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Feasibility Study on the Removal of Arsenic from Drinking Water by Using Biomass

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Abstract

Presently, arsenic poisoning is an important issue in Bangladesh, where at least thirty percent of the water wells have an arsenic level above the drinking water standard prescribed by Bangladesh National standard (GOB, 1997). In Bangladesh, people drink ground water with higher arsenic level which eventually cause death or serious health risk. Among the locally available biomass, living water hyacinth, charcoal (obtained from mango tree), dried root of water hyacinth, and used tea leaf were used to remove arsenic from drinking water. All these four methods demonstrated considerable effectiveness in removing arsenic. Significant amount of arsenic was removed by Water hyacinth. From water with an initial arsenic concentration of 63.56 ppb, water hyacinth it reduced to a minimum level of 41.54 ppb and dried water hyacinth root reduced the level to 46.86 ppb. The other two biomasses: used tea leaf to 57.46 ppb and charcoal sedimentation reduced the level to 48.74 ppb, respectively.

Key words: Arsenic removal, Water hyacinth, Drinking water, used tea leaves

1. Introduction

Bangladesh is now facing the world's biggest man made calamity of mass arsenic poisoning in groundwater. The British Geological Survey discovered the contamination of arsenic in groundwater at Barogharia Union of the district Chapainawabgonj in 1993 (Shams, 2002). The public health engineering department and UNICEF have surveyed the prevalence of contamination and affected people in the year 2002. About 13459 people were affected by Arsenocosise. But NGO's Arsenic Information and Support Unit (NAISU) reported that 38118 people were affected throughout Bangladesh (Mortoza, 2002). Only three hilly districts (Rangamati, Khagrachari, Bandarban) are out of severe contamination. About 27 percent shallow tube wells of 321 upazilas of the rest 61 districts and 0.7 percent deep tube wells have been contaminated severely. The Bangladesh's Government set the permissible limit of arsenic in drinking water at 50 parts per billion (ppb). The World Health Organization and the United States Environmental protection agency (USEPA, 2000) have set a drinking water standard of 10 ppb. About 5 to 10 percent of the tube wells in Bangladesh have arsenic levels over 300 ppb. The drinking water standards are shown in Table 1.

Table 1. Drinking water quality standards

Parameters	*USEPA(2000), ppb	WHO(1993), ppb	Bangladesh Govt. (1997), ppb
pH	6.5×10^3 - 8.5×10^3	7×10^3 - 8.5×10^3	6.5×10^3 - 8.5×10^3
Iron	300	300	300-1000
Chloride	25×10^4	25×10^4	15×10^4 - 60×10^4
Hardness(as $CaCO_3$)	10×10^4 - 50×10^4	-	20×10^4 - 50×10^4
Sulphate	25×10^4	25×10^4	40×10^4
Manganese	100	50	100
Fluoride	2000	1500	1000
Nitrate	10×10^3	50×10^3	10×10^3
Arsenic	100	10	50
TDS	40×10^4 - 50×10^4	10×10^5	10×10^5

*USEPA: United States Environmental Protection Agency

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The depth of arsenic contamination of groundwater is between 200 to 300 m and causes in Bangladesh might be due to over pumping of groundwater for irrigation (Haque, 1998). Soil erosion and agriculture run-off could also be large contributors to the arsenic concentration in sediments (Mortoza, 2001).

Several technologies are currently being promoted for removing of arsenic from drinking water. Chatterjee *et al.* (1999) patented a filter and tablet system to remove arsenic from water. The tablet contains Fe_3^+ salts, an oxidizing agent and activated charcoal. The filter was made by using fly ash, clay, charcoal etc. The system was made up of two jars. For 20 liter of water, using one tablet, 95 – 100% removal of arsenic was achieved. Khair (1999) found Bijaypur clay from Mymensingh and processed cellulosic materials like delignified jute, bleached sawdust and pulped newspaper to be capable of adsorbing both As (III) and As (V) in solutions acidified with vinegar or hydrochloric acid. Iron (III) hydroxide–coated newspaper pulp in lab scale adsorption filters coagulated arsenic. The material showed potential for use in small-scale home treatment units. Workable exposure length, flow rate and extracting volume demonstrated arsenic removal at least or even below 50 ppb. The sludge was regenerated by sodium hydroxide elution. BCSIR (1999) developed a low cost arsenic filter. The technology consists of adding a flock forming composition to the arsenic contaminated water followed by stirring and settling. The chemicals are composed of iron oxide, alum, activated charcoal and calcium carbonate, which are to be mixed in definite proportions, homogenized and micronized. After settling the water is passed through a filter bed composed of sand and some iron bearing minerals of definite particle size range, which are to be activated by suitable chemical and heat treatment. The dose of the flock forming composition depends on the extent of arsenic contamination. Water containing up to 2.7 ppm arsenic could be purified below safe limit set by WHO.

Hussain *et al.* (2001) addressed the removal of arsenic from tube well water by passing it through wood charcoal, by chemical treatment, by sedimentation method or by removing the layer floating on arsenic bearing water. Arsenic bearing water passed through wood charcoal at different flow rates showed up to 98% removal of arsenic. About 90% removal of arsenic was achieved by adding 0.10% (by weight) calcium oxide to arsenic contaminated water. When arsenic water (450 ppb) was kept in a big tank of about 3000 liter capacity for about 9 days, arsenic concentration level was reduced at the top layer to acceptable level (50 ppb). In this way, arsenic level can also be reduced to acceptable level by repeated removal of the floating layer from iron rich water. Munir *et al.* (2001) tested a three pitcher locally called as (Kolshi) water filtration system made from locally available materials and its efficacy in removing arsenic. In this filter, the first kolshi had cast iron turnings and sand and the second kolshi had wood charcoal and sand as the active ingredients. About 6000 l of groundwater containing 80-1900 µg/l of arsenic was filtered.

1.1 General information on phytoremediation

Phytoremediation is the process of using plants to remove pollutants from soil or water. Plants that phytoremediate can be divided into two categories: excluders and non-excluders. Excluders are plants that either keep pollutants, such as metals, completely out of the plant or keep the pollutants out of the top part of the plant. Non-excluders (also known as accumulators) are plants that allow pollutants in and then transport the pollutants to the top part of the plant. Hyper accumulators are plants that accumulate metals in higher concentrations than the concentrations in the soil or water in which they are living.

1.2 Mechanisms of arsenic removal by water hyacinth

Water hyacinths are free floating aqueous weed that multiply very quickly. They have fibrous roots and obtain all of their nutrients from the water. Water hyacinths are common in Bangladesh and have the ability to remove arsenic from water. Knudson *et al.* (2003) reported some plants including water hyacinth take up arsenic through their phosphate uptake system. Misbahuddin and Fariuddin, (2002) found that just the roots of water hyacinth removed 81% from a 400 ppb arsenic solution.According to knudson *et al.* (2003) some plants take up arsenic through their phosphate uptake system. This would make sense because in a phosphate compound (PO_4^{-3}), the phosphorus has an oxidation no. of 5+. In a metaarsenic ion (AsO_3^{-1}), the arsenic has an oxidation no. of 5+. Moreover the arsenic is right below phosphorus on the periodic table of the elements and elements in the same period tend to behave similar, so it is quite possible that plants can not tell the difference between phosphate and arsenate (V). This lack of ability to distinguish put lead to accidental uptake of arsenate (V) by plants as they try to take up phosphate. Zhang *et al.* (2002) revealed that the plant reduced the As (V) in the arsenate to free As (III) as part of its detoxication system.

1.3 General information on adsorbents

Arsenic can be removed by adsorption onto many adsorbent materials. Some of adsorbent materials are very costly and some are less effective. The criteria for selection of suitable adsorbent include: the cost of the medium, the ease of operation or handling, operation cost, the useful service life per cycle, the adsorption capacity of the adsorbent, the potential of reuse, the number of useful cycles and the possibilities of regeneration of adsorbent.

The objective of this experiment is to reduce the arsenic level in arsenic contaminated drinking water by using biomass (water hyacinth, charcoal, used tea leaf, and dried water hyacinth root) from tubewell water.

2. Methodology

2.1 Study area

The study was conducted in the village of Ijarapara of Sarishabari upazilla of Jamalpur district after consultation with the Public Health Engineering dept, Mymensingh. The village was small, 2000 people living in the village. 80% of the tube well was contaminated with arsenic. About 30% of the total population was affected by drinking that poisonous water.

2.2 Sample collection

A severe contaminated tube well was selected with the help of the people in the study area. The containers were washed out with HCl (0.5N) and distilled water to avoid any kind of chemical contamination. Sample water was collected from the most affected tube well in two containers 10 liters capacity each.

2.3 Design of devices and experimental set up

2.3.1 Dried water hyacinth root

Powder was prepared from dried root of water hyacinth (*Eichhornia crassipes*) collected from Brahmaputra River. Contaminated water sample of 250 ml in each pot was treated with the root powder in different quantities for 18 hours. Root powder is verying quantities 3g, 6g, 9g and 12g, was used as adsorbent in four pots. The effect of varying quantity was observed after 18h. The water sample as well as the root powder was collected for testing the arsenic concentration. The root powder was dried for digestion before testing.

2.3.2 Living plant of water hyacinth (*Eichhornia crassipes*)

Living plants (Fig.1) were kept in four buckets each containing 3000 ml of water. Each bucket contained 20 tubers and the same no. of leaves on average. The plants were healthy and fresh looking. The average length of the root was 16.25cm. They were kept for 8, 16, 24 and 32 h separately. After that sample water was filtered and preserved in the freezer prior to test. Solid sample was collected for digestion.

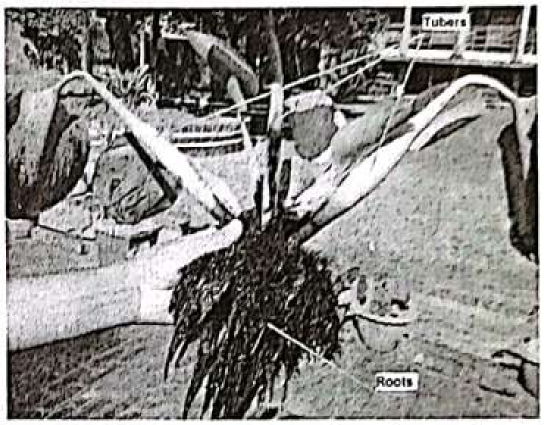


Fig. 1. Treating water by living plant of water hyacinth

2.3.3 Used tea leaf

Used tea leaf (Fig.2) of 10g was added to contaminated water in plastic pots containing 250 ml of water each and kept for 8, 16, 24 and 32 hours. Liquid Sample was filtered and kept in the refrigerator. Solid sample was also collected and dried for digestion.

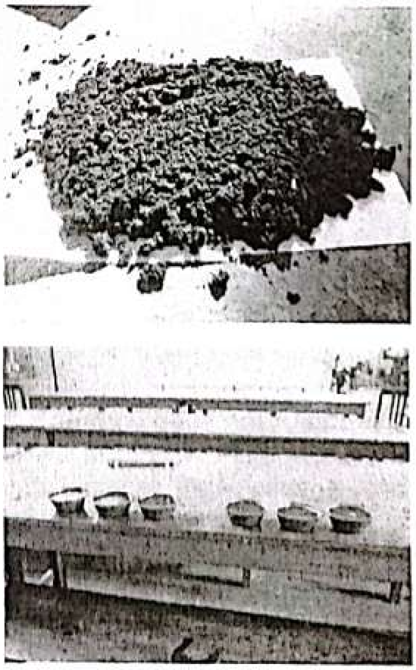


Fig. 2. Treating water by used tea leaf

2.3.4 Charcoal sedimentation

In a charcoal sedimentation method, three earthen pot were placed (top, middle, and bottom) one above another with the help of an iron tripod (Fig.3). Each pot had a volume of about 6 liters. The top and middle pot had a small hole of about 1 cm diameter at their bottom. The holes were made to pass arsenic contaminated water and twisted wick was used to control the flow rate. The first and second pot contained charcoal of charcoal and sand layer. The average diameter of the charcoal was about 1.3 cm. The thickness of charcoal layer varied in four different operations. The thicknesses of charcoal layers were 1.27, 2.54, 3.81 and 3.08 cm, respectively in four consecutive operations. The contaminated water was poured slowly into the top pot, allowed to pass through the middle one and collected at the bottom pot. Contaminated water was allowed to flow at different rates due to varying thickness of charcoal layer. Any kind of foreign material was not present in the sand or charcoal.

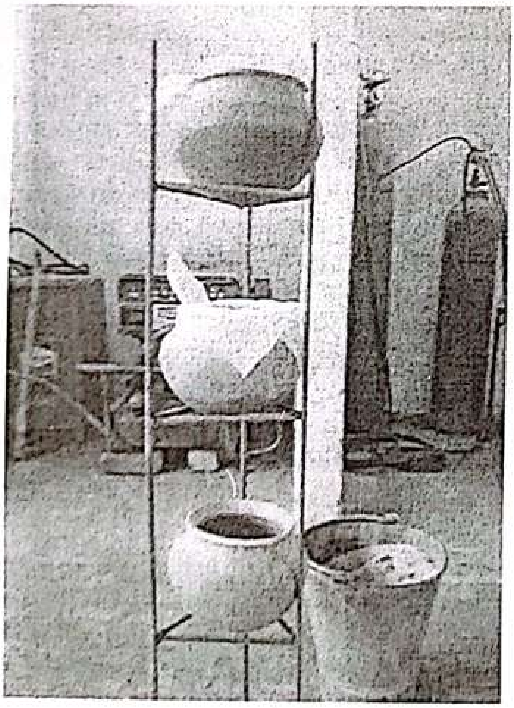


Fig. 3. Treating water by charcoal sedimentation method

2.3.5 Digestion of the solid sample

Hydrogen per oxide and nitric acid are usually used to remove arsenic from arsenic treated solid biomass. To digest the sample, 30% concentrated hydrogen per oxide and 97% concentrated nitric acid was used. At first the samples were dried in the micro oven at 50°C for 36 hours to make sure no presence of moisture. The solids were powdered. One gram of each solid sample was inserted into the tube of the digestion set. With each sample, 10 ml Hydrogen per oxide was mixed. After two to three minutes 5 ml nitric acid was added to this solution. This solution was digested for 8 hours at 120°C. Then the samples were reckoned at 100 ml with distilled water.

2.4 Measurement of arsenic level using atomic absorption

2.4.1 Analytical principle of measuring arsenic level by atomic absorption

Some chemical elements like arsenic, mercury, selenium are best quantified by analyzing their hydrides (Paulgouda, 1994). The generation of Arsenic hydride known as arsine (gas) is based on the reaction of acidified aqueous solution of the test element, with a reducing agent such as sodium borohydride ($NaBH_4$) (Clesscere *et al.*, 1998). The chemical reactions to produce arsine, AsH_3, under the stated conditions are as follows :

$$NaBH_4 + 3H_2O + HCl \longrightarrow H_3BO_3 + NaCl + 8H$$
$$As^{n+} + H \text{ (excess)} \longrightarrow AsH_3 + H_2 \text{ where } n \geq 3$$

Arsine after gas phase separation is transported to the quartz cell, aligned with the light path of the source light of the element of interest, the hollow cathode lamp (HCl) of arsenic, as the inert carrier gas for arsine is argon. The arsine gas in the quartz cell is atomized by heating the quartz cell with an air-acetylene flame. The atomic plasma absorbs light emitting from the HCl and produces and absorption signal detected by the photomultiplier of the spectrophotometer. The intensity of signal is proportional to the concentration of the arsenic and this process follows the Beer-Lambert Law (Paulgouda, 1994).

2.4.2 Preparation of the reductant

500 ml 0.6% w/v NaBH4 in 0.5% w/v NaOH solution was prepared for using in the operation of measurement (Paulgouda, 1994).

2.4.3 Carrier HCl solution for hydride generation

500 ml 10% HCl v/v was prepared in a flask.

2.5 Measurement procedure

1. When the pump run-in was finished and the flame was ignited, the reagent aspiration tubes were put into the specified bottles cautiously so that aspiration tubes were not misplaced.
2. The sample was set and aspiration tube was put in.
3. After a short delay following the start of the sample aspiration, the absorbance signal increased and attained steady state in 30-70 seconds depending on the element.
4. It was to make sure that the absorbance signal was stabilized.

3. Results and Discussion

The four methods used in removing arsenic from water demonstrated the results shown in Table 2. Among these methods living plant (water hyacinth) gave the best result in removing arsenic. It has been proved earlier (Misbahuddin and Fariuddin, 2002) that aquatic plant got a very good potentiality to absorb elements from water. The initial concentration of arsenic in water was 63.56 ppb and the plant absorbed 65.35% arsenic within 32 hours which met the permissible limit set by the Bangladesh government drinking standard. The reduction of arsenic level in water was increased with time while the number of tuber remained constant.

The charcoal sedimentation method showed better result with increasing thickness of the charcoal and sand layer. When the thickness was 1.3 cm, removal of arsenic level was not satisfactory to meet the drinking standard. This method only could reduce the level at 48.74 ppb when the thickness of charcoal layer was 5.1 cm.

In this experiment dried water hyacinth root was found to be less effective. It might be due to contamination of the root with arsenic from the river water or any other chemicals or materials used in the experiment. The actual source of error could not be identified due to lack of appropriate technology. For these reasons it was not possible to remove a greater amount of arsenic from the water. In this experiment it was possible to reduce the arsenic level at a minimum of 46.86 ppb and the other three trials reduced the arsenic level at 48.24 ppb 51.32 ppb and 52.08 ppb from an initial level of 63.56 ppb by using 12, 9, 6, and 3 g of dried root of water hyacinth, respectively in 250 ml water in each pot.

Used tea leaf was not found so much effective in reducing arsenic level. They were treated for different time period as 8, 16, 24 and 32 hours which reduced the arsenic level at 60.34, 59.21, 59.14 and 57.46 ppb from an initial level of 63.56 ppb respectively. So it can be said that this method was not significant as well as not recommended to use further. The comparative analysis among four treatments is shown in Fig. (4, 5).

Table 2. Removal of arsenic by using the four methods

Sl. No.	Initial arsenic Conc., ppb	Given treatment	Amount of water treated, ml	Parameter to be changed		Final arsenic Conc., ppb
				quantity	time	
1.	63.56	Dried water Hyacinth root				
		R_1	250	3 g	18 h	52.08
		R_2	250	6 g	18 h	51.32
		R_3	250	9 g	18 h	48.24
		R_4	250	12 g	18 h	46.86
2.	63.56	Living plant				
		LP_1	3000	20 tubers	8 h	47.54
		LP_2	3000	20 tubers	16 h	45.72
		LP_3	3000	20 tubers	24 h	44.03
		LP_4	3000	20 tubers	32 h	41.54
3.	63.56	Charcoal sedimentation				
		CS_1	1000	Thickness: 5.1 cm	25 min	48.74
		CS_2	1000	Thickness: 3.8 cm	25 min	50.16
		CS_3	1000	Thickness: 2.5 cm	25 min	52.97
		CS_4	1000	Thickness: 1.3 cm	25 min	53.14
4.	63.56	Used tea leaf				
		ST_1	250	10 g	8 h	60.34
		ST_2	250	10 g	16 h	59.21
		ST_3	250	10 g	24 h	59.14
		ST_4	250	10 g	32 h	57.46

Table 3. Comparative analysis among four treatments

Sl. No.		N	Mean	Std. deviation	Variance
1.	As.conc.(ppb)against quantity of dried water hyacinth root(gm.)	4	49.6250	2.48083	6.155
2.	As.conc.(ppb)against time(hour)[Living plant of water hyacinth]	4	44.7075	2.55214	6.513
3.	As.conc.(ppb)against thickness of charcoal layer(inch)	4	51.2525	2.16169	4.673
4.	As.conc.(ppb)against time(Hour)[Used tea leaf]	4	59.0375	1.18677	1.408

From the comparison (Table 3), second one, living plant of water hyacinth was found to be the best for reducing arsenic level because its mean is comparatively low and standard deviation and variance are high respectively.

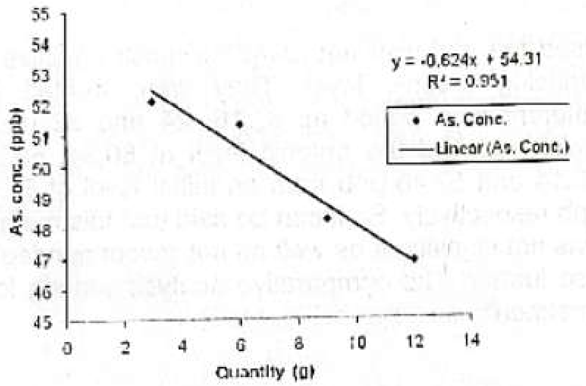


Fig. 4(a). Comparison between As. conc. and dried water hyacinth root

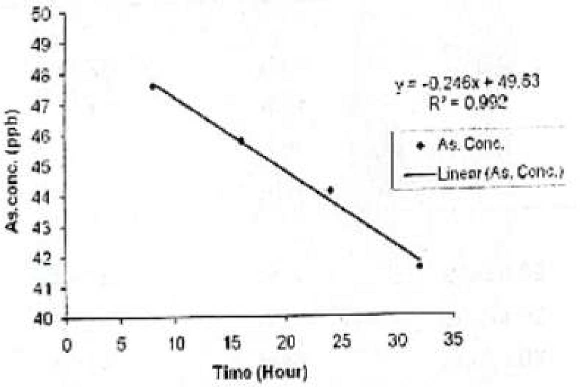
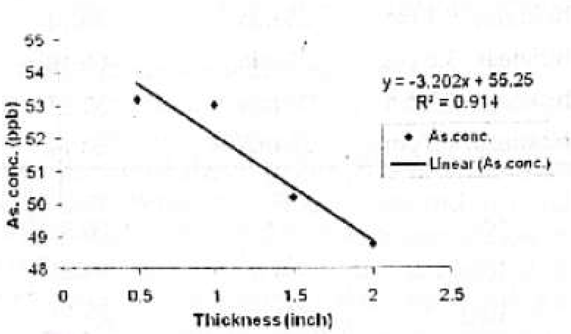


Fig. 4(b). Comparison between As. conc. and time (living plant)



Fog. 5(a). Comparison between As. conc. and thickness of charcoal layer

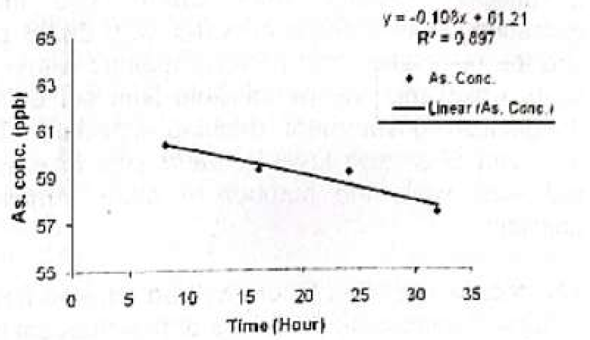


Fig. 5(b) Comparison between As. conc. and time (used team leaf)

4. Conclusion

To save millions of people from arsenic poisoning it is important to detect the arsenic concentration in drinking water and also to provide a suitable, user friendly and cost effective arsenic removal process for the rural people of Bangladesh. The instruments are expensive and the removal technologies so far tried for the rural people have potential but not tested thoroughly for adoption. The four treatments used in this project reduced arsenic level at different scale. The initial level of arsenic in untreated water was 63.56 ppb. Dried water hyacinth root reduced arsenic level from 63.56 ppb to 46.86 ppb by adding 12 g. in 250 ml water. The living plant of water hyacinth reduced arsenic level at 47.54 to 41.54 ppb in 8 to 32 hours, respectively. In charcoal sedimentation method arsenic level was reduced to 48.74 ppb with a layer thickness of 5.1 cm. Used tea leaf reduced arsenic level to 60.34 to 57.46 ppb in 8 to 32 hours, respectively. From these results it was found that living plant of water hyacinth reduced arsenic level effectively at the minimum level of 44.03 ppb. Charcoal sedimentation method also reduced arsenic level below the drinking standard.

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