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Arsenic removal through bio sand filter using different bio-adsorbents

Ghulam S. KEERIO[1)], Hareef A. KEERIO[2)] ✉, Khalil A. IBUPHOTO[3)], Mahmood LAGHARI[1)], Sallahuddin PANHWAR[4)], Mashooque A. TALPUR[5)]

[1)] Sindh Agriculture University, Department of Energy and Environment, Tandojam, Pakistan
[2)] Hanyang University, Department of Civil and Environmental Engineering, Seoul, South Korea
[3)] Sindh Agriculture University, Department of Farm Structures, Tandojam, Pakistan
[4)] Mehran University of Engineering and Technology, US-Pakistan Centers for Advanced Studies in Water, Jamshoro, Pakistan
[5)] Sindh Agriculture University, Department of Irrigation and Drainage, Tandojam, Pakistan

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Abstract

Arsenic is one of the most harmful pollutants in groundwater. In this paper, the Nepali bio sand filter (BSF) was modified with different bio-adsorbents, and proved to be an efficient method for arsenic removal from groundwater. Three different bio-adsorbents were used to modify the Nepali BSF. Iron nails and biochar BSF, ~96% and ~93% arsenic removal was achieved, within the range of WHO guidelines. In iron nails, BSF and biochar BSF ~15 $dm^3 \cdot h^{-1}$ arsenic content water was treated. In the other two BSFs, rice-husk and banana peel were used, the arsenic removal efficiency was ~83% of both BSFs. Furthermore, the efficiency of rice-husk and banana peel BSFs can be increased by increasing the surface area of the adsorbent or by reducing the flow rate.

Key words: *arsenic, banana peel, bio-adsorbent, bio-sand filter, biochar, rice-husk, water treatment*

INTRODUCTION

The arsenic level in local Mirpurkhas has been found to be above the maximum passable breaking point with correlation to WHO (10 ppb) [ASGHAR *et al.* 2006]. The arsenic level in the Larkana region exceeded this, with tests showing hazardous levels of arsenic [MURTAZA *et al.* 2007]. Arsenic has been found within the underground water of zone of Matiari and Khairpur Mir. The levels found were between 100–250 ppb and making the water hazardous for human use [ARAIN *et al.* 2007]. An arsenic level higher than the WHO guidelines [ARAIN *et al.* 2007] can be found in many countries, particularly within Asia e.g., Bangladesh, India, Nepal, Vietnam, China, and Myanmar, where arsenic presents a risk to the general wellbeing [ISLAM-UL-HAQ *et al.* 2007]. In light of this, the Government of Pakistan has been part of various projects with assistance from UNICEF since 1999. New and cost-effective techniques need to be proposed in Pakistan in order to remove the arsenic from the groundwater.

A study looking at the three headways against social, and budgetary criteria showed that the Kanchan arsenic filter (KAF) is the most promising development for Nepal [NGAI *et al.* 2007]. A two-year and social evaluation of more than 1000 KAFs set in common towns of Nepal set up that the KAF normally removes 85–90% arsenic. Many arsenic-removal techniques have been proposed to remove the arsenic from wastewater, such as precipitation/coagulation/sedimentation, oxidation/reduction, membrane/filters, distillation, and adsorption/ion-exchange [MOHAN, PITTMAN 2007].

There are several different materials for the adsorption of arsenic ions that have been used such as rice polish, zeolite, red mud, activated alumina, surface-modified carbon black, iron hydroxides and oxides, open-celled cellulose sponge and further adsorbents [PEHLIVAN *et al.* 2013]. In this study, the Nepali bio sand filter (BSF) was selected and modified using different organic adsorbents such as biochar, rice-husk, and banana peel, and performance of the adsorbents were analysed and compared.

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MATERIAL AND METHODS

The experimental study was carried out in the Department of Energy and Environment (EE), Faculty of Agriculture Engineering (FAE), Sindh Agriculture University (SAU), Tandojam. In this experiment, water containing arsenic (150 ppb) was purified through modified Nepali bio sand filter (BSF). Three different adsorbents were used to modify Nepali BSF [NGAI *et al.* 2007], biochar modified BSF, rice husk modified BSF, and banana peel modified BSF.

MATERIALS USED FOR BSFS

Different materials proposed for the modification of Nepali BSF. **Iron nails**: ordinary iron nails of 25 mm length were used in BSFs for arsenic removal. Iron nails were used in the proposed BSFs as an arsenic removal/adsorbent [NGAI *et al.* 2007]. **Biochar:** the wood-derived biochar was used in the BSFs as bio-adsorbent. Biochar, made in our laboratory from acacia wood through slow pyrolysis of 400 to 500°C for 2 hours [HUANG *et al.* 2020]. **Rice husk**: rice-husks, purchased from the local market. Before use, the rice husks were rinsed several times with distilled water and dried in an oven at 70°C [LEE *et al.* 1999] and used as a bio-adsorbent in the BSFs. **Banana peel:** the bananas were purchased from the market, their peels collected, rinsed, and dried at 70°C and utilized as a bio-adsorbent [ARUNAKUMARA *et al.* 2013]. **Pit sand and gravel**: the coarse sand (from 1 to 6 mm) and fine sand (<1 mm). Sand was used in the BSFs as a pathogen removal media. Gravel (from 6 to 15 mm) was used in the bottom layer to facilitate the outflow of water [NGAI *et al.* 2007].

Fabrication of bio sand filters (BSFs). The BSF body was prepared with a plastic sheet. The volume of BSF kept $90 \times 30 \times 30$ cm^3 as in the previous report [NGAI *et al.* 2007]. The bottom of the BSF was closed using endcaps. A 30-mm diameter inlet and outlet pipe was fixed to the side of the pipes just below the top and above the bottom, having star fashioned a T using nylon mesh with small holes for taking out the processed water. All materials including iron nails, biochar, rice husk, banana peels, gravel, fine and coarse sand were washed with distilled water before packing in the BSFs. A 5-cm layer of gravel (particle size 6 to 15 mm) was placed in the bottom. The respective materials such as sand, bio-adsorbents, and iron nails were packed in the pipes [NGAI *et al.* 2007].

MODIFICATION OF BIO SAND FILTERS (BSFS)

Three different bio-adsorbent were used to modify the Nepali BSF. The modified BSFs were evaluated for arsenic removal from drinking water and have been compared with the Nepali BSF (control). The layouts of modified filters are presented below.

Nepali BSF (control): the Nepali BSF contains the layers of rusted iron nails, gravel, coarse and fine sand and it was fabricated the same as presented in the previous study [NGAI *et al.* 2007]. The average arsenic adsorption value was taken after repeating the test five-times. The 150-ppb contained water that was pumped with a flow rate of 48 s·(200 cm^3)$^{-1}$.

Biochar-modified BSF (BC-BSF): the Nepali BSF was modified using biochar. Simply, the 1 kg of wood charcoal (particle size 5 to 30 mm) was used as a bio-adsorbent in between the iron nails and the sand (Fig. 1). The same wastewater (150 ppb content) was pumped with the flow rate of 68 s·(200 cm^3)$^{-1}$.

Rice husk-modified BSF (RH-BSF): in this BSF the 1 kg of rice husk was used. The rice husk was washed/dried before using it (Fig. 1).

Banana peel-modified BSF (BP-BSF): in this category, 1 kg of banana peels were used as bio-adsorbent (Fig. 1).

ARSENIC CONTAMINATED WATER

Arsenic concentrated water was pumped from a depth of 80 feet (24.4 m) depth, from the villages Abdul Nahya, District Tando Allahyar, and Sindh, Pakistan. The average arsenic concentration was recorded 150 ppb. Raw water was pumped into the top diffuser basin, passing over the brick chips, adsorbents, nails, sand, and coming out of the spout, and the arsenic level was recorded.

ARSENIC MEASUREMENT

The arsenic was determined through the Merck Arsenic Kit. The samples were taken in bottles. Two drops of AS1, one level red dosing spoon AS2, and one level green dosing spoon AS3 was added. The bottles were filled to the mark. The reaction bottle with the screw cap was added and re-closed.

A flip-up the black test strip holder was integrated into the screw cap, with the white dot facing. The test strip was then immediately inserted into the opening, reaction zone first, as far as the mark and flip the test stip. Then, inserted fully. It was then left to stands for 20 minutes, swirling two or three times during this period. Care was taken to avoid any contact between the test strip and the solution. The strips were then removed and briefly dipped into distilled water, with excess liquid shaken off. The colour field was then determined on the label the colour of the reaction zone coincides with most accurately.

DETERMINATION OF ARSENIC REMOVAL EFFICIENCY

All BSFs were filled with arsenic-contaminated water for 10 hours (pause time). This was required to allow time for the microorganisms in the bio-layer to consume pathogens in the water and to allow time for the nails to rust properly. The BSFs were allowed to pass the water with the flow rates of approximately 15–20 dm^3 per day accept biochar BSFs (household requirement per day), further details about the flow rate mentioned in the result and discussion section. This was achieved through control valves. The filtered water from all BSFs was collected separately in the plastic water cans. The water samples from the filtered water of each BSFs were tested for residual arsenic.

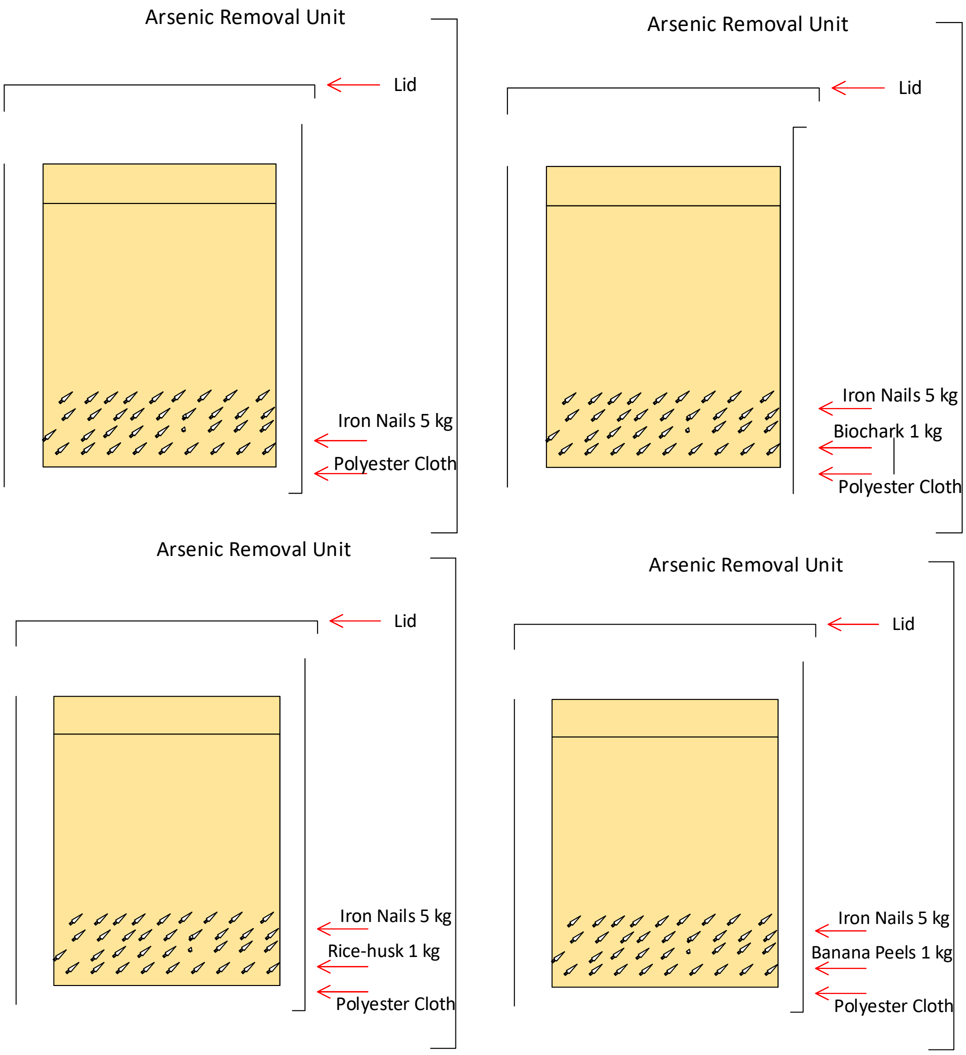

Fig. 1. Four different modified bio sand filters (BSFs); source: own elaboration

The arsenic removal efficiency of BSFs was computed from the arsenic content of influent and effluent water.

RESULTS AND DISCUSSION

Iron nail BSFs: the scientific principle for arsenic removal using iron nails was well described by [NGAI *et al.* 2007]. Non-galvanized nails are exposed to the water and air, rusting immediately, and producing ferric hydroxide on the nails surface [NGAI *et al.* 2007]. This mechanism was similar to arsenic adsorption on zero-valent iron reported by [LIEN, WILKIN 2005] and arsenic adsorption on think iron(III) oxide-hydroxides reported by [NGAI *et al.* 2007]. The experimental model shown in Figure 1, was fabricated by [NGAI *et al.* 2007]. The output concentration was 5 ppb which was in the range of WHO guidelines [WHO 2006]. Compared to [NGAI *et al.* 2007] paper the arsenic removal efficiency of our experiment was 10–13% higher (Fig. 2). The dm^3 water volume per hour was treated which is almost similar to the results presented from the Nepali BSFs [NGAI *et al.* 2007].

Biochar BSFs: the adsorption properties and modifications are well described by [HUANG *et al.* 2020]. The biochar has a large surface area as well as a negatively

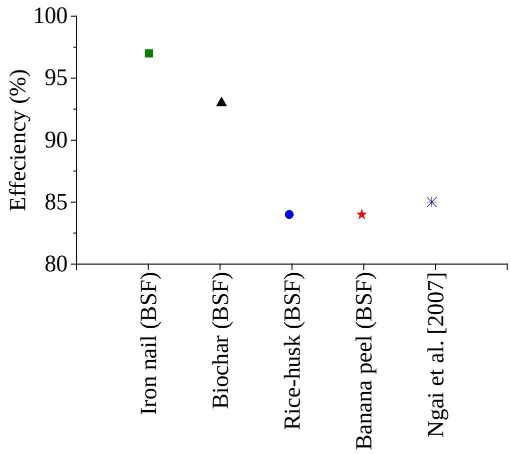

Fig. 2. The efficiency of bio sand filters (BSFs); source: own study

charged surface and it has the capacity of binding cations [ZHOU *et al.* 2017]. That is the reason biochar is used for heavy metals removal from the wastewater [ZHOU *et al.* 2017]. Biochars always lack an-ion exchange capacity (*AEC*) because of their negatively charged surface [LAWRINENKO, LAIRD 2015]. Different approaches have been established to increase the *AEC* of biochar in order to increase its adsorption capacity for arsenic removal. The most common method is to modify the surface area using an iron to increase the number of positively charged sites [BAKSHI *et al.* 2018]. However, the Nepali BSF was modified with biochar (Fig. 1) and arsenic was removed successfully. Output arsenic efficiency was recorded, and it was equal to the WHO guidelines (10 ppb). Due to the high adsorption capacity of biochar as published by [ZHANG *et al.* 2020], the arsenic removal efficiency of modified BSF was similar to the Nepali BSFs. From the experimental results it shows that biochar adsorbent has an advantage in our iron nails, it has low cost and equal arsenic removal efficiency.

Rice husk: a rice husk is insoluble in water, due to its chemical stability and structural strength as a result of its high silica content. These properties allow for it to be used as an effective treatment to remove heavy metal from water [LATA, SAMADDER 2014]. Rice-husks have been widely used for arsenic removal [AGRAFIOTI *et al.* 2014]. Our experimental results showed levels much higher than the WHO guidelines and 1.5 times higher than the Nepali report. These results suggest that either we need to reduce the flow rate or increase the surface area of the adsorbent to allow its efficiency be increased. There are various conditions that affect the adsorption of arsenic in the column method [AMIN *et al.* 2006]. In rice-husk BSF the optimization is needed to achieve the acquired results.

Banana peel: the processed banana peel has been used widely for arsenic removal as reported by many researchers [ARUNAKUMARA *et al.* 2013; TABASSUM *et al.* 2019]. The banana peels modified experiment gives almost the same results as rice-husk (Fig. 2). In banana BSF the outflow arsenic value was 25 ppb, and it was higher than the WHO guidelines. The efficiency of banana peel was not in the range of WHO guidelines. For enhancing, the efficiency of arsenic removal the process needs some modifications for example, enhancing the surface area of banana peel, reduce the flow rate of wastewater, or low arsenic-contaminated water can be used with the same operational procedure.

CONCLUSIONS

An economical and effective method for arsenic removal from groundwater remains a major challenge in Pakistan. Many technologies have been used to remove arsenic from groundwater. In this paper, we modified the Nepali bio sand filters (BSFs) using four different, cost-effective, easily accessible, and easily disposable bio-adsorbents. 1 kg of bio-adsorbents (banana peel, biochar, and rice husk) were added in the Nepali BSFs and efficiency was measured and compared. Amongst all BSFs, the biochar and iron nails work efficiently to remove the arsenic from groundwater (96% and 93% removal efficiency). Banana peel and rice husks need more modification to enhance efficiency. Furthermore, the experiment is not yet over and additional findings are to be presented in the next paper.

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