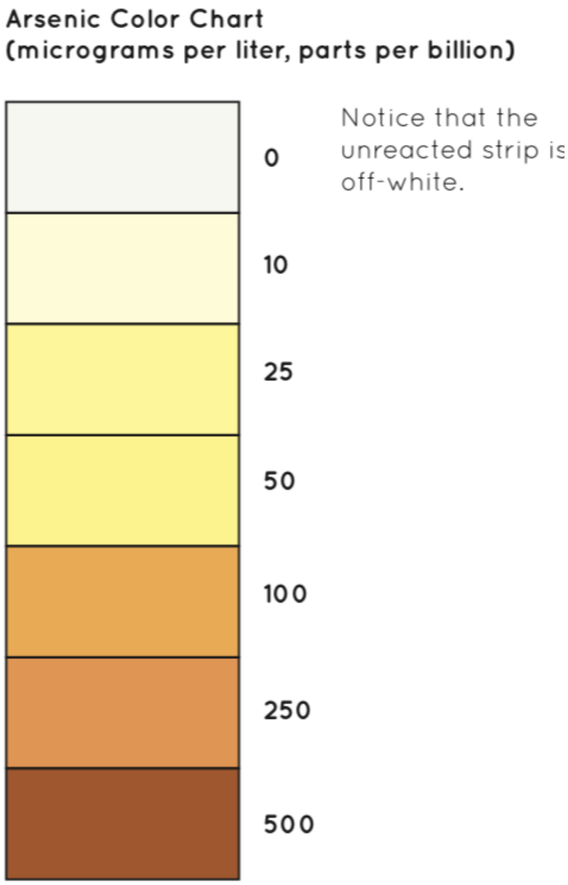

Figure 8. Arsenic colorimetric scale designed by Dorsey Kaufmann

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