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# Novel Environmentally Benign Technique for the Removal of Fluoride, Arsenic and Coliform from Wastewater

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**Abstract**

An environmentally benign homemade bio-sand filter is used for the removal of fluoride, arsenic and coliform from drinking water. This method is facile at rural area and has low cast. The physiochemical analysis of water samples had been done before and after the treatment time with filter using standard methods. Optimum operating time was determined for maximum removal of these impurities by running experiment for 2,4,6,8 and 10 hours respectively. The maximum reduction of fluoride, arsenic and coliform bacteria in percentage was 81.4, 91.1 and 100. These residual values are under the permissible limits prescribed by WHO and drinking water specification IS 10500. This method has advantages, such as simple work-up procedure, avoidance of organic solvent and highly sophisticated equipment, which will contribute in serving as a green process greatly. The homemade bio-sand filter was easily recovered and reused without any considerable loss of activity.

***Keywords:*** Fluoride; Arsenic; Coliform bacteria; Homemade bio-sand filter.

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## 1. Introduction

Safe drinking water is one of the important basic needs of every people of the world to live healthy lives. Many people in developed countries are enjoying the good quality water through the centralised water supply system. However, in undeveloped and developing countries safe drinking water is greatly threatening. Every year, millions of people die due to the consumption of polluted water. United Nations International Children's Fund (UNICEF) has suggested that about 1.1 billion people around the globe do not have access to safe water [1]. Consumption of poor quality water can exposes humans to bacterial diseases, metal poisoning and other health hazards. To minimize the risk of water pollution, several point-of-use mechanisms (POU) such as boiling, chlorination and solar disinfection are suggested as the cheaper methods to purify the water at household level [2].

In India, endemic Fluorosis is thought to affect around one million people and is a major problem in 17 of the 25 states, especially Rajasthan, Andhra Pradesh, Tamil Nadu, Gujarat and Uttar Pradesh [3]. According to World Health Organisation (WHO) standards, the Fluoride in drinking water should be within a range that slightly varies above and below 1 mg/L [4]. In temperate regions, where water intake is low, Fluoride level up to 1.5 mg/L is acceptable. The Bureau of Indian Standards, BIS (IS-10500), has prescribed a desirable limit and permissible limit of Fluoride in drinking water as 1.0 and 1.5 mg/l respectively [5]. For arsenic, WHO guidelines revised the permissible limit from 0.05 to 0.01 mg/l in year 1993 due to adverse health reports arising from different parts of the world [6].

The most commonly used methods for the defluoridation of water are adsorption [7, 8], ion exchange [9], precipitation [10], Donnan dialysis [11] and electrodialysis [12]. Several techniques have been developed for removal of fluoride from drinking water by adsorption and precipitation processes. In [13], Bulusu has been developed a technique in which fluoride can be removed from drinking water by treatment with alkali, chlorine and aluminium sulphate or aluminium chloride. Reardon and Wang [14] have also been proposed a fluoride precipitation technique by using a limestone reactor. It is also not optimally suitable for potable purpose as it removes fluoride up to 2 mg/l only. Among these methods, adsorption by wooden charcoal is the widely used method for the removal of fluoride as well as arsenic from water [15, 16].

Arsenic is one of the naturally occurring toxic metalloid located at the earth's crust. It ranks as 20$^{th}$ in natural abundances and as 12$^{th}$ in human body [17]. Arsenic occurs in both organic and inorganic form in nature. Arsenic is mostly present in combination with sulfur, oxygen and iron in nature [18]. Generally, arsenic has four main oxidation states: As (-III), As (0), As (+III) and As (+V). However, in natural waters, the inorganic form of trivalent arsenite As (+III) and pentavalent arsenate As (+V) are the most predominant forms. It is reported that the trivalent form of arsenic is 60 times more toxic than oxidized pentavalent state [19]. This is the reason why it is necessary to convert trivalent state of arsenic to pentavalent state during treatment of arsenic poisoned water. Organic form of arsenic is more predominant in surface water due to biological activity and industrial pollution [18, 20].

Raebareli is one of the district of Uttar Pradesh state in India. The land area of this district is covered by two rivers namely Ganga and Sai. The drinking water of this district is not safe because it is contaminated with fluoride, arsenic and coliform bacteria. This paper reveals first time the detection and estimation of arsenic and coliform bacteria in drinking water of Rae Bareli district. The fluoride level in some of the villages has concentration 4.2 mg/l and more which is harmful for the villagers of this district [21]. Arsenic, above the WHO permissible limit, in shallow aquifer is found in parts of Rae Bareli district [22]. Water samples from India Mark II hand pumps, Private hand pumps and dug wells from different villages have arsenic concentration more than 10 ppb. Few blocks of Raebareli district have arsenic contamination more than 50 ppb [22, 23]. These villages are located in flood plains and near the Ganga river bank. In high concentrations, arsenic poisoning can also lead to an acute condition called arsenicosis [24].

Coliform Bacteria are the indicator of contaminated water with human or animal wastes and if these are absent then only water can be considered as safe for drinking purpose. These bacteria are generally not harmful but other microbes along with these bacteria can cause short-term effects like diarrhea, cramps, nauseas, headaches or other symptoms [25].

Various technologies had been used for the removal of fluoride, arsenic and coliform bacteria from drinking water. Several small scale water treatment techniques are practiced to alleviate these problems for rural communities of developing countries. Homemade bio-sand filter is one of the options for the removal of fluoride, arsenic and coliform bacteria and this is also economical to construct, operate and maintain. Therefore, the objective of this study is to make a novel constructed environmentally benign homemade bio-sand filter in which wooden charcoal plays an important role for fluoride and arsenic removal.

## 2. Materials and Methods

The homemade bio-sand filter has two layers namely pathogen removal unit and fluoride-arsenic removal unit. The lower part is a pathogen removal unit and the upper part is a fluoride-arsenic removal unit. It is made by using the locally available materials, such as wooden charcoal, coarse sands, polyester cloth, gravels and fine sand. The dimensions of the filters can be adjusted according the need. The fluoride-arsenic removal unit is made up of wooden charcoal, brick chips, a metal diffuser box and a polyester cloth, while the pathogen removal unit has fine sand, coarse sand and gravels. The brick chips help to keep the wooden charcoal stable when the water is poured through the top of the filter.

A 200-litre barrel with a diameter of 74.1cm and a height of 86cm is fitted with a half-inch outlet pipe, under drain valve and outlet top. To keep the filter media from drying the outlet tap is fitted in such a way that the height of the outlet taps is 3cm above the top layer of the filter sand bed (Fig. 1).

Five sets are made to operate the experiments in batches under different treatment time of 2,4,6,8 and 10 hours. The filtration rate is controlled between 0.2 L/h to 1.0 L/h and filtration rates for central unit having a treatment time of 2, 4, 6, 8 and 10 hours are 0.2, 0.4, 0.6, 0.8 and 1.0 L/h respectively. The maximum filtration rate at the beginning of operation with each setup is adjusted at 1.0 L/h in order to recover the head loss [26].

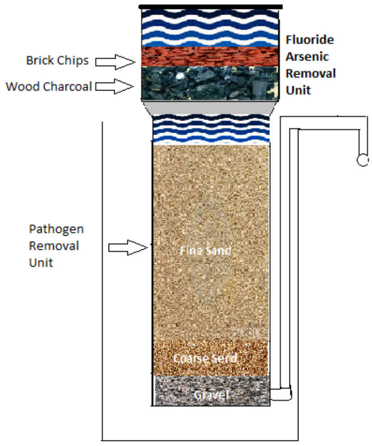


**Fig. 1:** Environmentally benign Homemade Bio-sand filter

The water is passed through the filter beds of homemade bio-sand filter. Then the filtrate from all the units were analysed separately for fluoride, arsenic and coliform bacteria concentration at duration of 2, 4, 6, 8 and 10 hours of the filter run according to the standard methods [27]. The concentration of wooden charcoal is also calculated for percent removal of fluoride, arsenic and coliform bacteria under all the treatment batches.

## 3. Results

The physicochemical analysis of the drinking water sample is depicted in following table. It is evident that drinking water was highly polluted with turbidity, fluoride, arsenic and coliform bacteria when compared with BIS and WHO permissible limits for these parameters as shown in table 1.

**Table 1:** Physiochemical analysis of ground water and permissible limits of BIS and WHO

| Sr. No. | Parameters | Observed Values | Standard Values (BIS) | WHO limit |
|---|---|---|---|---|
| 1. | pH | 7.16 | 6.5-8.5 | 6.8-8.5 |
| 2. | Turbidity (nephalometer turbidity unit) | 356 | 5 | 5-10 |
| 3. | Fluoride (mg/l) | 4.2 | 1.0 | 1.5 |
| 4. | Arsenic (mg/l) | 0.18 | 0.01 | 0.01 |
| 5. | MPN(Coliform cells/ 100ml) | $2x10^9$ | Nil | Nil |

The drinking water is treated under batch mode operation having different treatment times with homemade bio-sand filter and fluoride, arsenic and coliform bacteria concentrations were measured before and after treatment for each batch separately.

It is clear from Table 2 that the removal of fluoride with wooden charcoal filter media is more than the ordinary filter under all the treatment times. The fluoride removal was maximum after a treatment time of 8 hr with residual value of 0.78 mg/l. It is also found that the contribution of wooden charcoal under different treatment time of 2,4,6,8 and 10 hours the percent removal of fluoride is 24%, 36%, 45%, 46.4% and 45.7% respectively.

**Table 2:** Removal of fluoride from drinking water by homemade bio-sand filter with initial concentration of 4.2 mg/l

| **Treatment time (Hours)** | **Residual fluoride concentration(mg/l)** | | **Contribution of wooden charcoal in percent removal of fluoride** |
|---|---|---|---|
| | **Without Charcoal (m)** | **With Charcoal (n)** | **(m-n)/4.2*100** |
| 2 | 4.12 | 3.11 | 24.04 |
| 4 | 3.69 | 2.18 | 35.95 |
| 6 | 3.24 | 1.34 | 45.25 |
| 8 | 2.73 | 0.78 | 46.42 |
| 10 | 2.72 | 0.8 | 45.71 |

From table 3, it is clear that the wooden charcoal filter media is very potential for the removal of arsenic from drinking water under all the treatment time conditions. The maximum removal of arsenic for filter media is achieved with a treatment time of 8 h and the residual value of arsenic is 0.016 mg/l. Contribution of wooden charcoal in percent removal of arsenic is also calculated and maximum value is attained with a treatment of 8 hour and it is found to be 46.66%. For other treatment times, the value of percent arsenic removal along with treatment time are 11.11% with 2 hour, 27.77% with 4 hr, 44.44% with 6 hr, 46.66% with 8 hr and 45.55% with 10 hr. It was also observed that there was a regular trend for percent removal of arsenic under all the treatment time.

**Table 3:** Removal of arsenic from drinking water by homemade bio-sand filter with initial concentration of 0.18 mg/l

| **Treatment time (Hours)** | **Residual arsenic concentration(mg/l)** | | **Contribution of wooden charcoal in percent removal of arsenic** |
|---|---|---|---|
| | **Without Charcoal (m)** | **With Charcoal (n)** | **(m-n)/0.18*100** |
| 2 | 0.17 | 0.15 | 11.11 |
| 4 | 0.15 | 0.1 | 27.77 |
| 6 | 0.12 | 0.04 | 44.44 |
| 8 | 0.1 | 0.016 | 46.66 |
| 10 | 0.098 | 0.016 | 45.55 |

There were excellent results for the removal of coliform bacteria from drinking water with wooden charcoal filter media under all the treatment time conditions (Table 4). The maximum removal was achieved under a treatment time of 8 hr and the residual values of 2 coliform cells/ 100 ml for wooden charcoal filter.

**Table 4:** Removal of coliform bacteria from drinking water by homemade bio-sand filter with initial concentration of $2x10^9$ (coliform cells/ 100 ml)

| **Treatment time (Hours)** | **Residual coliform bacteria (coliform cells/ 100 ml)** | | **Contribution of wooden charcoal in percent removal of coliform bacteria** |
|---|---|---|---|
| | **Without Charcoal (m)** | **With Charcoal (n)** | **$(m-n)/2x10^9*100$** |
| 2 | $7 \times 10^7$ | $1 \times 10^4$ | 34.99 |
| 4 | $9 \times 10^4$ | $7 \times 10^1$ | 67.89 |
| 6 | $1 \times 10^2$ | 10 | 86.75 |
| 8 | 90 | 2 | 99.99 |
| 10 | 91 | 0 | 100 |

From figure 2 it is clear that wooden charcoal used in filter media is very efficient for the percent removal of fluoride, arsenic and coliform bacteria from drinking water and it showed maximum to minimum percent removal range of 24 - 46.4%, 11.11 - 46.66% and 34.99-100% respectively for fluoride, arsenic and coliform bacteria. It is also evident from this graph that percent removals of fluoride, arsenic and coliform bacteria with homemade bio-sand filter were 81.4%, 91.1% and 100% respectively.

Data obtained for removal of fluoride, arsenic and coliform bacteria are more significant, appropriate and improved than other methods. Treatment time is an important parameter for residual concentrations of impurities present in the drinking water. An effective time period for removal of fluoride, arsenic, coliform cells and other pathogens is reduced by minimum 2 hrs when it is compared with traditional bio-sand filter or modified slow sand filter. The residual concentration in this method is minimized to 8 hrs however in other methods, this level is achieved at 10 hrs or more.

The Bio-sand filter is based on the principle of adsorption and coagulation. Therefore, it is easily recovered and reused without loss of any considerable activity. After 15-20 days, the pore openings in the wooden charcoal become clogged. To clean the bio-sand filter, an upper portion fluoride – arsenic diffuser unit is withdrawn from filter. The warm water is poured into the diffuser unit containing wooden charcoal, brick chips and polyester cloth. For half an hour, warm water occupied entire portion of diffuser unit. The water is evacuated from unit after the process of agitation. This procedure is repeated when input water has higher concentrations of fluoride and arsenic. For pathogen unit, the dead coliform cells and other microorganisms are removed without evacuation of gravels, coarse sand and fine sand. The process consists in agitating the surface sand, thereby suspending captured material in the standing layer of the water. The dirty water is than removed and dumped away. The process can be repeated as many times as necessary to regain the desired flow rate. The need for cleaning depends on the amount and quality of water being put through the filter.

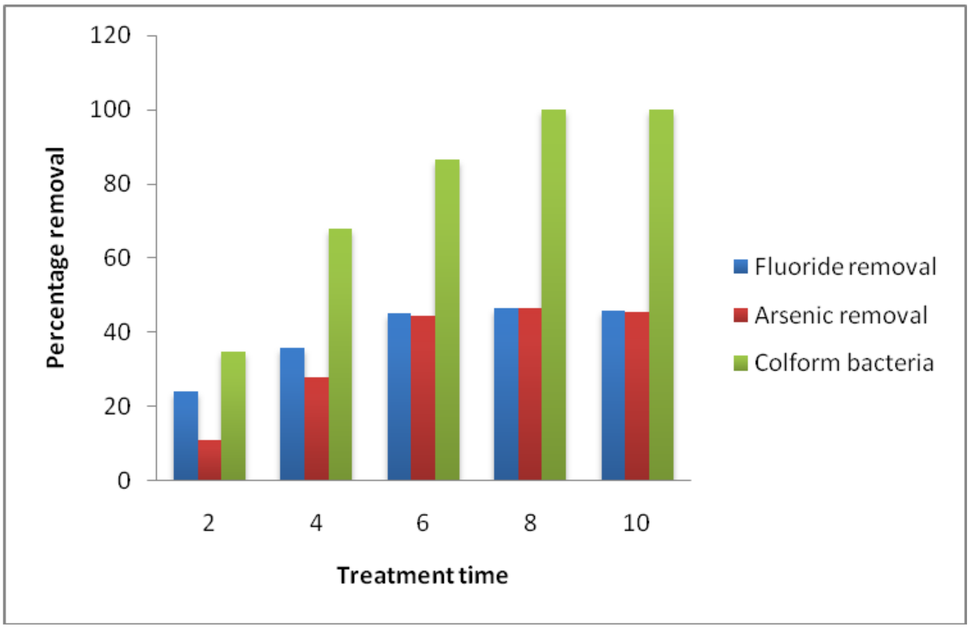


**Figure 2:** Contribution of wooden charcoal in percent removal of fluoride, arsenic and coliform bacteria

From Table 2, 3 and 4, it is found that there is a regular pattern of increase in percent removal of fluoride, arsenic and coliform bacteria with the increase of treatment time. Equilibrium is achieved with a treatment time of 8 hour for fluoride, arsenic and coliform bacteria. The comparative analysis of fluoride, arsenic and coliform bacteria removal (Fig. 2) indicates that under all treatment times, it is very efficient for coliform bacteria as compared to fluoride and arsenic. It is also evident from tables that initially with a treatment time of 2, 4 and 6 hrs it is more efficient for fluoride removal and 6, 8 and 10 hrs for arsenic removal.

## 4. Conclusion

It is concluded from our study that environmentally benign homemade bio-sand filter is a very good option for the treatment of ground water for villagers who are aware with wooden charcoal, gravels, brick chips and sand. These are easily available materials in rural areas of Uttar Pradesh state that is why it is the best and novel method for simultaneous removal of fluoride, arsenic and coliform bacteria from drinking water. It is based on the principle of adsorption and coagulation. Therefore, it is easily recovered and reused without loss of any considerable activity. This filter has great concern with green chemistry because no organic or inorganic solvent is used in this process, so that the residual material is eco-friendly. Further the process used for recharge of wooden charcoal is environmentally benign and having low operating cost. The filter is simple to use and can be produced locally anywhere in the world because it is built using materials that are readily available. Moreover, it is easy to install and operate by any layman after a training of few days.

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