A Novel Arsenic Filtration System for Low-Income Families in Rural Bangladesh

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ABSTRACT: Over 200 million people globally are affected by arsenic-contaminated water. Moreover, groundwater from tube wells is often contaminated with arsenic which, if ingested, can result in diarrhea, blood vessel diseases, and cancers. Arsenic filtration processes, like the SONO filter, 3-Kolshi filter, and ion exchange methods are promising developments that significantly reduce arsenic levels. However, cost, maintenance, and availability of these methods prevent many low-income families from using them. The aim of this project is to engineer a novel filtration system that significantly reduces arsenic and is maintainable and affordable for poverty-stricken populations. In this project, laterite soil was substituted for iron as the method of arsenic filtration to reduce costs. Through analysis, the constructed One Step Red Soil Filtration (OSRSF) was found superior to the 3-Kolshi filter, making it an economically beneficial option for poor people to have safe drinking water.

KEYWORDS: Chemistry; Arsenic; SONO filter; Composite Iron Matrix (CIM); Tube Well Water; 3-Kolshi; One Step Red Soil Filtration (OSRSF); Laterite Soil; Bangladesh.

Introduction

Arsenic is an element from within the Earth's crust and can contaminate water. In its inorganic form it is extremely toxic.[1-3] Arsenic-contaminated water is an exceedingly prevalent occurrence in rural areas. In these areas, families use tube wells to pump out groundwater, which is often contaminated.[1,2] Because of this, over 200 million people drink high levels of arsenic-contaminated water.[4] High concentrations of arsenic can lead to arsenic poisoning, a health issue in countries like Chile, India, and Bangladesh.[1] Arsenic poisoning causes complications such as diarrhea, affected hair and nails, darkened skin tone, and skin and bladder cancer.[1,5-8] The World Health Organization (WHO) and the Human Rights Watch have named Bangladesh a country largely affected by arsenic-contaminated water, so this study was held in Bangladesh to find a new approach to reducing arsenic levels in the water for poor people. In Bangladesh, over 20 million people drink arsenic-contaminated water and over 43,000 people die from arsenic related illnesses annually.[6,8]

Research into reducing arsenic levels in groundwater has been conducted in several countries. Filtration is the most viable solution to removing arsenic from water.[9] In 2006, Bangladeshi chemist and professor Abul Hussam invented the SONO Arsenic Filter to filter tube well water. The filter is made of 3 stacked buckets filled with coarse river sand, a 4-5 cm thick layer of a specifically designed composite iron matrix (CIM), charcoal, and wet brick chips. By pouring water through the buckets, large particles are filtered through the sand, arsenic is removed through chemical reactions in the CIM, and the charcoal and wet brick chips remove organics. The creation of the SONO filter has led to a significant decrease in arsenic levels in drinking water and has been implemented in many villages.[10,11]

While the SONO filter has had unprecedented success, it does have several drawbacks. A questionnaire administered in rural Bangladeshi villages revealed problems such as breakage, maintenance issues, high cost, weak sludge-disposal guidance, and slow flow rate of filtered water.[12] Alternative household tube wells have since been developed, but these also have issues with slow water release as well as complicated set-up and maintenance.[13,14] Additionally, many Bangladeshi villagers have a daily income of less than five USD, so the 60-70 USD replacement filter cartridges is unaffordable.

The CIM, where the arsenic is removed, is considered very beneficial for the SONO filter. It works using the following chemical reactions:[10]

Equation 1: $FeOH + H_2AsO_4^- \rightarrow FeHAsO_4^- + H_2O$ $(K=10^{24})$

Equation 2: $FeOH + HAsO_4^{2-} \rightarrow FeHAsO_4^{2-} + H_2O$ $(K=10^{29})$

Based on existing literature, the author hypothesized that applying laterite soil, commonly known as red soil, is lieu of an iron matrix will remove arsenic.[14] To test this hypothesis, a one-step arsenic filter was developed that was economic and efficient in lowering arsenic levels in water to a safe range. While CIM is the most efficient way to remove arsenic, poverty-stricken families cannot afford to maintain the SONO filters. The author invented a novel approach, called One Step Red Soil Filtration (OSRSF). Water sampling, testing, and data collection came from a small village in Assasuni Upazila of the Satkhira District in Bangladesh (Figure 1). This study presented a filter consisting of laterite soil and sand, cloth, charcoal, and brick chips (Figure 2).

This study aims to reduce arsenic in water to a tolerable level for poor people unlike other filters that significantly reduce arsenic levels to WHO standards.[1,8]

DOI: 10.36838/v3i1.5

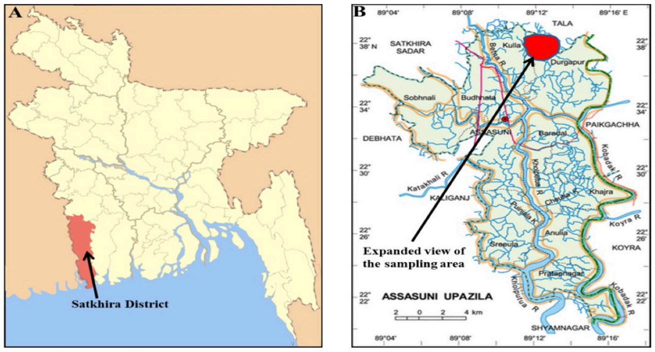

Figure 1: A map of arsenic-conteminated area in Satkhira District, Bangladesh from where water samples were taken. (A) Bangladesh map with Stahkira district highlighted. (B) Expanded view of Assasuni Upazila highlighting the study area. Map A was adapted from Wikipedia and Map B was adapted from WordPress.com.

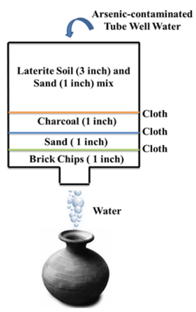

Figure 2: Development of a novel filtration system to reduce arsenic in tube well water.

■ Methods

Before implementing the novel OSRSF, collecting water samples from a low-income region was essential. Data collection occurred in a small village in Bangladesh where samples from thirty tube wells were collected. The arsenic concentrations were measured in each sample using the Hach EZ Arsenic High Range Test Kit. The kit included test strips, a reaction bottle and cap, two reagents, and a comparison chart (Figure 4). A test strip containing mercuric bromine was inserted into the special cap that locks onto the strip. A reaction bottle was filled with 50mL sample water. The two reagents, labeled “Reagent 1” and “Reagent 2” by Hach, were added to trigger sulfamic acid crystals to acidify the sample. The cap was attached to the bottle and swirled for one minute and then left for 40 minutes to react, the liquid being swirled twice.[16,17] During this time, the air reacted with the sample solution and imprinted the product on the test strip.[17] After the reaction time was over, the test strip was removed and compared to the chart to determine the arsenic concentration in parts per billion (ppb) in the sample. This process was repeated for each sample.

The OSRSF was held in a tin, octagonal prism with a height and diameter of 7” and the whole system was enclosed in a tin, octagonal prism with a height of 25” and a diameter of 10”. A plastic stand held the filtration system in the larger tin container. The OSRSF included a 4” layer of the 3:1 laterite soil to sand ratio, a 1” layer of charcoal, a 1” layer of sand, and a 1” layer of brick chips. All the layers were separated by sari cloth (Figure 2, Figure 5).

Three liters of each sample, 100 ppb, 250 ppb, and 500 ppb, were collected and filtered through the OSRSF. Filtration took approximately 45 minutes for each sample. The filtered water was then collected in a kolshi, is the traditional vessel used in Bangladesh to collect and carry water (Figure 5). The author tested the OSRSF and the 3-kolshi system with the most prevalent concentrations: 100 ppb, 250 ppb, and 500 ppb. The 3-kolshi system was considered the control.

Statistical Analysis:

Statistical analyses were performed by the author’s t-test. Any p-value less than or equal to 0.05 is considered statistically significant.

■ Results

Testing arsenic levels:

Tube well water samples were taken to find the range of arsenic concentrations in the Satkhira village region. With the villagers’ consent, 30 tube wells were selected and marked for this project (Figure 3). Water samples were then collected and tested using the Hach EZ Arsenic High Range Test Kit.

Figure 3: Arsenic concentrations tested from 30 tube wells in a rural village in Bangladesh.

Information about the samples, including the well’s owner, the depth, the arsenic concentrations, and a comment on the concentrations, were recorded (Table 1). The study’s participants are not well educated, so providing information about the arsenic levels as well as the local guidelines for arsenic-contaminated water is helpful to them. The maximum arsenic concentration measured was 500 ppb. Twelve samples had a 250 ppb concentration, and fifteen had a concentration of 100 ppb (Table 1). The tube well depths were measured to test a correlation between arsenic levels and well depth, which was not found.

Testing OSRSF :

Arsenic levels were measured using Hach EZ Arsenic High Range Test Kit (Fig. 4). By using OSRSF (Figure 5), arsenic concentrations of tube well water could be reduced to a at least 50 ppb, the safe level according to Bangladeshi regulations.[1] WHO sets a much lower threshold, 10 ppb, for drinkable water, but the Bangladeshi government set their own standard for rural populations because they drink tube well water that contains extremely high levels of arsenic.

The OSRSF was first tested with sample of 250 ppb concentration. In one filtration, the concentration dropped to 50 ppb

(Figure 6). A 100 ppb concentration sample was reduced to 25 ppb with one filtration of the OSRSF (Figure 7). A third trial was done a 500-ppb sample, the maximum arsenic level measured. The sample required two filtrations to reach the acceptable limit. The first run through lowered the concentration to 100 ppb, and the second filtration lowered it again to 25 ppb (Figure 8).

Table 1: Tube well depth and arsenic concentration in tube well water.

Tube Well	Owner	Depth (feet)	Arsenic Conc. (ppb)	Comment
01	Abul Khaer	220	250	High
02	Mohidul Mallik	200	250	High
03	Alimuddin Sardar	160	100	Moderately high
04	Ebadul Sardar	200	500	Very high
05	Asadul Islam	220	250	High
06	Shahidul Islam	200	500	Very high
07	Nazrul Islam	200	250	High
08	Majed Dhali	200	100	Moderately high
09	Alamgir Hossain	200	500	Very high
10	Abubakar Siddique	200	250	High
11	Shahidul Islam	200	100	Moderately high
12	Mizanur Dhali	240	250	High
13	Mizanur Rahman	200	100	Moderately high
14	Shahaban Sardar	200	100	Moderately high
15	Hachim Sardar	180	100	Moderately high
16	Nurul Sardar	180	100	Moderately high
17	Faruq Hossain	200	100	Moderately high
18	Monarul Islam	200	100	Moderately high
19	Sayed Mali	200	250	High
20	Aktarul Islam	180	100	Moderately high
21	Abdul Qafi	200	100	Moderately high
22	Zahiruddin Dhali	220	250	High
23	Abdul Quddus	150	100	Moderately high
24	Mfizul Islam	150	250	High
25	Radwan Mehedi	200	100	Moderately high
26	Mukter Hossain	200	100	Moderately high
27	Emdadul Hossain	200	250	High
28	Abdul Hai	220	100	Moderately high
29	Khalil Sardar	200	250	High
30	Amjed Sardar	200	250	High

Figure 4: Materials for testing arsenic concentrations in tube well water.

Figure 5: Picture of the newly developed OSRSF.

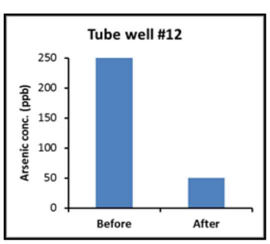

Figure 6: Bar graphs depicts before and after filtering with OSRSF on a 250 ppb sample from tube well #12. For 250 ppb sample, OSRSF was effective in bringing arsenic level down to 50 ppb.

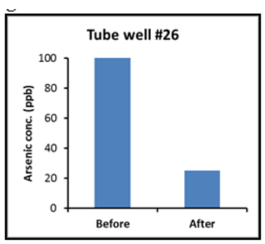

Figure 7: Bar graph depicts before and after filtering with OSRSF on a 100 ppb sample from tube well #26. For 100 ppb sample, OSRSF was effective in bringing arsenic level down to 25 ppb.

Comparison of OSRSF with existing filtration system:

The OSRSF system was compared to a locally made 3-kolshi system. The 3-kolshi filter also required two run throughs to get a 500 ppb concentration down to an acceptable level (Figure 8). Three liters of water were poured into each system and about 2.8 liters came out for both. For the 500-ppb concentration, the filtered water from the 3-kolshi system had 200 ppb after the first filtration whereas the water filtered using the OSRSF had a concentration of 100 ppb (Fig. 8). The difference between the results is noticeable from just the first filtration. During the second filtration the OSRSF brought the concentration from 100 ppb to 25 ppb, and the 3-kolshi brought the concentration from 200 ppb to 50 ppb, which is still an acceptable arsenic level for Bangladesh. The OSRSF and the 3-kolshi both yielded identical results for the 100 ppb and 250 ppb samples.

Statistical analyses and calculations were performed on the 250 ppb concentration samples (Figure 9). The average concentration after filtering through the 3-kolshi system was 43.75 ppb while the average concentration after OSRSF was 41.66 ppb. The 3-kolshi system's standard deviation was 11.31 and 12.31 for the OSRSF. The t-test was used to calculate the statistical significance. The p-value was 0.36, so there was no

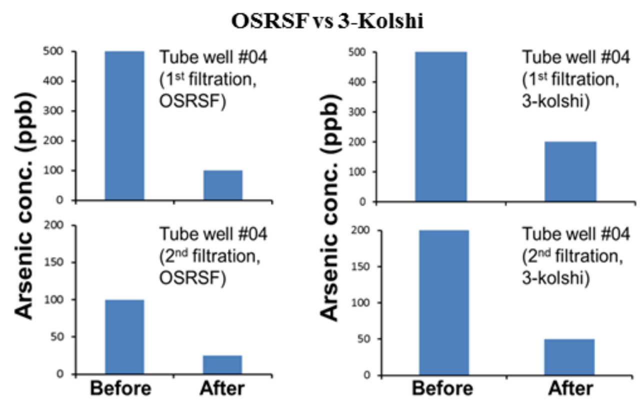

Figure 8: Bar graphs depict before and after filtering with OSRSF (left) a 3-kolshi (right) on a 500 ppb sample from tube well #04. Results suggest that the second filtration by OSRSF was very effective in making the water sample drinlable in terms of Bangladeshi rules and regulations.

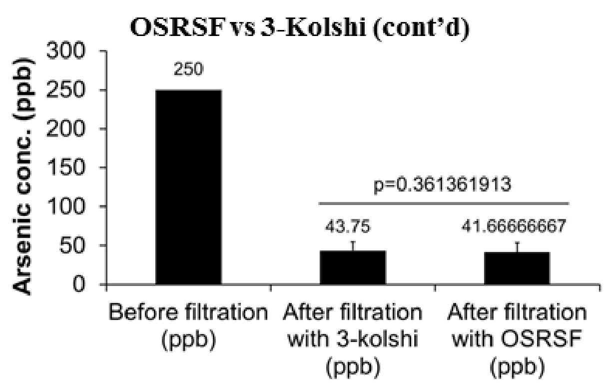

Figure 9: Bar graphs depicts arsenic levels before and after filtering with 3-kolshi and OSRSF. Statistical analysis suggests that water samples obtained from OSRF were comparable to 3-kolshi and can be economically beneficial for low income rural populations.

DOI: 10.36838/v3i1.5

statistical significance. However, the data suggests the OSRSF and the 3-kolshi systems are equally as effective.

Discussion

It was observed that the OSRSF system filtered arsenic better than the locally used 3-kolshi system. There is no statistical significance in using either the 3-kolshi system or the OSRSF (Figure 9). However, the OSRSF is realistically superior. It is the much cheaper option, and many villagers reported the OSRSF to be easier in use and maintenance via a questionnaire. Based on this data, the laterite soil may be able to better handle high levels of arsenic in comparison to iron chips found in the 3-kolshi even with the drawbacks of the soil.

The project is strengthened due to the OSRSF's low cost. It is cheaper than either the SONO filter or the 3-kolshi system. The total construction of the OSRSF was approximately 3 USD while the 3-kolshi production cost was reported by Satkhira villagers as 10 USD. The laterite soil needed to maintain the OSRSF is available in Satkhira for free. The tin containers are approximately 2 USD, and the charcoal and brick chips are less than 1 USD. Additionally, OSRSF owners may use a private collection of any of the needed materials. It is recommended the filter soil be replaced weekly to restore the amount of iron in the filter.

Compared to similar systems like the SONO filter and the 3-kolshi system, the OSRSF is cheaper, easier to maintain, and can be easily reproduced without a custom iron matrix. The 3-kolshi is effective, but the OSRSF is superior in usage, affordability, and efficiency. The OSRSF may not filter arsenic as well as the SONO filter, which can reduce levels to less than 10 ppb1, and was also not tested in this study. This study is novel in its application of a one-step filtration system for the poor that exploits the natural iron content in the local soil.

There are some limitations to the OSRSF. It takes approximately 45 minutes to filter water and only small amounts of water can be filtered at a time. While the OSRSF is not currently large-scale, one could recreate a proportionally scaled OSRSF to filter more water. Another concern is the possibility of pathogens in the filtered water due to the laterite soil. If such a problem occurs, boiling the filtered water can kill harmful pathogens.

Conclusions

This novel filtration system is economical for poverty-stricken populations to afford and maintain safe drinking water. The quality of life is improved for rural, low-income populations through this filtration system. Based on the results of this study, several conclusions were made on the OSRSF's effectiveness:

1) The OSRSF reduces arsenic levels of up to 500 ppb down to the Bangladeshi safe standard of 50 ppb. The 500-ppb sample had to be filtered twice to reach the safe level using the OSRSF, but it occurred in the 3-kolshi system as well.

2) The OSRSF is economically advantageous for poverty-stricken people, costing about 3 USD.

3) Laterite soil seems to be an acceptable replacement to the SONO filter's CIM and the 3-kolshi system's iron chips for low-income populations in Satkhira because laterite soil is readily available in that area.

4) Limitations of the OSRSF include no large-scale usage, slow water flow, and possible pathogenic contamination.

The future of the study may include finding an alternative to laterite soil for areas with a little to no laterite soil so the residents can still have an affordable arsenic water filter. Participants of the study have continued using the OSRSFs implemented in their village, and so examination of their hair and nails as well as skin status could be useful. Testing these may indicate a health improvement in the population, and it would also allow comparison between the health of OSRSF users versus users of other filters and/or those who do not use filters.

In summary, this project devised an alternative arsenic filtration system for poverty-stricken people and reduced the arsenic levels in contaminated water to a tolerable level. With the OSRSF system, the poor can drink safe water that will improve their quality of life, and the implementation of the OSRSF in other villages can improve rural quality of life around the world.

Acknowledgements

I would first like to thank my parents for their support throughout this project. I would also like to thank MR. Nazmul Haque and Mr. Redwan Mehidi who helped me interact with local villagers to collect water samples. I would also like to thank Mr. Rafiqul Haque for assisting me in gathering information about arsenic-affected populations in rural Bangladesh as well as helping me construct the OSRSF. I would finally like the participants of my study who allowed me access to their tube wells. Without these contributions, this project would not have been possible.

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DOI: 10.36838/v3i1.5