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Development of a treatment unit for removal of arsenic from groundwater

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ABSTRACT

The purpose of this study was to develop a treatment unit for arsenic contaminated groundwater samples. The samples were collected from different locations of Taluka Sakrand by means of installed hand pumps and tube wells. The treatment unit was developed locally with three layers, each with iron nails, activated carbon and milled rice husk from the top to bottom. The arsenic contaminated groundwater samples were put from the top layer and treated samples were collected from the bottom of the unit through tap valve. The arsenic contamination level of the samples was checked before and after treatment with the help of arsenic measuring kit. The contact time of the samples through the beds of developed unit was around 30 minutes. The highest concentration of arsenic in groundwater samples was found 60 ppb taken from village Miru Kalhoro. No arsenic amount was found in all treated samples after passing through the layers of installed unit. It is concluded that the developed unit is a suitable and effective for the treatment of arsenic contaminated groundwater samples up to 60 ppb concentrations.

1. Introduction

Arsenic is the twentieth most common element in nature. It is widely distributed throughout the earth's crust and usually found in the atmosphere, soils, rocks, organisms and in natural waters (Cheng et al., 2009). It can easily combine with other elements to form inorganic and organic arsenic compounds. The inorganic arsenic appears in compounds with oxygen, sodium, potassium, copper, chlorine, iron, and sulphur. Arsenic in plants and animals combines with carbon and hydrogen to form organic arsenic. Organic arsenic is less toxic than inorganic arsenic (Yan et al., 2010; Jakhrani et al., 2009; Zoungrana et al., 2016). Once the arsenic reaches into the body, it gets concentrated overtime and cause long-term damage. Arsenic is generally said to be about four times as poisonous as mercury. It exists in oxidation states of -3, 0, 3 and 5. The trivalent arsenic is considered to be 60 times more toxic than pentavalent (Jain and Ali, 2000).

Arsenic is used for manufacturing of semi-conductors, petroleum refining, wood preservatives, animal feed additives and herbicides. It is metabolized in the environment through a combination of natural processes such as weathering, biological reactions and volcanic emissions as well as through a wide range of anthropogenic activities. The principal pathways of arsenic entrance into the body are via ingestion and inhalation. Dermal contact may not be considered as a primary route of exposure. Exposure dosage of arsenic is the combined exposure by all routes (Mondal et al., 2010; Mandal and Suzuki, 2002).

1.1. Health effect of arsenic contamination

Arsenic-contaminated aquifers are currently estimated to affect approximately 150 million people around the world, which includes both organic and inorganic compounds of arsenic (Podgorski et al., 2017). The inorganic arsenic compounds are usually found in water, which is highly toxic, whereas, the organic compounds are normally found in seafood, which is less detrimental to health. The direct indicators of acute arsenic poisoning are nausea, abdominal pain and diarrhea, which are followed by emotionlessness, itchy of the edges, muscle

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constricting and death. The leading indicator of long-term exposure to inorganic arsenic is from drinking-water and food. These are commonly observed in the skin, which include color changes, skin scratches and hard spots on the palms and soles of the feet (hyperkeratosis). Such symptoms can be found after almost five years of exposure to arsenic compounds and may be antecedent to skin, bladder and lungs cancer. Other adverse health impacts of arsenic include age-related effects, neurotoxicity, diabetes, and respiratory and cardiac diseases. It is also connected with adverse pregnancy distresses and infant mortality (Kapaj et al., 2006; Sambu and Wilson, 2008; Naujokas et al., 2013; Quansah et al., 2015; Jakhrani et al., 2012).

1.2. Methods of arsenic removal

The conventional methods of arsenic removal comprise of oxidation, coagulation-precipitation, adsorption, ion exchange and membrane techniques. Ion-exchange methods have very limited ability to remove arsenic because of exchange competition from other anions found in groundwater. Membrane processes are very effective at removing arsenic from groundwater, but these are costly. The emerging arsenic removal technologies include electrochemical arsenic remediation, regenerating adsorptive media, and subterranean arsenic removal.

Other treatment options include use of iron compounds, activated alumina and carbon and agro residues, such as rice husk (Ng et al., 2004; Mohan and Pittman, 2007; Duarte et al., 2009; Channa et al., 2017). It is estimated that approximately 50 million to 60 million people of Pakistan use arsenic contaminated groundwater. This number is alarmingly high and demonstrates the urgent need for verification and testing of all drinking water wells in the Indus Plain, followed by appropriate mitigation measures (Podgorski et al., 2017; Amin and Alazba, 2014). The purpose of this study was to develop and analyze the performance of an arsenic removal unit for elimination of arsenic contaminants from groundwater using locally available cost-effective materials.

2. Materials and method

The materials used for the development of arsenic treatment unit were polyvinyl chloride (PVC) pipes and sheets, plasticized polyvinyl chloride pipes, pipe head caps, meshes, handle valve, and socket valve. The adsorbents include iron nails, activated carbon and rice husk.

2.1. Development of a treatment unit

The developed arsenic filtration unit is shown in Fig. 1. The original length of the purchased pipe was 2.44 m (8ft). It was then cut it into two pieces, one 1.5 m (5ft) and the other 0.91 m (3ft). The 0.91 m (3ft) pipe was again spherically cut into three more portions each of 0.3 m (1ft) apart. Each part was then cut from top to bottom with such dimension to be fit within (inside of) the 1.5 m (5ft) pipe length. The pipe of 1.5 m (5ft) size was kept vertically at the angle of 90º to the horizontal. One cap was placed over the top of the pipe and other at the bottom of the pipe in order to keep the water within the pipe. The inlet and outlet were made in the caps for entry and the exit of water samples. A 3 cm portion of each 0.3 m (1ft) length pipe was cut from the top to bottom for formation of beds or layers. The spherical cut was given with the help of hand saw, and the length was cut by means of wood cutting saw machine at the workshop of the university. Three PVC sheets or plates of thickness 12.7 mm (0.5 inch) were made in round shape with the help of wood cutting saw machine. The diameter of the sheets was kept slightly less than 0.3 m (1ft) so that these could be set in the developed unit over the base of 0.3 m (1ft) pipe. Small size holes at the spacing of 22 mm (0.87 inch) were kept in the sheets with the help of drilling machine in the machine shop. The meshes were sized with the help of scissors manually, which were placed over the sheets for filtering groundwater and retarding of the sorbents over the bed. In addition, the inlet and outlet holes were made in the pipe for entry and exit of water. The size of the inlet hole was kept 22 mm (0.87 inch) and the outlet 28 mm (1.10 inch). The holes were made with the help of hydraulic drilling machine.

A total of three different materials, viz. rusted iron nail, activated carbon and rice husk were used for the treatment of arsenic contaminated water samples as shown in Figs. 2 to 4. At first, the iron nails were exposed to the atmospheric air to make these rusty, as the rusty nails have affinity to remove arsenic from the water. The thicknesses of all three beds were around 50 mm (1.97 inch). The rusted iron nails were placed over the top most bed. The base of the layer was made of PVC sheet with a mesh of size 60 µm. Then, the activated carbon were placed over the middle bed, and placed over the mesh size of 80 µm. The rice husk were milled and passed through the sieve of size 45µm and then placed over the bottom sheet over the mesh size of 100 µm.

2.2. Collection of samples

Initially, various groundwater samples were collected from different locations of Taluka Sakrand, District Shaheed Benazirabad as shown in Table 1. The initial arsenic concentrations of samples were checked at the site using arsenic test kit. Once the arsenic contaminated samples were found more than standards, the sample numbers were assigned and these were preserved in the water coolers and cans. The arsenic contamination of twenty locations was found within WHO permissible level of 10 ppm or µg/L.

Table 1: Location of groundwater samples collected in Taluka Sakrand

Number	Union Council	Name of Village	Sample Number	Latitude (Degree)	Longitude (Degree)	Altitude (feet)	Depth (feet)
1	Marvi	Sukhpur	S1	26.2633	67.5839	119	30
2	=	=	S2	26.2632	67.5839	119	31
3	=	=	S3	26.2632	67.5839	119	35
4	=	=	S4	26.2632	67.5839	119	32
5	=	=	S5	26.2626	67.5839	119	30
6	=	Gasbo	G1	26.0503	67.1106	122	35
7	=	=	G2	26.0503	67.1106	122	34
8	=	=	G3	26.0503	67.1106	122	33
9	=	=	G4	26.0503	68.1106	122	30
10	=	=	G5	26.0503	68.1106	122	35
11	=	Miro Kalhoro	M1	26.5601	68.0343	121	40
12	=	=	M2	26.5601	68.0343	121	40
13	=	=	M3	26.5605	68.0343	121	42
14	=	=	M4	26.2651	68.0343	121	43
15	=	=	M5	26.2051	68.0343	121	44
16	Dalel Dero	Allah Bux Magsi	A1	26.1236	68.1802	231	28
17		=	A2	26.1236	68.1801	231	29
18		=	A3	26.1236	68.1802	231	28
19		=	A4	26.1236	68.1806	231	25
20		=	A5	26.1236	68.1802	231	27
21	Khadhar	Khadhar	K1	26.0853	68.2211	119	35
22	=	=	K2	26.0853	68.2211	119	30
23	=	=	K3	26.0853	68.2211	119	30
24	=	=	K4	26.0853	68.2211	119	35
25	=	=	K5	26.0853	68.2211	119	30
26	=	Umar Bodleja	U1	26.0908	68.2355	103	28
27	=	=	U2	26.0908	68.2355	103	28
28	=	=	U3	26.0908	68.2355	103	30
29	=	=	U4	26.0908	68.2355	103	30
30	=	=	U5	26.0908	68.2355	103	28
31	=	Dargah Khayari Shareef	D1	26.1854	68.3580	85	28
32	=	=	D2	26.1854	68.3580	85	25
33	=	=	D3	26.1853	68.3580	85	27
34	=	=	D4	26.1854	68.3581	85	28
35	=	=	D5	26.1854	68.3581	85	28
36	Karam Jamali	Taj Jamali	T1	26.0687	68.2608	104	35
37	=	=	T2	16.0687	68.2608	104	33
38	=	=	T3	16.0687	68.2608	104	30
39	=	=	T4	16.0687	68.2608	104	30
40	=	=	T5	16.0687	68.2608	104	35

However, the samples taken from two union councils namely Marvi and Dalel Dero of Taluka Sakrand were found arsenic contaminated with level more than WHO guideline value. The villages of Marvi union council were Sukhpur, Gasbo and Miru Kalhoro, and the village of union council Dalel Dero was Allah Bux Magsi. Before collecting the groundwater samples, the global positioning system of each location was recorded through mobile sets, and then the samples were taken from the existing hand pumps and water wells. Latitude, longitude and altitude of each sampling location were recorded at the site. The depth of hand pumps or tube wells was documented as per knowledge given by local people and were also verified through bore holders of the area.

2.3. Experimental procedure

The presence of arsenic in groundwater samples was examined with the help of arsenic measuring kit. Initially, 100 ml groundwater sample was taken in the bottle, and then reagents were added for conversion of liquid arsenic into gaseous arsenic. After half an hour time, the presence of gaseous arsenic facilitates to measure the arsenic concentration level in the groundwater in the samples. The presence of arsenic in the solution generated a color on the strip which was attached with the cover. The generated color is then compared with the color provided on the leaflet recommended by WHO. Arsenic contaminated water samples were again checked after passing from the developed unit by adopting the procedure as followed for raw samples analysis.

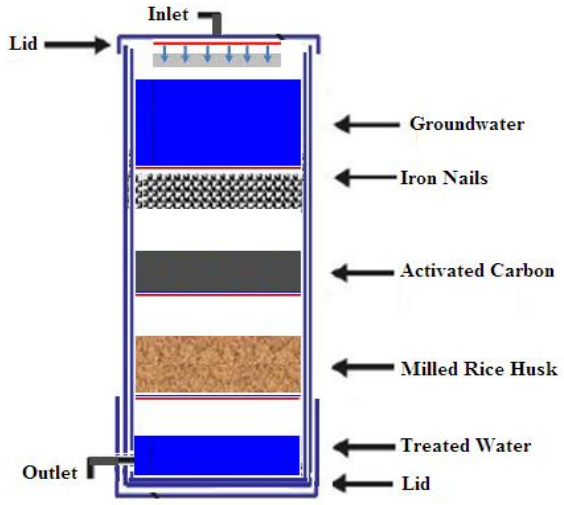

Fig. 1: Developed arsenic filtration unit

Fig. 2: Different materials, viz. fresh and rusted iron nail

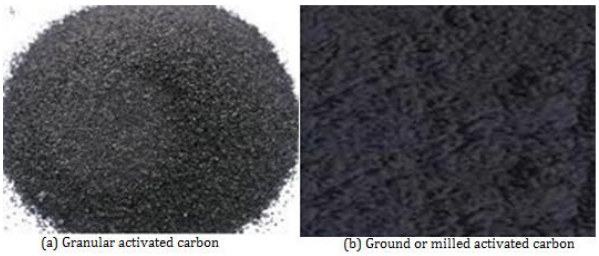

Fig. 3: Different materials, viz. granular and ground or milled activated carbon

Fig. 4: Different materials, viz. raw and ground or milled rice husk

3. Results and discussion

3.1. Initial arsenic concentration level in groundwater samples

Initially, the groundwater samples of forty locations were collected and checked for the presence of arsenic. Out of forty locations, the samples taken from twenty locations were found within WHO permissible level of 10 ppm as shown in Fig. 5. Whereas, the water samples of remaining twenty locations were found arsenic contaminated, and the level was more than permissible values of the drinking water. The five locations of the village Sukhpur were found arsenic contaminated as shown in Fig. 6. The maximum level of arsenic contamination in groundwater samples was found from the sample number S4 with 40 ppb. The minimum arsenic level was noted from two locations, namely S1 and S3 with 30 ppb, and in the remaining two locations, the concentration was 35 ppb.

Moreover, the maximum arsenic concentration in groundwater samples of village Gasbo was found from sample number G5 with 50 ppb as shown in Fig. 7. The minimum level of arsenic was noted from two locations, namely G2 and G3 with 20 ppb. The remaining two locations, G1 displayed 40 ppb and G4 25 ppb of arsenic in groundwater samples.

Similarly, the maximum level of arsenic in groundwater samples of village Miru Kalhoro was found from the sample number M3 with 60 ppb as shown in Fig. 8. The minimum level of arsenic was observed from M3 with 45 ppb. The level of arsenic concentration in M1 and M2 samples was found 55 ppb each and M5 exhibited 46 ppb. Likewise, the maximum level of arsenic in groundwater samples of village Allah Bux Magsi was found from sample number A1with 50 ppb as shown in Fig. 9. The minimum level of arsenic was observed from two locations, namely A2 and A4 with 30 ppb. The remaining two locations, A3 exhibited 35 ppb and A5 33 ppb of arsenic level in groundwater samples. In general, the groundwater samples collected from a minimum depth of 25 feet of sample S4, to a maximum of 44 feet of sample M5. The maximum level of arsenic in groundwater sample number M3 exhibited 60 ppb and minimum level was observed from sample numbers G2 and G3 in Fig. 10.

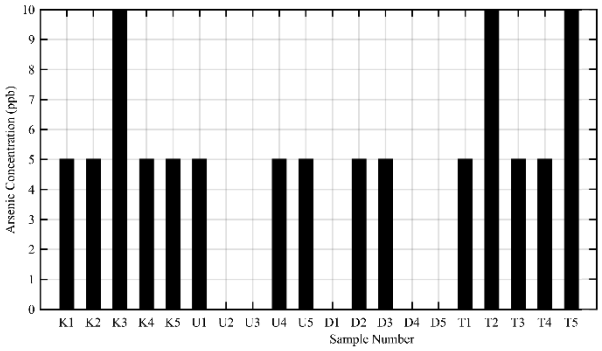

Fig. 5: Groundwater samples whose arsenic level was less than WHO standards (i.e., 10 ppb)

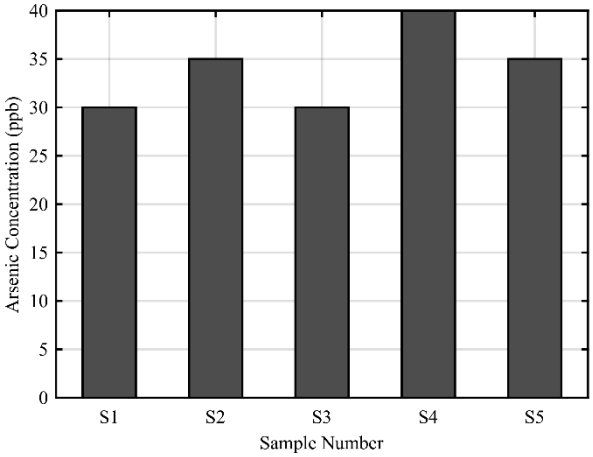

Fig. 6: Arsenic contamination level in raw groundwater samples of Village Sukhpur

4. Conclusion

The groundwater samples collected from a minimum depth of 25 feet of the sample S4, village Allah Bux Magsi to a maximum of 44 feet of sample M5 from the village Miru Kalhoro. The highest concentration of arsenic in groundwater with 60 ppb was found in sample number M3 collected from village Miru Kalhoro of Union Council Marvi, whereas, the lowest level was noted from two

samples having identification numbers G2 and G3 of village Gasbo, Union Council Marvi, Taluka Sakrand. Arsenic contaminated groundwater samples then were passed through the developed treatment unit.

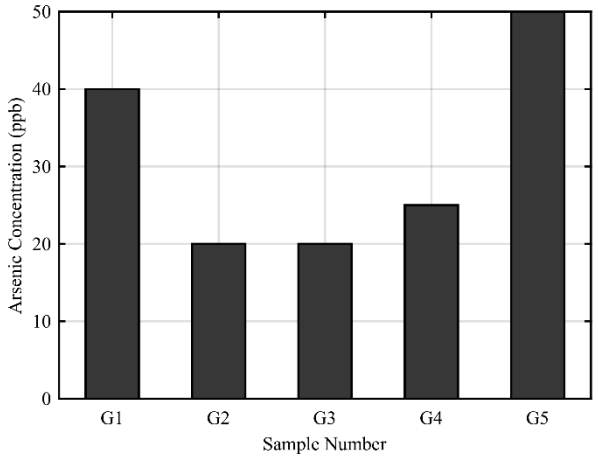

Fig. 7: Arsenic contamination level in raw groundwater samples of Village Gasbo

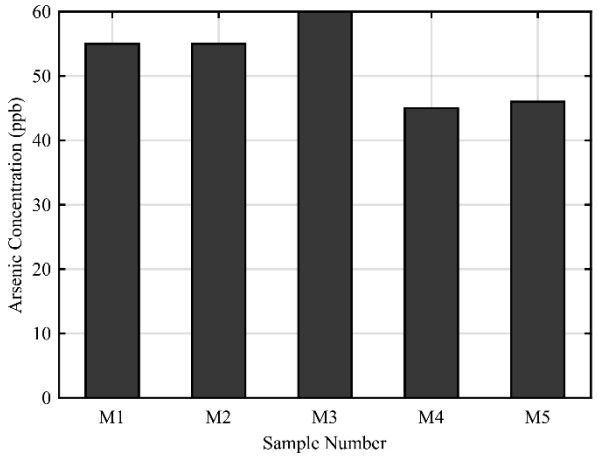

Fig. 8: Arsenic contamination level in raw groundwater samples of Village Miru Kalhoro

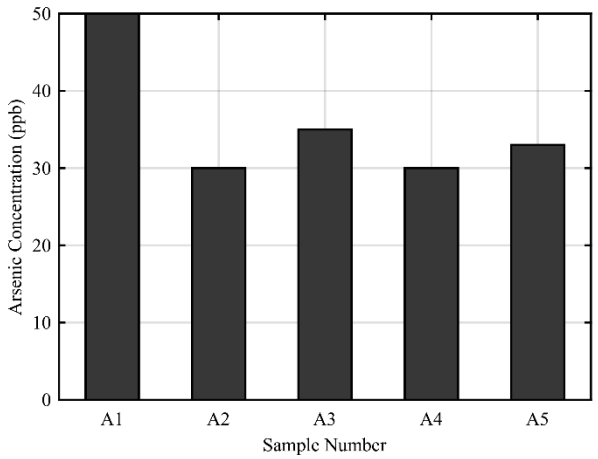

Fig. 9: Arsenic contamination level in raw groundwater samples of Village Allah Bux Magsi

The top bed was made up of iron nails, the second one was activated carbon and the lower bed was made up of milled rice husk. The groundwater samples were passed through all beds from top to bottom in the unit took around 30 minutes. The treated samples were collected from the bottom of test rig through tap valve. Then, all samples were analyzed using arsenic measuring kit. No arsenic concentration was found from all treated samples.

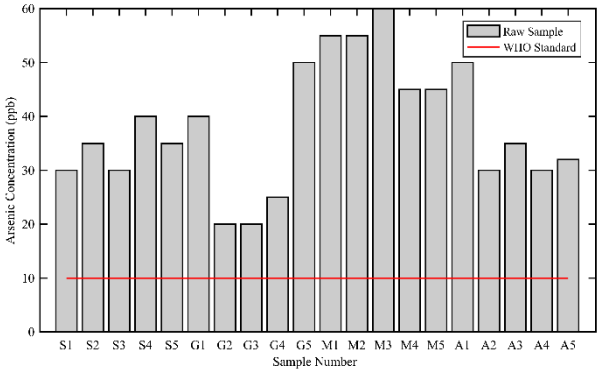

Fig. 10: Arsenic contamination level in raw and treated groundwater samples

The developed arsenic removal unit was found effective for the treatment of arsenic contaminated groundwater samples up to 60 ppb concentration. It is concluded that the developed unit is a suitable, cost effective method for the treatment of arsenic contaminants from groundwater samples, as the adsorbents used were locally available on reasonable price. It is suggested that the efficiency of adsorbents may be investigated individually as well as in combination using different size of beds, arsenic concentration levels, flow rates and pH levels. The disposal of arsenic contaminated waste may also be adopted for the protection of environment.

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