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Original Research

Biosand Filter Containing Melia Biomass Treating Heavy Metals and Pathogens

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Abstract

Water contamination poses serious threats to human health and is more prevalent in developing countries. A bio sand filter (BSF) is useful technology for developing nations because of its low cost and good treatment efficiency. Being a locally available plant species, melia (*Melia azedarach*) biomass was used in BSF to test its efficiency for metal and pathogen removal. Different concentrations (2~6 mg/L) of iron and lead and *Escherichia coli*-contaminated water were passed through a control sand filter (having no plant biomass) and BSF. The results showed that all three contaminants had higher removal rates in the BSF compared to the control sand filter. The removal of *E.coli* reached up to 100 percent on some days in the BSF, which was not the case with the control sand filter. The percent removal of Fe and Pb in BSF was 97.9~99.9% and 31~61%, respectively. Significant turbidity removal was also observed in BSF. Melia biomass is a useful bio-resource that can help to improve water quality in BSF.

Keywords: BSF, metal contamination, drinking water, water treatment, melia biomass

Introduction

Increasing impacts of climate change, development, and urbanization on water availability have promoted increased water reuse and recycling. The World Health Organization has identified sustainable access to improved drinking water as a significant challenge in the developing world [1]. Heavy metal pollution has pervaded many parts of the world, especially developing countries [2]. It is expected that with further development of human society, the need for fresh water will only increase. More than 90% of available fresh water resources will be consumed in the next 15 years [3, 4]. Therefore, water reuse and reclamation is inevitable in the years to come.

The increasing industrialization trend throughout the globe has resulted in the generation of industrial effluents in large quantities with high organic content [5]. Industrial wastewater contains large amounts of suspended material; through the efficient separation media these suspended solids and turbidity of the wastewater can be minimized. In addition, the presence of toxic substances in wastewater can easily lead to a sludge-swelling phenomenon that may affect its treatability [6]. Access to clean drinking water is limited in developing countries and people may, therefore, consume contaminated water. Only 25.61% (rural 23.5%

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and 30% urban) of the population in Pakistan have access to potable water [7]. Heavy metals are of great concern because of their toxic properties and some heavy metals are also essential for the survival and health of humans. In many parts of the country, heavy metal contamination has been reported as a serious problem. Many health illnesses have been reported in Pakistan, which is related to the use of contaminated drinking water [8-10]. Trace heavy metals such as arsenic, cadmium, lead, chromium, nickel, and mercury are important environmental pollutants, particularly in areas with high anthropogenic pressure [9, 10]. The presence of trace heavy metals in the atmosphere, soil, and water can cause serious problems to all organisms and the ubiquitous bioavailability of these heavy metals can result in bioaccumulation in the food chain, which can be especially dangerous to human health [11-12]. Consequently, removal of heavy metals from wastewater and industrial wastes has become an important environmental issue. The National Environmental Quality Standards for Pb and Fe in Pakistan are 0.05 mg/L and 1.0 mg/L as recommended by the U.S. Environmental Protection Agency.

The use of melia biomass is relatively recent and it was tested for As adsorption in a lab-scale study [13]. The proposed adsorbent was appropriate, suitable, and easily applicable in local areas because of its simplicity, easy operation and handling, and cost effectiveness, and can be used for arsenic removal from drinking water. The employment of biological media to the sand filters may enhance their efficiency in removing metal contaminants from drinking water. A recent study showed that plant biomass can enhance BSF efficiency [14]. This study concluded that plant biomass had more removal efficiency for especially *E. coli*, total coliform, and turbidity reduction [14]. Furthermore, it was proposed that BSF was a feasible option that could be used for multipurpose treatment of water as it was cost effective, easy to handle, and a viable option for drinking water treatment [15-16]. The current study was aimed at using melia biomass in a BSF for treating selected metals and coliform bacteria from drinking waters.

Materials and Methods

Melia Biomass and Sand Filter Design

The current study involved the use of a modified BSF previously used by Baig et al. [14]. Because of economic viability, easy maintenance, and its easy construction with a number of variations, it fits well into water treatment technologies. The design involving multilayered *M. azedarach* plant biomass was used in order to gain the multiple benefits that focus not only the biological contamination but also to treat the various levels of lead and iron contamination (Figs 1-2).

BSF was constructed from locally available materials (sand, gravel, plant biomass). Two BSF were constructed, one was control (without melia biomass) and the other acted as experimental BSF with melia biomass. The specifications were: length, 75 cm; internal diameter, 15 cm; external diameter, 25 cm; 10 cm, PCC (plain cement concrete) having galvanized iron outlet pipe for unsaturated flow mechanism (Figs 1-2). All the experiments were operated at 25ºC indoor, corresponding to normal household temperatures.

The solutions of different metal concentrations were prepared in the laboratory. This included the combined solution of iron and lead having three different concentrations. Analytical-grade $PbCl_2$ and $FeCl_2.4H_2O$ were purchased from local vendors and were used in the research. The experimental treatments were 2, 4, and 6 mgL^{-1}. These concentrations were passed through the BSF for 15 days.

Biological Contamination and Turbidity Removal Tests

The sewage (black water) from a boy's hostel was used at the rate 0.1 $mL.L^{-1}$ to create biologically contaminated tapwater and to make it turbid under laboratory conditions. The contaminated water from both sand filters was checked for their metal contents via atomic absorption and also for their turbidity analysis using the turbidity meter. The water that contained *E. coli* was subjected to laboratory analysis for *E. coli* removal. This microbially contaminated water reflected the real drinking water situation at the consumer end (Water Quality Improvement and Promotion of Hygiene) in 2005.

Water Analysis

Following standard procedures, microbial contamination was analyzed in various water samples. The plate count method was used for the identification of *E. coli* contamination [17]. Then different metal concentrations of treated water samples were analyzed according to standard methods [18].

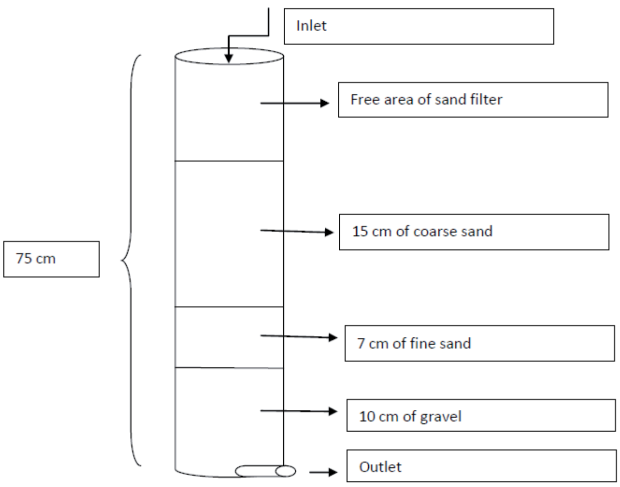

Fig. 1. Schematic presentation of a sand filter.

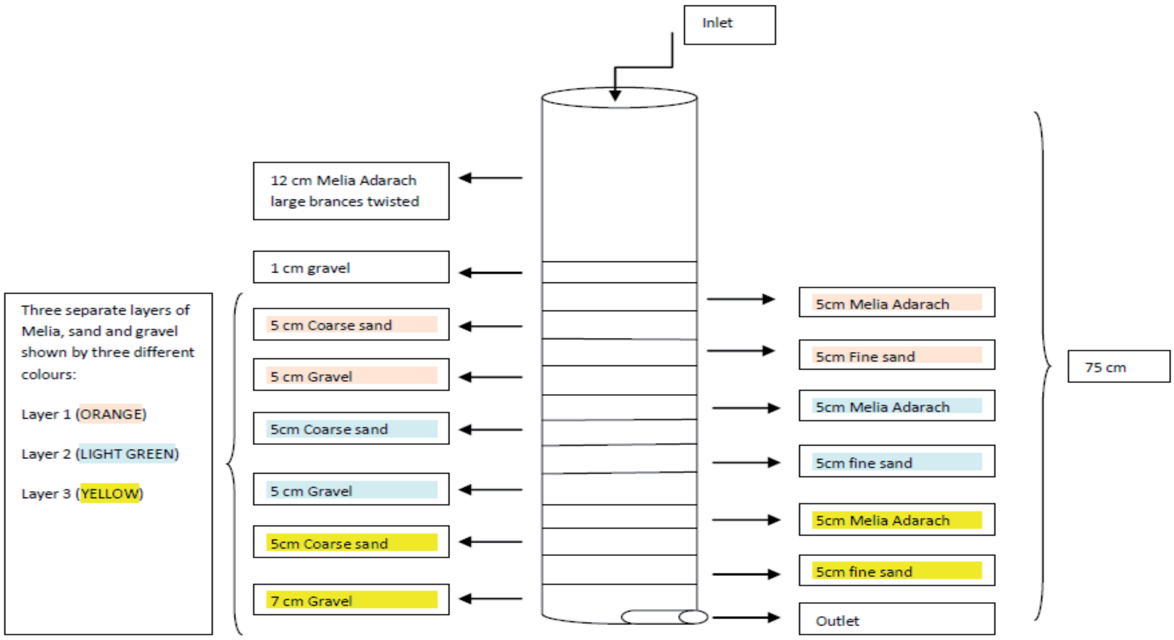

Fig. 2. Schematic diagram of a BSF containing melia biomass.

Results

E. coli Removal by BSF

The influent of control SF and BSF contained uncountable coliform bacterial colonies. It was noted that the BSF was much more effective in removing the *E. coli* as compared to the control sand filter having no plant biomass in it (Fig. 3). There were three days (Nos. 14, 16, and 20) that saw 100% removal of *E. coli* in the BSF. BSF may entrap the microbial communities during its operation in the biological melia layer. Adsorption, physical straining, and natural die-off are the principal processes to remove the microbial populations from the raw water.

Iron Removal from Control Sand Filter and Bio Sand Filter

The results of treatment of various Fe concentrations (2~6 mgL^{-1}) in control and BSF have been presented in Fig. 4 a-c. The removal rate of iron in all the different dilutions of iron solutions was greater than 98%. The removal rate was greatest in the 2 mg/L solution, followed by slightly decreasing rates in 4 mgL^{-1} and 6 mgL^{-1}. As the days passed, the removal efficiency of the ordinary sand filter slightly increased, but far more consistent and better results were observed in the BSF.

Lead Removal from Control Sand Filter and Bio Sand Filter

Different concentrations of Pb (2 mgL^{-1}, 3 mgL^{-1}, and 4 mgL^{-1}) were prepared from the stock solution of Pb (II) oxide and were passed through the control and BSF. The percentage removal of Pb by both sand filters was presented in Fig. 5 a-c. The data obtained clearly indicated that non-significant differences existed between control (SF) and BSF regarding Pb removal. However, during the final stages of the experiment, the BSF was slightly more efficient in Pb removal from drinking water. The above graph shows that the BSF is much more effective in removing lead as compared to the control sand filter. The maximum lead concentration from the effluent of BSF was less than 1.6 mgL^{-1}, whereas the control sand filter exceeded the value of 1.6 mgL^{-1}. It was also evident that Pb removal was declining with the passing days. The major mechanism involved in the metal removal seemed to be adsorption and electrostatic attachment to the melia biomass. Further study of the mechanisms involved in the BSF regarding metal removal is recommended.

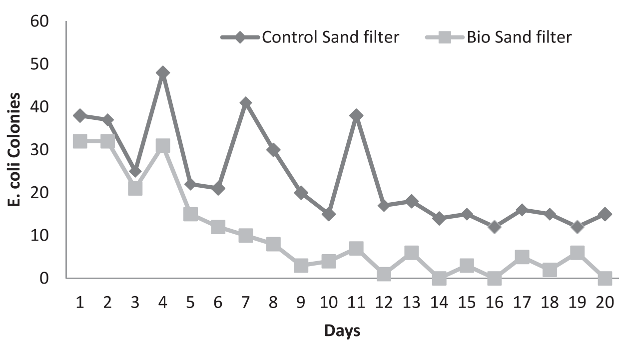

Fig. 3. *E. coli* reduction in sand filter and BSF, the figures presented are the remaining colonies on growth medium after passing through the sand filter and BSF.

Turbidity Removal from Control Sand Filter and Bio Sand Filter

Turbidity is the expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. That is, turbidity is the measure of relative sample clarity, not color. The greater the cloudy appearance the greater the turbidity. The standard values for drinking water must be less than 5 NTU, only then is the water considered suitable for drinking. The removal of turbidity from the synthetic water is presented in Fig. 6.

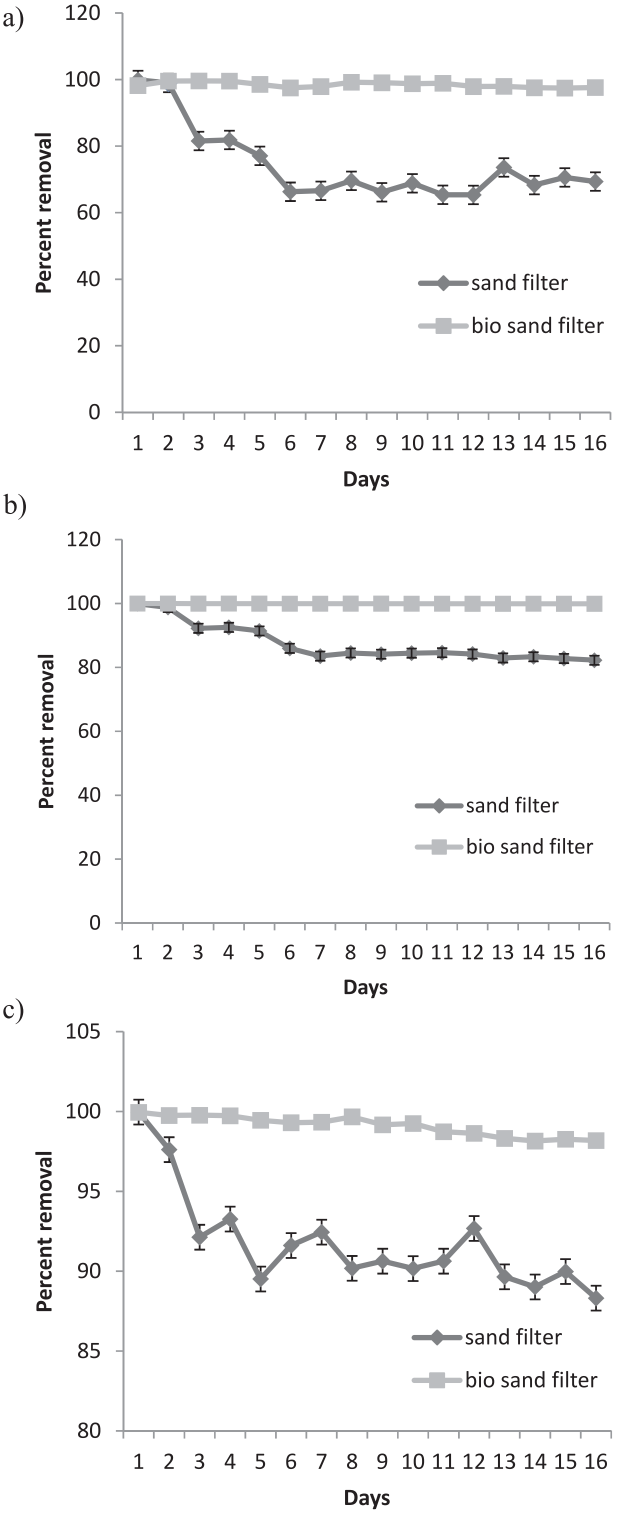

Fig. 4. a) the dynamics of Fe @ 2mgL^{-1} removal in filters, b) trends of Fe removal @ 4mg L^{-1}, and c) Fe removal trends @ 6 mgL^{-1}.

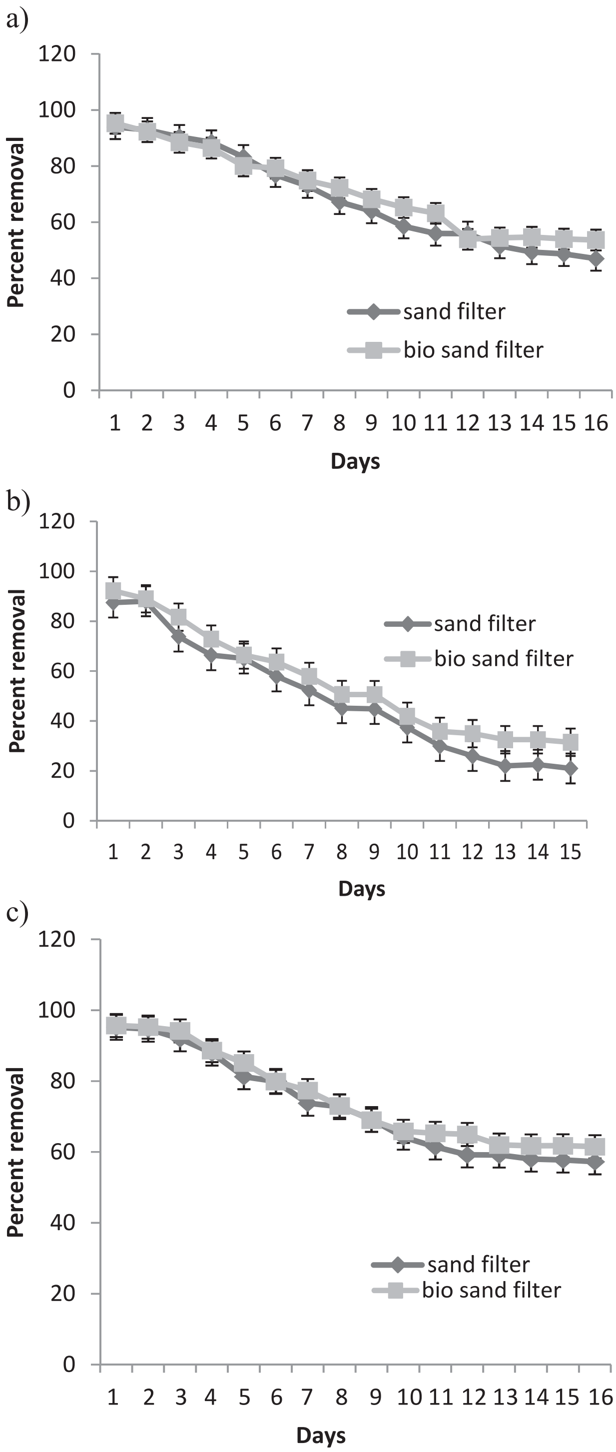

Fig. 5. a) the dynamics of Pb @ 2 mgL^{-1} removal in filters, b) trends of Pb removal @ 3 mg L^{-1}, and c) Pb removal trends @ 4 mgL^{-1}.

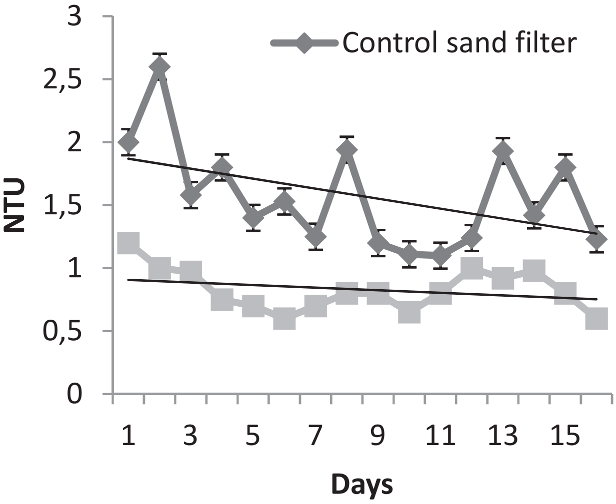

Fig. 6. Turbidity reduction from an initial value of 7 NTU.

Turbidity removal is concerned with the suspended particles entrapped in the BSF. It seems that phenomena like adsorption were mainly responsible for the attachment of suspended particles in the BSF. The tendency toward lower turbidity reduction with time showed the compression of the filter media, alteration of the surface properties of the media as a result of physical straining, and slowing the filtration rate [14].

The above values showed efficiency of both control sand filter and BSF depicting good results of turbidity reduction, each lowering the turbidity far below the permissible limit. But the BSF had a greater efficiency of lowering the turbidity levels to even less than 1 NTU in all three tested solutions. Following 11 days, the turbidity from the BSF was nearly 1 NTU, which was showing a slight increasing trend.

The BSF showed good performance against *E.coli*, reducing them to zero after the 13-day mark. So, it is understood that due to the presence of plant biomass there was a higher removal rate of *E. coli*. The BSF due to the presence of *M. azedarech* as an adsorbent indicates that this would be a great intervention along with the sand filter to implement as an improved household water treatment where there is *E. coli* contamination in the water. Previously, a BSF containing pine biomass (5 cm thick) was successful in removing *E. coli* and total coliforms effectively [15].

The results of iron removal by BSF at concentrations of 2, 4, and 6 mgL^{-1} showed that the BSF has much more effecieny as compared to the sand filter. The presence of an additional adsorbent was suitable and an effective intervention in the design of the BSF. After one month time of operation, the BSF efficiency was the minimum for the Fe effluent having a pre concentration value of 6 mgL^{-1} (results not shown). In the case of Pb, it was evident that melia biomass was relatively ineffective in adsorbing Pb, as there was no significant difference between SF and BSF. The possible reason for this preference of more removal of Fe as compared to Pb can be the presence of insoluble ferric ions in the influent sample, and so the active sites of the biomass are more prone to attach these insoluble ferric ions as compared to the Pb ions.

BSF is much more effective in decreasing the turbidity of the water samples. Although from the graphs it is taken into account that both sand filters are efficient in turbidity removal because after the effluent is passed from the sand filters, the turbidity values of both sand filters were brought under permissible limits. BSF values are more satisfying as compared to the control sand filter values. Because of the presence of additional adsorbent in the BSF, there was more turbidity removal in the BSF as compared to the control sand filter without having any additional adsorbent. For turbidity removal, adsorption process is very crucial, as it takes place under physicochemical and molecular forces, which cause bridging between particles and influence the particle charge on electro kinetic forces and are responsible for the attachment between sand grains and the particles. In a bulk material, all the bonding requirements (be they ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. [19]. Adsorption has advantages over the other methods because of simple design and can involve low investment in terms of both initial cost and land required. The adsorption process is widely used for treatment of industrial wastewater from organic and inorganic pollutants and meets with great attention from researchers [20].

Conclusions

The use of adsorbent *Melia azedarach* in the BSF was more effective in removing different contaminants compared to the control sand filter. Iron removal was better in BSF as compared to lead. BSF could effectively remove *E. coli* and turbidity from the contaminated water. Thus melia biomass can be added to a sand filter to enhance its efficiency.

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