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Research Article

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Modification of indigenous rural water filter for arsenic mitigation using different bamboo charcoals

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ABSTRACT

Purification of drinking water using charcoal and river sand which is locally known as sand filter (SF) is very common in the rural areas of Assam, but limited research work has been reported on its scientific view points as well as on its modification. The main aim of this piece of work was to test the scientific importance of this indigenous rural water filtration technique and minimization of As problems in underground drinking water using different bamboo charcoals. Removal efficiency of four different bamboo charcoals viz. Bambusa balcooa, Bambusa nutans, Bambusa tulda and Bambusa padilla with river sands of variable grain size distribution was studied. At the pH range of 7.0-7.8 with As concentration in the range of 0.001-1.0 mg/L, removal efficiency of bamboo charcoals of B balcooa, B nutans, B tulda and B padilla were found 69.77, 64.09, 60.38 and 56.24% respectively. The extent of As removal by these bamboo charcoals were found highly pH dependent and also the removal rate decreased with the increase of the initial concentration of As beyond 1 mg/L at pH range 7.0-7.8. Study also revealed that contact time of raw water with modified filtration bed less than 1 hour and more than 2 hours was found to be less effective in As removal from ground water.

Key words: Sand filter, bamboo charcoals, arsenic, mitigation, ground water

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INTRODUCTION

Sand filtration is a widely used traditional process for eliminating harmful contaminants from surface and underground waters to produce safe drinking water [1] [2]. In this process, water flows through filtration bed made up of sand, charcoals and other locally available materials and the contaminants particles are accumulated on the surface of it. Sand filtration technique has been successfully used for over 200 years for removing contaminants from ground water and surface water sources to produce safe drinking water because of their simplicity, efficiency, economical construction, easy operation and maintenance using household materials and skills as well as no requirements of chemicals [1] [2] [3] [4]. Among rural population, this filtration is the best reliable technique to eliminate pollutant particles such as heavy metals, viruses, bacteria's and similar harmful agents from drinking water. Sand filters were proved to be beneficial for the prevention of water-borne diseases. Depending on raw water quality, it can eliminate up to 99.9% of the water born bacteria [5] [6] [7], total coliform bacteria [8] [9] [10], and fecal coliform [11]. It can also prevent gastrointestinal diseases [12]. Therefore, the improvisation of this promising indigenous water filtration is most important at present.

In recent years, cumulative apprehension on the increasing toxicity of heavy metals in ground water has lead to extensive research into developing effective alternative technologies for the removal of toxic metals. The most common methods are chemical precipitation, ion exchange, solvent extraction, dialysis, electrolytic extraction, oxidation-reduction, reverse osmosis, ultra filtration, membrane filtration, co-precipitation etc. But all methods have their own natural limitations such as less efficiency, sensitive operating condition, production of secondary sludge and higher cost of materials [13] [14] [15] [16]. Therefore, these methods cannot be adopted by the common peoples of developing states like Assam. Heavy metal removal from water using commonly available natural substances has gained important credibility because of their performance, very low cost of the materials and easy availability. Environment-friendly agro wastes, unconventional raw materials like saw dust, rice husk, wood charcoal, rice hull and tree leaves have emerged as important adsorbents at present [17] [18] [19]. Depending on experiences gained in laboratory as adsorbent, these substances can be used to design and construct an efficient filter for purification of water as these have been using traditionally for a long time by common people and found to be economically feasible. The adsorbents uses in the preparation of filtration bed viz. charcoal and river sand are easily available and eco-friendly and found highly efficient without changing variable ambient conditions of raw water such as pH, concentration, contact time etc. [20]. So far extensive study on traditional sand filters using low cost bamboo charcoals and river sand for the removal of toxic metals from water has not been reported in Assam. Therefore, a study was carried out on the traditional sand filter using four different bamboo charcoals with river sand on the extent of heavy metal removal as well as on its modification.

Bamboo is an integral part of life for rural peoples of Assam for fulfilling their basic necessities. It provides us construction materials for shelter, tools and implements for agriculture, pulp for paper and materials for many traditional handicrafts. In addition they conserve soil and rejuvenate the forests. Many cultural traditions in rural areas of Assam are intimately associated with bamboos. Different aspects of traditional use of bamboos by the rural people of this region provide a socio-economic support directly or indirectly especially to the lower and middle class groups of people [21]. Association of human with bamboos in India is as old as human civilization. India is the second largest producer of bamboo in the world next to China and also has the rich diversity of bamboos harboring almost 130 species. Out of this large number, 78 species distributed in the northeastern region of India and 42 species are found in Assam [22]. Arsenic is a ubiquitous hazardous metalloid in the environment occurring in both organic and inorganic (As^{+5} and As^{+3}) forms and mostly known as epigenetic carcinogen to human health [23], [24] [25]. Problem of As contamination in Assam is not colossal in scale but extensive water quality assessment detects new arsenic contaminated areas recently. Long time uptake of drinking water containing low levels of arsenite, induces dermatological lesions, hypertension and chromosomal abnormalities leading to carcinogenesis in skin, lung and kidney tissues (Arsenocosis) [26]. The risk of cancer in people drinking water with an arsenic level above 100 ppb increases over 15 times compared with people living in areas with less than 10 ppb [27]. The WHO recommended limit for arsenic concentration in drinking waters is 0.01mg/L [28].

More than 80% of rural populations of Assam depend on ground water sources for drinking and irrigation purposes. Therefore, developments of appropriate technologies are urgent need for purification of ground water to enable safe use. There is a need to look into alternatives to investigate a low-cost method which is effective as well as economic and can be used by common masses. The goal of this work was to modify the rural water filtration technique using four different locally available bamboo charcoals with river sands and to find out the removal efficiency of As from ground water. The removal efficiency of the modified filter was also investigated by changing the ambient conditions of raw water such as pH and concentration of metals in raw water.

EXPERIMENTAL SECTION

Preparation of Adsorbent Materials

For this investigation, four different bamboo charcoals viz. *Bambusa balcooa, Bambusa nutans, Bambusa tulda and Bambusa pallida*, locally known as Bhaluka Bah, Makal Bah, Jati Bah and Bijuli Bah respectively were collected separately for the preparation of filtration bed with river sand (Table 1).

Table 1. Bamboo species used in the modified sand filter

Local name	Scientific name
Bhaluka Bah	*Bambusa balcooa*
Makal Bah	*Bambusa nutans*
Jati Bah	*Bambusa tulda*
Bijuli Bah	*Bambusa pallida*

A total of 1.5 kg bamboo charcoals from 1-2 years of old bamboo trees, after the use as fire wood by villagers have been collected washed several times with boiling water followed by distilled water to eliminate the water soluble impurities and finally oven dried at 105°C. Charcoals were crushed and sieved through different mesh size. The river sand was thoroughly washed with boiling water followed by distilled water, dried in sunlight and then in oven at $105^{o}C$.

Experimental Setup of the Modified Sand Filter

Four cylindrical concrete chambers of 3.5 feet high and 2.5 feet in diameter closed at the bottom were used as filtration chamber in this modified sand filter (Fig. 1). For each sand filter the filter media or filtration bed was prepared by four different bamboo charcoals mixed with river sand, placed in the order of decreasing sizes in the direction of flow. Each filtration bed was composed of five layers having thickness of 40-50 cm with different composition of charcoal and sand mixtures. The first layer, i.e. the bottom layer was made of gravels of 10-12 mm diameter having thickness of 5-7 cm just above a porous concrete plate placed at 1/3 distances from the bottom of the filtration chamber. The second layer was made of mixture of river sand with powdered like bamboo charcoals (200 mesh) having thickness of 8-10 cm above the gravel layer. The thickness of the third layer was of 12-14 cm made of well mixed river sand with crushed bamboo charcoals having almost equal size of sand and charcoal. The fourth layer was made of normal size bamboo charcoals of thickness 7-9 cm and the fifth layer i.e. the top layer was of gravels to prevent the floating of the charcoals. The average flow rate of filtration through this filtration bed was slightly more than 5 lit/h.

Physico-chemical Analysis of Water Samples

The raw water samples used in this modified sand filtration technique were collected directly from four different sampling sources using the standard method described in the guidelines for the quality of drinking water [29]. Raw waters were collected during November, 2010-March, 2012 from the sampling sites of Negheriting TE (Sample No. S_1 and S_2) and Khomtai TE belts (Sample No. S_3 and S_4) of Golaghat district of Assam, where the maximum value of As concentration were found to be 0.119 mg/L respectively. The water quality parameter estimation and calibration of equipments were done using standard methods and techniques [29] [30] [31]. Stock solutions (1000 mg/L) of As^{+3} were prepared by dissolving the desired quantity of As_2O_3 in double distilled water respectively. The working concentrations were obtained by a proper dilution of stock solutions. Raw water solutions having different pH were prepared by adding appropriate amount of NaOH or CH_3COOH solutions to the raw water. After pouring raw water through the sand filter the outlet of it was stopped for 30, 60, 90 and 120 minutes respectively and water samples were collected and tested for As content by AAS (Perkin Elmer-2380).

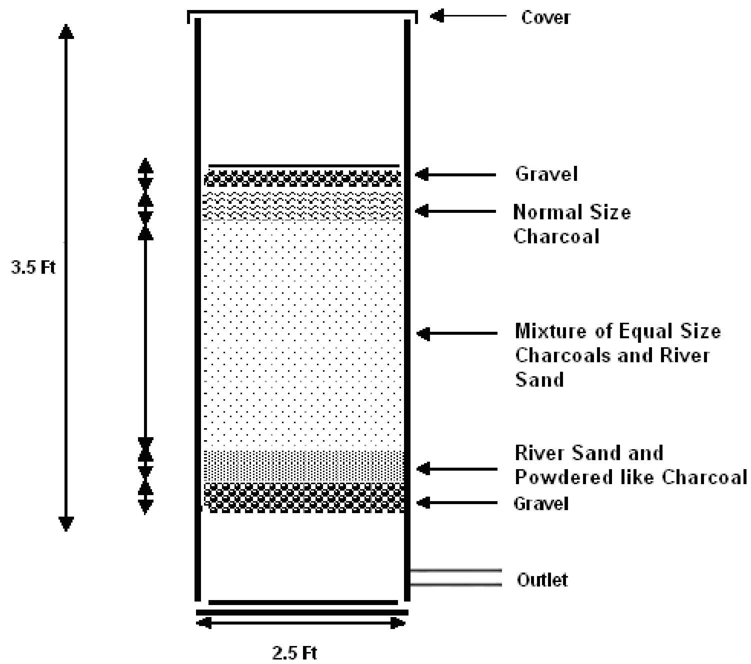

Fig. 1. A schematic diagram of modified sand filter

All experiments were run in triplicate and arithmetic means of the results were considered for data analysis. A probability level ($p < 0.05$) was used throughout the study and conclusions were drawn only if the results were statistically significant. The removal efficiency was calculated as follows: Removal Efficiency = $\left[\frac{(C_0 - C_1)}{C_0}\right] \times 100$. Where, C_0 and C_1 are the concentrations of Fe and As in the water sample solution before and after treatment respectively.

RESULTS AND DISCUSSION

The average values of physico-chemical parameters of raw water collected from Negheriting TE (S_1 and S_2) and Koomtai TE (S_3 and S_4) used in the modified sand filter experiments are presented in the Table 2. Physico-chemical parameters pH, EC, Na^+, K^+, TDS, Cl^-, NO_3^--N, SO_4^{2-} and HCO_3^- were found within safe limit of drinking water standard prescribed by WHO and BIS.

Table 2. Physico-chemical characteristics of raw ground water samples

Parameters	Sampling locations and sample number			
	Negheriting TE		Koomtai TE	
	S_1	S_2	S_3	S_4
pH	7.21	7.66	7.23	7.12
EC (µS/cm)	227	167	356	612
Turbidity (NTU)	4.53	3.09	6.77	8.45
DO (mg/L)	4.50	6.20	5.20	2.10
Na (mg/L)	32	17	28	44
K (mg/L)	16	9	9	17
Ca (mg/L)	126	112	209	733
Mg (mg/L)	66	26	180	3
Alkalinity (mg/L)	271	354	630	822
TDS (mg/L)	1005	670	913	279
Cl^- (mg/L)	13.50	45.0	6.61	2.67
NO_3^--N (mg/L)	0.00	0.03	0.45	0.02
SO_4^2 (mg/L)	41.85	29.75	12.30	51.20
HCO_3^- (mg/L)	230	326	423	349
Fe (mg/L)	7.46	0.71	5.14	1.79
As (mg/L)	0.119	0.00	0.117	0.00

At the pH of 7.5 and As concentration in the range 0.001-1.0 mg/L the removal efficiency of *B balcooa* and *B nutans* were found to be 69.77% and 64.09% respectively whereas maximum efficiency of *B tulda* and *B padilla* was found to be 60.38 and 56.24% at pH 7.8 (Table 3). Increase in pH from 6.5 to 7.5, As removal efficiency of *B balcooa* and *B nutans* increased from 38.82-69.77% and 35.89-64.09% respectively. Further increase in pH removal efficiency was found to be decreased drastically.

Table 3. Effect of pH on removal efficiency of As at concentration of 0.001-1.0 mg/L

pH of raw water	Rate of removal (%)			
	B balcooa	*B nutans*	*B tulda*	*B padilla*
6.0	36.21	29.46	27.19	23.11
6.3	37.88	33.83	28.33	29.77
6.5	38.82	35.89	39.87	31.09
7.5	69.77	64.09	46.45	38.92
7.8	48.37	44.39	60.38	56.24
8.0	26.03	17.13	45.09	40.13

The study also showed that the removal rate was decreased considerably with the increase in initial concentration of As beyond 1.0 mg/L respectively at pH range of 7.0-7.8. Experimental data on As removal efficiency of all the four bamboo charcoals at two different initial concentration range 0.001-0.05 mg/L and 0.005-1.0 mg/L having pH range between 7.0 to 7.8 showed almost same efficiency. Maximum efficiency was observed at the concentration range of 0.05-1.0 mg/L for all bamboo charcoals. Initial concentration of As higher than 1.0 mg/L, extent of adsorption of *B balcooa*, *B nutans*, *B tulda* and *B padilla* came down considerably to 44.96, 50.17, 43.45 and 32.78% respectively (Table 4). The As removal efficiency was observed maximum for *B balcooa* followed by *B nutans*, *B tulda* and *B padilla.*

Table 4. Effect of initial con. on the extent of As removal at pH range 7.0-7.8

Initial Conc. (mg/L)	Rate of Removal (%)			
	B balcooa	*B nutans*	*B tulda*	*B padilla*
0.001-0.05	68.39	64.09	58.71	54.39
0.05-1.00	69.77	64.01	60.28	56.24
>1.00	44.96	50.17	43.45	32.78

Studies on contact time of raw water with modified filtration bed showed that contact time less than 30 minutes was found to be less effective and more than 60 minutes was also unnecessary for maximum effective removal of As from raw water. Results showed that water samples collected at 60, 90 and 120 minutes of stopping of the filter outlet contains same amount of As in filtered water. Experiments also showed that average flow rate of water as well as As removal efficiency of all the four filtration beds of different bamboo charcoals with river sand were found to be decreased after 2/3 months of preparation of the modified sand filers. Therefore, after every two months of intervals second and third layer of the modified sand filter (from bottom) were removed and charcoals and gravels of the other layers were washed with boiling water followed by distilled water and finally oven dried at 105°C for reused. Similar results were also observed with these new filtration beds. Among the four bamboo sorbents charcoals with river sand, experiments showed that *Bambusa balcooa* was found to be more efficient in As removal from water in the modified sand filter. Study showed that As removal efficiency was maximum at the alkaline pH of raw water which was within the permissible limit of standard drinking water guideline value. Moreover, normal range of pH of ground water of Assam also falls within the effective pH range of the modified sand filter developed; therefore this filter may be used by the rural people of this region without changing the pH of raw water. If needed, the pH of raw water can be achieved by adding simply lime to the raw water, which is a traditional practice of the rural inhabitants of Assam.

Study also showed that As concentration beyond 1.0 mg/L, removal rate was found to be decreased. This decrease in removal percentage at higher concentrations might be due to the relatively smaller numbers of active sites available at higher concentrations [24]. Experiments showed that at the initial stage, the rate of removal was found higher, due to the availability of more than required number of active sites on the surface of bamboo charcoals and river sand. It became slower at the later stages of contact time, due to the decreased or lesser number of active sites on the adsorbents. Similar trends of results were observed where experiments were done for Ni removal by sphagnum moss peat and groundnut shell [32] [33], As by activated carbon [24], Pb by coconut shell [34] and Fe by tamarind bark [14].

The efficiency of As removal was decreased with contact time can be attributed that at higher pH and concentration large amount of soluble Fe^{+2} precipitated as insoluble Fe^{+3} hence makes a layer over the adsorption sites of the bamboo charcoals and river sand, resulting slow flow rate. Moreover, arsenic in ground water is associated with pyrites and Fe^{+2} salts which gets oxidized to Fe^{+3} and results in precipitation of $Fe(OH)_3$, which acts as an sink for arsenic [35].

Removal efficiency was also directly proportional to the depth of the filtration bed. In the modified sand filtration technique the depth of the filtration bed was kept remain same as that of rural filtration techniques, only change was done on it's composition with different layers having different size. Efficiency of a new filter depends on raw water quality and design of filtration media in the modified filter. An efficient water filter design and operation mostly rely on experiences gained at laboratory. A large numbers of dependent water quality parameters affect on its performance. But in this method raw water was used directly and the dependent conditions such as temperature, pH and chemical composition of the raw water of the study area well agreed with the effective conditions for maximum efficiency of the modified filtration bed. Extensive study on kinetics, thermodynamics and spectroscopy are much needed to develop bamboo charcoals as an effective commercial alternative in near future. This low cost sand filtration technique has high potentiality as the waste product of bamboo firewood is easily available in Assam and easy to prepare the filtration bed.

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