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Arsenic: A Low-Cost Household Level Treatment for Rural Settings in Developing Countries

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Abstract

The presence of Arsenic, in drinking water, is a growing problem all around the world. The situation, in many developing countries, including Pakistan, has become quite alarming. Development of a low-cost treatment method for the removal of arsenic is desired. Recently, iron nails were found useful in removing arsenic in slow sand filters. It is referred as Kanchan Arsenic Filter (KAF). This study aimed to further build upon the above stated research work on KAF. Three different form of iron: (1) iron slag; (2) nails; and (3) mesh were tested. The raw water contained 100 ppb of arsenic. Equal weight of 1 kg for three iron forms was used. Rate of filtration was 30 L/hr. at the start which decreased to around 20 L/hr. after eight weeks. Removal efficiency of mesh, nails and slag was 99.90%, 98.94% and 98.01% respectively at 8th week and 224 L of water treated. The effluent concentration of arsenic was 1.99, 1.06 and 0.099 ppb for iron slag, nails and mesh, respectively. It can be concluded from above results that among different shapes of iron used, mesh was the most efficient form of iron. Percentage removal of turbidity for mesh, nails and slag at the end of the filter run was 88%, 86% and 88% respectively. Removal of chlorides for mesh, nails and slag after eight weeks was 65%, 70% and 73%. pH change of water after eight week of filter run was negligible. Hardness removal for all three filters was ranging from 16 to 28%. The newly developed filter is referred as Pakistan Arsenic Filter (PAF). The cost of PAF is US $5 while that of KAF is US $20. PAF is light weight and easily portable.

Keywords: Arsenic; Low-cost treatment method; Kanchan arsenic filter; Effect of shapes of iron

Introduction

Arsenic (As) is a commonly occurring toxic metal in natural waters. As salts present in natural waters in the forms of arsenate ions i.e. $H_2ASO_4^-$, HAO_4^{-2}, H_3AsO_4 and AsO_4^{-3} and arsonite ions as $HAsO_3^-$ and H_2AsO^{-3} [1]. As is a potential carcinogen. About 150 million population in 70 different countries drink As polluted water [2]. Use of drinking water with high As contents has chronic effects. It may result in skin, lung, bladder, kidney cancer, pigmentation changes, skin thickness, neurological disorders, muscular weakness, loss of appetite, and nausea [3]. As may also cause other problems like anaemia and leukaemia, peripheral neuropathy, hypertension, cardiac vascular diseases, respiratory diseases, diabetes mellitus, and malignancies including caancer of lungs, bladder, liver, and skin [4]. As can cause severe diseases like dermatosis, the cancer of nasal passage and viscous [5].

As contamination has hit many countries. Pakistan, India and Bangladesh are among those affected. Various studies in Pakistan showed high As contents. WHO guidelines give an upper level of 10 ppb in drinking water, while value in National Standards of Pakistan is 50 ppb [6]. In Rahim Yar Khan city As concentration varies between 20 to 500 ppb [7]. As concentrations as high as 1900 ppb were found in the water samples from village Kalanwala located close to Lahore city [8]. Groundwater in tehsil Melsi district Vehari, has As concentration of 812 ppb at some locations [9]. As concentration in groundwater of Jamshoro District ranges from 13 to 109 ppb [10,11]. Surveys show that 3.4 out of 1000 persons have hyperkeratosis of palms and soles as shown in Figure 1, while 13 out of 1000 persons are facing skin lesions problems in Pakistan due to drinking As contaminated water [12]. Groundwater in Muzaffargarh city has As concentration greater than 200 ppb, causing different health issues [13].

High concentrations of As in groundwater is a major concern in India. Indian standard for As in drinking water is 50 ppb. A 28-year field survey (1988-2016) revealed that high As levels in subsurface water had affected the health of people in west Bengal, Bihar, Jharkhand and Uttar Pradesh. Same study revealed that more than 170,000 tube wells had As concentration more than 10 ppb to 3,700 ppb. Such a high level of As caused severe effects in local people such as dermal, neurological, reproductive and pregnancy effects, cardiovascular effects, diabetes mellitus, diseases of the respiratory and gastrointestinal systems and cancers typically involving skin, lungs, liver and bladder. In a study, out of 8000 children examined, 4.5% were affected by skin lesions due to As. Besides children, adult male and female from poor background were also affected with As related diseases [14]. Out of 200 tube wells in Smria Ojha Patti village in Bihar, 95% showed As concentration greater than 300 ppb. This high concentration caused skin lesions in 13% of the adults and 6.3% of the children as revealed by medical examination. Same study revealed that biological samples of hair, nails and urine taken from patients showed great correlation (0.72-0.77) with drinking water As concentration level up to 1654 ppb [15].

High As levels in groundwater are of great concern in Bangladesh as well. Examination of 10,991 water samples from 42 As affected districts in Bangladesh revealed that 59% of water samples had concentration greater than 50 ppb (National Standard of Bangladesh). In the same study it was found that 24.47% of total patients in Bangladesh were affected with skin lesions [16].

Many other countries of the word i.e. Argentina, Mexico, Chile, Nepal, Vietnam and Taiwan have varying concentrations of As from 50 to 3000 ppb in groundwater [16]. As contamination in groundwaters is found in 50% of national priorities sites list in the united states [17]. Figures 1 and 2 show skin problems resulting from drinking water with high As concentrations.

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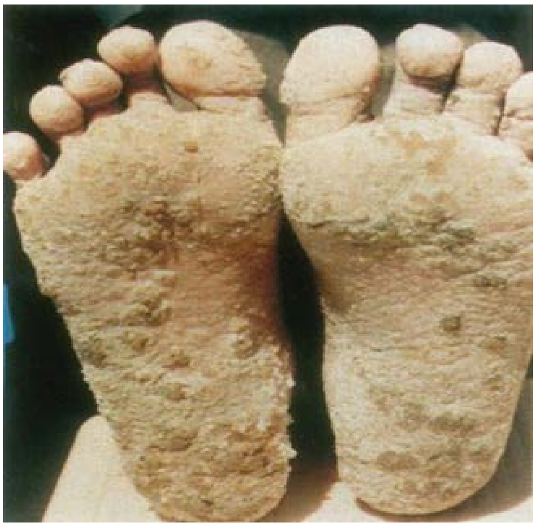

Figure 1: Hyperkeratosis on sole [15].

Figure 2: Infected person with skin arsenical liaison [14].

Conventional methods of As removal from groundwater include: ion exchange, photo-oxidation, coagulation, adsorption, filtration, reverse osmosis, Nano filtration, zero-valent iron nanoparticles [16], bioremediation and electro dialysis which reduce arsenites and arsenates [4]. In addition to conventional treatment process, it is deemed necessary to investigate into low-cost As removal method at household level. This could be valuable for poor village communities.

In the recent decades, some low-cost/household level methods were investigated for As removal from groundwater. One of the methods used the combination of nails (iron) and sand in a bio-sand filter referred to as Kanchan Arsenic Filter (KAF). A concrete container was used for KAF. It reduced As level to acceptable level [18]. Concrete casing was costly and posed difficulties in KAF portability. Another As removal method was 3-Kolshi filters constructed using zero valent iron chips, sand and charcoal. Use of fine sand in 3-Kolshi filters showed 99% efficiency in removing As from groundwater [19]. Another As removal method was the Sono-arsenic filter having two stacked bucket system containing composite iron matrix mixed with sand in upper bucket while wood charcoal and sand combination was used in lower bucket. It removed 95% to 99% As from water with a flow rate of 20-40 L/hr [20]. Fourth method for As removal was bio-sand filter having reactive zone containing mixture of Feo and sand on volumetric basis. The Feo/sand volumetric ratios of 50/50 and 40/60 in triplicate filter columns were used [21,22]. Filters constructed using Fe/sand ratios of 20/80, 50/50 and 40/60 removed As more than 98%, 89% and 96% respectively from drinking water [23].

The present research work was conducted with two objectives. First objective was to reduce the cost and weight of KAF while second objective was to test different forms of iron by weight i.e. nails, mesh and iron slag in combination with sand and to determine which form gives the best removal of As.

Materials and Methods

Raw water characterization

Tap water was used as feed water. Stock solution having 1000 ppb As concentration, was prepared using sodium arsenate ($NaAsO_2$) in distilled water. Measured amount of this stock solution was added to prepare 100 ppb As concentration feed water. Feed and treated water were characterized by performing tests given in Table 1.

Construction of newly developed household filter

The newly developed filter, during this study will be referred as Pakistan Arsenic Filter (PAF). Three different iron forms nails, mesh and slag were tested in this research work. The testing was conducted simultaneously. Locally available plastic bucket was used to prepare PAF. It was very lighter in weight as compared to concrete. The diameter and volume of the bucket were 32 cm and 25 litters, respectively. Diffuser plates were installed in the bucket to hold iron material. A PPRC pipe with tap was fixed to the buckets to make mechanism for water level adjustment and to draw samples, after treatment (Figure 3).

A schematic diagram showing complete details of PAF is shown in Figure 4. It can be seen that round gravel layer is at the bottom, overlaid by sand layer. Sand from river Ravi and Chanab was obtained. Sieve analysis was performed on both. Uniformity coefficient (D60/D10) and effective size (D10) were determined to assess the suitability and ascertain that the sand meets the laid down

S. No.	Test	Testing Procedure
1	pH	pH 4500-HB Laboratory Method
2	Chlorides	Chloride 4500 B-Cl^-
3	Hardness	Hardness 2340-C. EDTA Titrimetric Method
4	Turbidity	Turbidity 2130-B Laboratory Method
5	Arsenic	3114-B. Manual Hydride atomic absorption spectrometric method

Table 1: Tests conducted on feed and treated water.

Figure 3: Photograph of household filters for arsenic treatment.

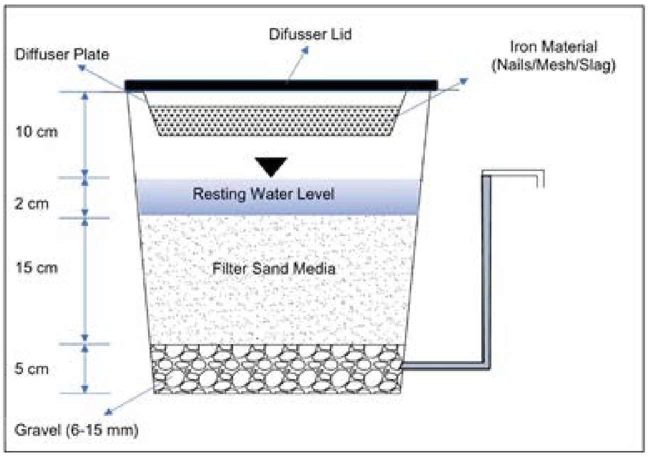

Figure 4: Schematic diagram showing complete details of the filter.

criteria for the sand filter. 2 cm feed water was kept standing on sand layer.

One-kilogram weight of different forms of iron (nails, mesh and slag) was placed in the diffuser plate of each bucket. PAF run was conducted for a time period of 8 weeks. At the start, flow rate of 30 L/min was measured at a maximum available head of 2 cm on sand top (Figure 4). This flow rate decreased to 20 L/min at the end of 8 weeks' time at the same head of 2 cm. Feed water, having arsenic concentration of 100 ppb, was poured through a diffuser plate. The water after passing through the diffuser plate (having iron) was passed through the sand and gravel. A PPRC pipe was attached at the bottom of bucket. A tap was fixed to the PPRC pipe to draw treated water samples.

Results and Discussion

Characterization of raw water used

Characterization results of feed water are presented in Table 2. pH of feeding water was in a range of 7.6-7.9. Turbidity varied between 3.5-5.6 NTU. Chlorides varied in a range of 200-240 mg/L. Hardness ranged from 508-524 mg/L. The university water supply water was used which comes from different tube wells having different characteristics. Therefore, variations in pH, turbidity and chloride content occurred.

Results of sieve analysis

Results of sieve analysis are shown in Table 3. Sand from both sources meets the recommended criteria for slow sand filter. The effective size for Chenab sand is larger than Ravi and so does its uniformity coefficient. Chenab sand was used.

Quality of treated water

Arsenic as main parameter along with other parameters like pH, turbidity, hardness and chloride removal were analysed. Results of all parameters except arsenic are presented in Tables 4 and 5. A minute change in pH was observed while considerable change in turbidity, hardness and chloride was observed. Percentage removal of turbidity for mesh, nails and slag after 8 weeks of filter run was 88%, 86% and 88% respectively. Removal of chlorides for mesh, nails and slag after eight weeks was 65%, 70% and 73% respectively. pH change of water after eight week of filter run was negligible. Hardness removal for all three filters was ranging from 16 to 28%.

Week	pH	Turbidity NTU	Chlorides mg/L	Hardness mg/L	Arsenic ppb
1	7.9	3.8	230	520	0
2	7.6	3.9	220	508	0
3	7.9	3.5	220	524	0
4	7.9	4.1	220	528	0
5	7.8	3.7	240	524	0
6	7.7	4.9	220	520	0
7	7.9	5.2	210	528	0
8	7.8	5.5	200	524	0

Table 2: Characterization of influent raw water sample (average values of a week).

Sample	% Passing				Effective Size, D10	Uniformity Coefficient
	Sieve size 16	Sieve size 50	Sieve size 100	Sieve size 200	(mm)	UC
Ravi	-	97.29	11.68	0.98	0.135	1.63
Chenab	99.83	46.4	2.17	0.94	0.159	2.42
Recommended Values of D10 and UC					Recommended 0.10 to 0.20	Recommended 1.5 to 2.5

Table 3: Results of sieve analysis.

Quantity of Water Treated (L)	pH				Turbidity (NTU)			
	Influent	Effluent			Influent	Effluent		
		Mesh	Nails	Slag		Mesh	Nails	Slag
28	7.98	7.85	7.79	7.8	3.83	0.64	0.7	0.7
56	7.6	7.55	7.3	7.6	3.99	0.69	0.66	0.7
84	7.9	7.7	7.69	7.8	3.55	0.63	0.69	0.6
112	7.9	7.75	7.56	7.7	4.14	0.66	0.72	0.7
140	7.8	7.44	7.52	7.5	3.75	0.61	0.66	0.6
168	7.7	7.36	7.45	7.1	4.93	0.71	0.78	0.7
196	7.9	7.36	7.45	7.1	5.2	0.7	0.76	0.7
224	7.83	7.5	7.42	7.1	5.56	0.7	0.75	0.7

Table 4: Results of pH and turbidity of influent and effluent water.

Quantity of Water Treated (L)	Hardness (mg/L)				Chlorides (mg/L)			
	Influent	Effluent			Influent	Effluent		
		Mesh	Nails	Slag		Mesh	Nails	Slag
28	520	420	460	432	230	170	160	130
56	508	400	456	424	220	120	110	130
84	524	404	448	428	220	130	110	110
112	528	400	448	432	220	110	100	100
140	524	392	436	420	240	100	90	90
168	520	384	444	424	220	90	80	80
196	528	384	440	424	210	80	70	60
224	524	376	440	420	200	70	60	60

Table 5: Results of influent and effluent hardness and chlorides.

Arsenic removal

Figure 5 shows trend in As concentration during 8 weeks of filter run. It can be seen that mesh and slag removed 88% of As in first week while treating 28 L of water, nails only removed about 50% (50 ppb) as shown in Figure 5. Thus, the water was not suitable for drinking during first week of removal. As concentration reached to 27.81 and 24.20 ppb in second week after filtering 56 L of water. Therefore, in case of nails water will be safe for drinking after 2 weeks of filter operation.

It was observed that slag and mesh can provide quick removal of As, as compare to traditional nails used in Kanchan Arsenic Filter (KAF). Same trend was followed in previous studies for KAFs in case of nails

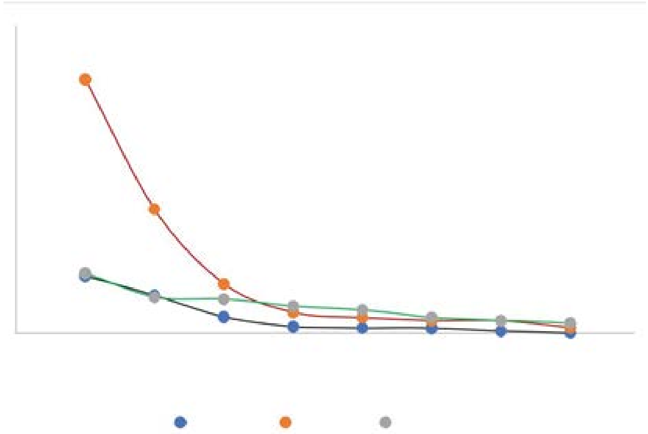

Figure 5: Arsenic concentration of effluent water after volume treated.

[24], but there was no previous study conducted on the behavior of iron slag and mesh. Therefore, this study indicates that mesh and slag remove As more efficiently. During, second week, removal efficiency of mesh and slag increased slowly but removal efficiency of nails quickly rose up to 75%. The removal efficiency at the end of 8 weeks and 224 L of water treated was 99.90%, 98.94% and 98.01% for mesh, nail and slag respectively. Mesh showed greater removal efficiency than other two iron materials.

Mechanism of arsenic removal from water

Previous studies indicated that As removal occurs due to the production of ferric hydroxide ($Fe(OH)_3$). Rust ($Fe(OH)_3$) is produced when iron meets oxygen present in water. Ferric hydroxide produces surface complexation with As as soon as As containing water is poured into the filter. Studies showed that ferric hydroxide is an excellent adsorbent for As Rust particles containing adsorbed arsenic are flushed into the water which are trapped by the fine layer of sand within few centimeters depth from top of the filter.

From the above discussion, we can conclude that As removal will be greater for the iron material which produces more ferric hydroxide [25]. The material having larger surface area will produce more rust, and hence more ferric hydroxide. Of all the three materials mesh has large surface area than the same weight of nails and slag. This study shows that As removal efficiency of Mesh>nails>slag.

Application and cost of newly developed filter

The average household size for Pakistan is 7 persons. If daily intake of 4 liters per person is adopted, the daily drinking water requirement of one household becomes 28 liters. Flow rate of PAF decreased from 30 L/hr to 18 L/hr after 8 weeks of filter run. It means that PAF will provide drinking water requirement of a single household in an hour. It was observed that As concentration reduced from 100 ppb to almost 0.099 ppb after 8 weeks, for mesh.

The estimated cost of the PAF comes out to be Rs. 595.75 (US$ 5.15) by using iron nails while Rs. 532.75 (US$ 4.61) when mesh scrape is used, as compared to US$ 20 for KAF (dimensions 0.9 m high, 0.3 m length and width with flow rate 10-15 L/hr) [26]. Construction costs of 3-Kolshi, 2-Kolshi and KAF reported previously were from 8 to US$ 12,5 to US$10 and 15 to US$ 25 respectively. PAF and KAF have flowrates better than the other Kolshi filters [24]. Keeping in view the cost and light weight PAF is much better than KAF currently in use. Concrete made KAF are currently in use in Cambodia [27] and Nepal [24] which showed removal efficiencies up to 90%. The effluent meets even WHO guidelines for As concentration in drinking water.

Conclusions and Recommendations

The results conclusively showed that iron mesh gave highest As removal efficiency as compared to nails and slag. The reason for higher removal efficiency of iron mesh was larger surface area that produces more ferric hydroxide (As adsorbent). PAF constructed using plastic bucket for current study cost US$ 5 which is cheaper than previously proposed concrete made KAF. It is suggested that PAF constructed using iron mesh and sand combination may be deployed at locations where As concentration ranges within 50 ppb to 100 ppb. It is recommended to investigate the PAF removal efficiency for initial concentrations up to 1500 ppb. It is further recommended to use a PAF in series where one PAF is not meeting the desired results.

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