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Arsenic Removal from Drinking Water using Different Biomaterials and Evaluation of a Phytotechnology Based Filter

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Abstract

This study established efficiency of arsenic removal from drinking water using different plant-based biomaterials that are widely available in the arsenic affected regions of Bangladesh. Dried and powdered roots of the water hyacinth (WH) plant was best at removal of As (III) and As (V) followed by banana pseudostem (BN), sugar cane bagasse (SC) and Jute. Small quantities (2 mg/ml) of each material in the form of a powder was agitated in 25 ml of drinking water, spiked with 300 µg/l of As(III)/As(V), at pH 7.0 for 2 hours in a flask using a shaker. The percentage removal of As (III) and As (V) using WH, SC, BN and Jute were (78%, 81%), (66%, 47%), (64%, 67%) and (26%, 11%), respectively. A prototype filter was prepared from WH (20 g) which was capable of removing 80% and 84% of arsenic from drinking water with concentrations of 250 and 1000 µg/l, respectively. Further studies are needed to improve the design of this filter and evaluate its performance with arsenic contaminated groundwater at the field level.

Keywords: Arsenic, removal, banana, sugar cane, water hyacinth, water, filter.

Introduction

Arsenic in drinking water is a major health concern in many countries worldwide with hundreds of millions of people affected[1-2]. These people are exposed to higher arsenic (As) concentration than the recommended level of 10 µg/L set by the World Health Organization (WHO). Most of the affected areas are in developing countries such as Bangladesh and India[3]. Many of the affected communities are economically disadvantaged and cannot afford to purchase commercially available arsenic removal filters. Therefore, there is an urgent need for developing cost effective, simple and inexpensive techniques, ideally based on locally available materials, for removal of As from drinking water[2]. Current technologies for arsenic remediation reported in the literature[4] includes the following: precipitation, membrane, coagulation and ion exchange technology. Each of these technologies includes different methods: the precipitation technology includes air and chemical oxidations; Membrane technology contains nanofiltration, reverse osmosis and electrodialysis; coagulation technology comprises alum coagulation, iron coagulation and lime softening; and ion exchange technology consists of activated alumina, iron coated sand and ion-exchange resin. There has not been much work on the use of biomaterials for arsenic removal, although they meet different criterions such as availability, cost effectiveness, sustainability and environment friendly.

This study focuses on the analysis of four different plant-based biomaterials for their performance in the removal of As from water. These materials were dried water hyacinth roots (WH), dried jute, dried sugar cane bagasse (SC) and dried banana pseudostem (BN). These plants and their biomass are widely available in the arsenic affected regions of Bangladesh and as such can provide materials for sustainable arsenic removal technologies. Water hyacinth is the fastest growing plant in the world and millions of tonnes of this plant is free available in Africa, South America and Asia where they are removed from water bodies as an undesirable weed which blocks rivers. The potential of using dried water hyacinth roots for removal of as from water was first reported by us[2]. Subsequent studies[5-7] have confirmed the findings of our study. The most recent study[6] demonstrated that by increasing the mass of DHR, it is possible to further increase the removal efficiency of As (III) present in water at concentration much higher than what was investigated in the earlier studies.

The aim of the current study was to compare different biomass, that are widely available in Bangladesh, for their efficiency in removing As from drinking water. The study also reports the design of a prototype household filter that could be used in the arsenic affected regions of Bangladesh and India where these plant-based biomaterials are widely available.

Material and Methods

Reagents: Deionised water (>18Ω/cm, Milli-Q) was used for the preparation of standards throughout the study. Standards of As (V) were prepared by diluting stock solution of As (V) standard (1000 ± 3 mg/l, CPI, International, USA) by using 1% v/v HNO_3. Standard solutions for As (III) were prepared from stock solutions of arsenic trioxide (As_2O_3), (Sigma-Aldrich, Germany) was dissolved in 4 g/l sodium hydroxide and made up to appropriate volume with 2%v/vHNO_3 (UPA, Romil, UK) as previously reported[8].

Sample preparation and analysis: Dried WH, SC, BN and Jute were obtained from Bangladesh. They were ground into fine powder using a coffee grinder. Subsequently, 50 mg of each powder was suspended in 25 ml of tap water spiked with 300 µg/l of As (III)/As (V), pH 7.0 and agitated using a shaker for 2 hours at room temperature. Treated water samples were filtered through a 0.45 µm syringe filter (Millipore, Bedford, USA) and measured using a SpectrAA-220 (Varian, UK) Graphite Furnace –Atomic Absorption Spectroscopy (GF-AAS) with Zeeman background correction. The instrument comprises a pump system for sample introduction, an autosampler, Zeeman background correction and graphite tube atomiser (GTA). Instrument operating parameters were used for As measurement in treated water as described previuosly[9]. The LOD the LOQ were calculated for GF-AAS by using the equations LOD = 3 x SD (0.25 µg/L) and LOQ = 10 x SD (0.84 µg/L), respectively. The SD was the standard deviation of ten measurements of the blank (1% v/v HNO3).

Results and Discussion

Figure 1 shows photographs of the dried plant-based biomaterials used in this study. The removal of arsenic by 50 mg powder of each biomaterial from 25 ml of water, spiked with 300 µg/l of As (III)/As (V), pH 7.0 for 2 hours using a flask shaker, are shown in figure 2. The percentage removal for the four different biomaterials is shown in figure 3. The design and the arsenic removal efficiency of the prototype filter is presented in figure 4.

Comparative evaluation of different biomaterials for arsenic removal: The percentage removal increases as the exposure time increase for all the biomass materials. The longest exposure time was 120 minutes and under this condition the percentage removal of arsenic was greatest for all the biomaterials. The percentage removal of As (III) and As (V) using WH, SC, BN and Jute were (78%, 81%), (66%, 47%), (64%, 67%) and (26%, 11%) , respectively. WH showed the best performance for removing both As (III) and As (V). A mixture of the four biomaterials (WH, SC, BN and Jute; 1:1:1:1) showed similar performance (77%) for As (III) removal as WH. This is a promising result as As (III) is 25-60 times more toxic than As(V)[10-11]. However, the mixture showed less performance (42%) for As (V) compared to 81% of the WH. The reason for this difference is not clear and needs to be investigated in the future.

The WH was previously used in different studies. A quantity as large as 30 to 45 mg/ml was used previously[2] and achieved removal percentage (93% and 95%) for As (III) and As (V), respectively. In the current study, far lower concentration (2mg/ml) was used and high percentage (78% and 81%) of As (III) and As (V), respectively was removed from water. A recent study[6] used 50 g of dried hyacinth root (DHR) for 50 ppm As(III) and achieved removal percentage (91.5%) of As (III) within 12 hours and 99.5% in 48 hours. They concluded that increasing the mass of the DHR will increase the removal efficiency of the As (III) in a short time. The mass of the DHR used in recent study[6] in their study is still higher than the mass used in this study (2mg/ml). It is clear that WH powder can be an effective material for removal of arsenic.

Other studies have used different biomaterials to remove arsenic from drinking water. The percentage removal for As (III) and As (V) has been reported for materials such as waste tea (100% and 77%), plant biomass (Garcinia cambogia) (100% As(III)), banana pith (12% and 18%), mushroom (22% and 35%), sawdust (28% and 36%) and rice husk ash (5% and 12%), respectively[12-14].

In agreement with previous studies reported by us and others, water hyacinth (dried root) showed a high performance of arsenic removal. We found that it is more effective than three other widely available biomaterials from Bangladesh. These are encouraging results which will help economically disadvantaged communities to use locally available biomass materials as a household filter to remove arsenic and potentially other toxic elements from their drinking water. The mechanism via which WH roots are able to remove arsenic remains unknown. This was speculated to be an adsorption and/or ion exchange process although further studies are required in this area.

(a) (b) (c) (d)

Figure-1

Photos of different plant-based biomaterials obtained from Bangladesh. (a) Dried sugar cane bagasse (SC) (b) Dried Jute (Jute) (c) Dried water hyacinth roots (WH) (d) Dried banana pseudo-stem (BN)

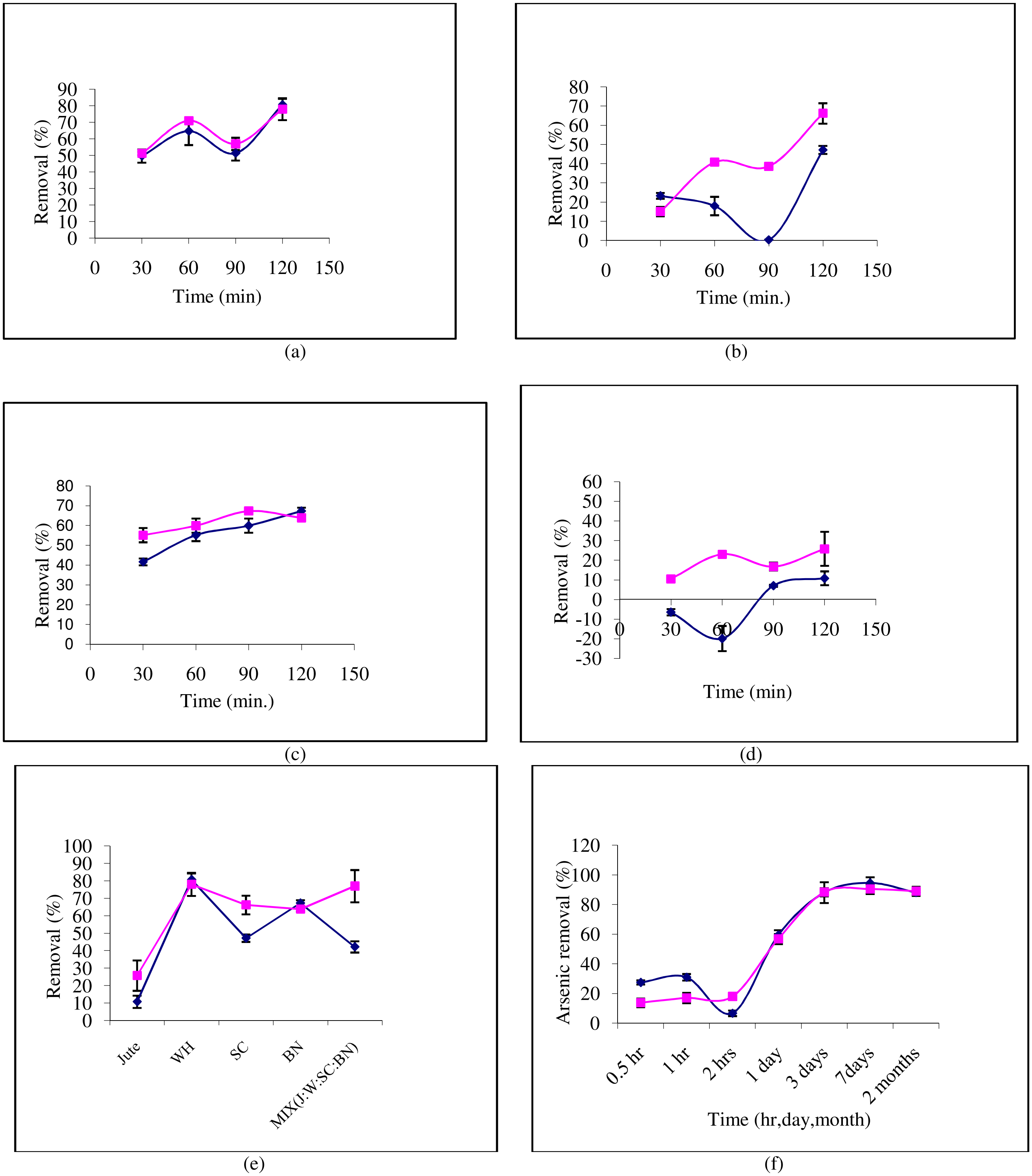


Figure-2

A(V) and As (III) removal by the plant-based biomaterials as a function of time. The error bars represent the standard deviation of three replicate measurements; (a) WH (b) SC (c) BN (d) Jute (e) 120 minutes (f) WH; ◆As (V) ■ As (III)

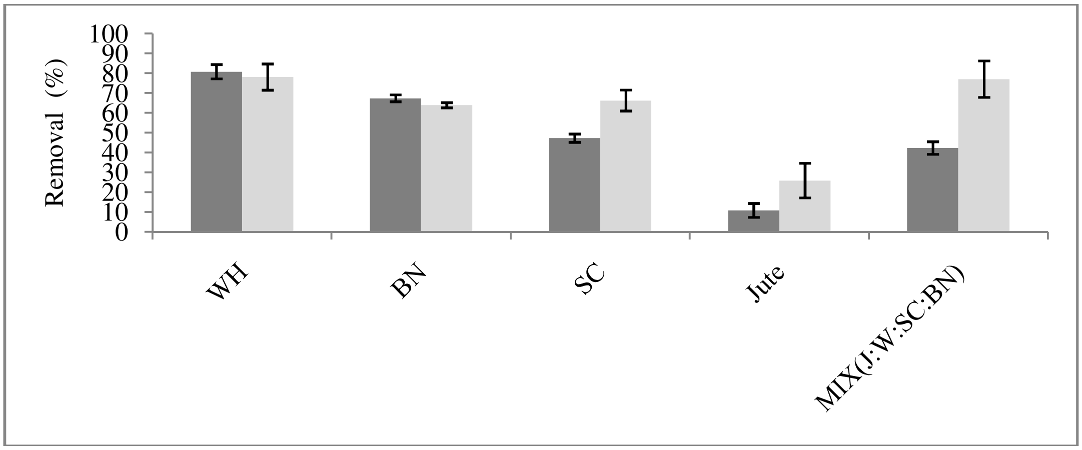
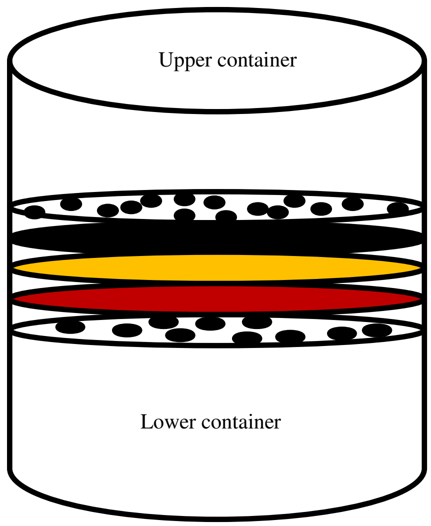


Figure-3

Comparative evaluation of percentage removal of ▇ As (V) and ▢ As (III) by different biomaterials, the error bars are SD (n = 3)



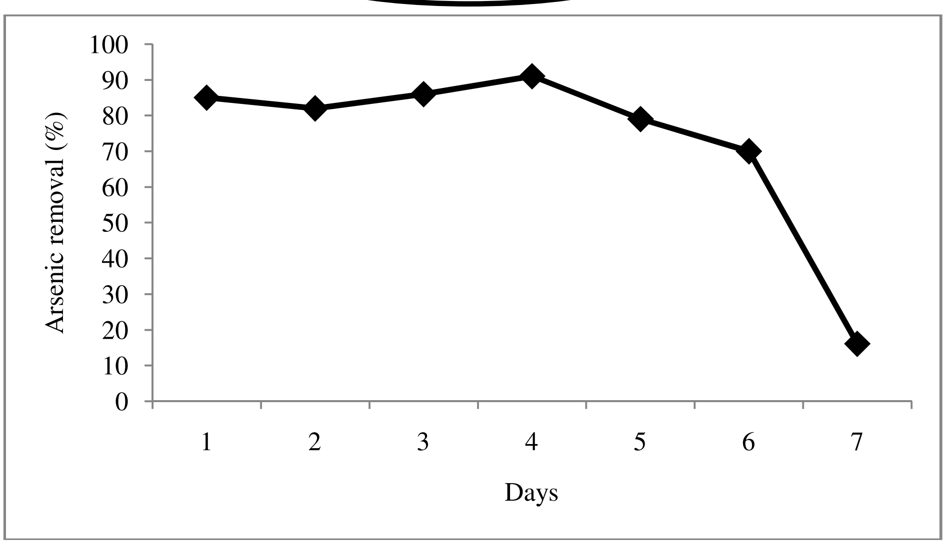


Figure-4

(a) A prototype filter based on the use of dried water hyacinth root powder for arsenic removal from drinking water; . Water hyacinth's dried powder (20g) ▇ Sand (1Kg) ▇ Brick pieces (1Kg); ▇ and (b) durable usage

Filter design from water hyacinth: As shown from figures 2 and 3 water hyacinth had the highest performance of arsenic removal from drinking water compared with other biomaterials. Therefore, a prototype filter based on water hyacinth was designed.

Figure 4 present a schematic diagram to illustrate the design of the prototype filter. It consists of three layers: the top layer contains dried water hyacinth root powder (20 g), the middle layer contains sand (1 Kg) and the bottom layer contains ground pieces of brick (1 Kg). The filtration system was constructed from two small buckets. The water to be filter is added to the upper container and the filtrate water is collected in the lower bucket. Tap water spiked with arsenic (concentration range of 250-1000 µg/l) was placed in the upper bucket and the efficiency of arsenic removal was determined by measuring the arsenic concentration in the filtrate. This simple filter removed 80% and 84% of arsenic (250 and 1000µg/L), respectively. The prototype filter had a flow rate of 0.22l/min.

Advantages of the prototype filter and performance: Water hyacinth is known to have fast rate of growth and spread across water bodies[4] (4-Mohan and Pittman, 2007), which makes it a highly abundant and obtainable biomaterial. Indeed, each year millions of dollars are spent to clear thousands of tonnes of this plant from rivers and lakes in different parts of the world. Small quantities (20 g) of its dried roots are sufficient for removal of arsenic from large volumes (11 L) of water. Water hyacinth is abundant in arsenic affected areas of Bangladesh where drinking water is contaminated with high concentration of arsenic. The prototype filter can be potentially used for removal of arsenic at the house hold or community level in Bangladesh as a simple, efficient and sustainable alternative to the more expensive technologies, The filter needs to be evaluated at the field level in arsenic affected regions of the world to ascertain its full potential.

Conclusion

Four different plant-based biomaterials, that are abundant in Bangladesh, were shown to effectively remove a higher percentage of As (III) than As (V). This is very promising because As (III) is far more toxic than As (V). Dried water hyacinth root powder (WH) shows the best performance for removing As (III) and As (V) followed by banana pseudostem (BN), sugarcane bagasse (SC) and Jute.

The percentage removal increases with increasing exposure time for all the biomaterials tested. A mixture of four biomaterials (WH, SC, BN and Jute; 1:1:1:1) shows similar performance for removal of As (III) as WH alone. We are working on chemically modifying some of these biomaterials including the jute plant to improve its arsenic removal efficiency.

Field studies on the filter is essential prior to its usage as a potential vital household method for removing arsenic from drinking water. Future studies should focus on understanding the mechanism of arsenic removal by water hyacinth and other plant-based materials. The disposal of used material is also one of the issues that need to be resolved in future.

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