Efficacy of arsenic filtration by Kanchan Arsenic Filter in Nepal

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ABSTRACT

Groundwater arsenic contamination has caused a significant public health burden in lowland regions of Nepal. For arsenic mitigation purposes, the Kanchan Arsenic Filter (KAF) was developed and validated for use in 2003 after pilot studies showed its effectiveness in removing arsenic. However, its efficacy in field conditions operating for a long period has been scarcely observed. In this study, we observe the efficacy of KAFs running over 6 months in highly arsenic-affected households in Nawalparasi district. We assessed pair-wise arsenic concentrations of 62 randomly selected household tubewells before filtration and after filtration via KAFs. Of 62 tubewells, 41 had influent arsenic concentration exceeding the Nepal drinking water quality standard value (50 μg/L). Of the 41 tubewells having unsafe arsenic levels, KAFs reduced arsenic concentration to the safe level for only 22 tubewells, an efficacy of 54%. In conclusion, we did not find significantly high efficacy of KAFs in reducing unsafe influent arsenic level to the safe level under the *in situ* field conditions.

Key words | arsenic contamination, efficacy, Kanchan Arsenic Filter, Nepal

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INTRODUCTION

The lowland region of Nepal called Terai is home for nearly 50% of the nation's population and 90% of Terai people depend upon groundwater as a source of drinking water. Groundwater arsenic contamination was discovered in Nepal in 1999 and this prompted a large-scale assessment of arsenic (Shrestha *et al.* 2003). As of 2011, over 740,000 tubewells have been tested by 12 separate organizations and 3 and 8% of the total have been found to exceed 50 μg/L (microgram/liter) and 10 μg/L of the Nepal Drinking Water Quality Standard (NDWQS) and World Health Organization (WHO) standard, respectively (Thakur *et al.* 2010). Discovery of groundwater arsenic contamination concurrently prompted research on arsenic mitigation. The Massachusetts Institute of Technology (MIT) and Environment and Public Health Organization in collaboration were involved in arsenic mitigation research and in 2003 developed the Kanchan Arsenic Filter (KAF) which is sustainable in local social and economic conditions (Ngai *et al.* 2007).

The general structure of KAF and its functioning is briefly presented in Figure 1. Performance of KAF is influenced by multiple factors, such as arsenic concentration and chemical parameters of influent water (such as levels of iron, chloride, phosphate, and hardness), flow rate, duration of use, and maintenance, monitoring and handling of the filter (Chiew *et al.* 2009; Pokharel *et al.* 2009; MIT 2011). Monitoring of these factors can be difficult not only for users but also for organizations involved in the mitigation program. In a pilot study, average arsenic removal efficiency of KAF was 90% and over 95% of filters ($n = 1{,}034$) were found to reduce arsenic concentration to below 50 μg/L (Ngai *et al.* 2007). The efficacy of KAF varied in that study depending upon the influent arsenic concentration: for example, of three KAFs tested with an arsenic level of 1,000 μg/L, one reduced to 90 μg/L and the other two to 150 μg/L; in contrast, of 72 KAFs tested with an arsenic level of 200 μg/L, 67 reduced to <50 μg/L and only five had >50 μg/L. In our study, we evaluate the efficacy of KAFs under *in situ* field conditions by measuring arsenic concentration of tubewell (influent water) and KAF-filtered water (effluent water).

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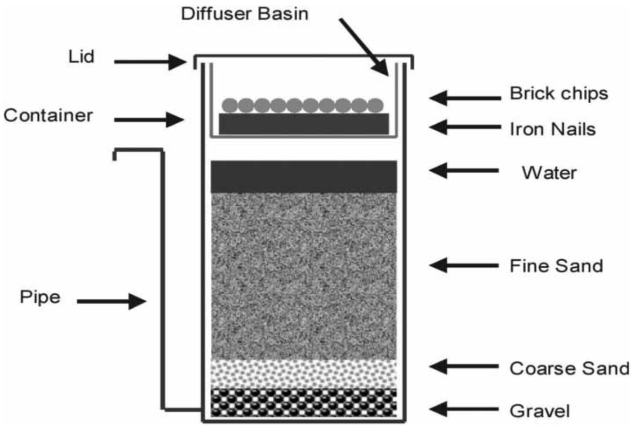

Figure 1 | Components of KAF (adapted from Ngai *et al.* 2007). KAF is a modified version of biosand filter and can be constructed using simple and easily available materials such as plastic containers, PVC pipes, iron nails, sand, gravel, and brick. The diffuser basin of the KAF is filled up with iron nails and brick particles into which arsenic contaminated groundwater is poured. When the iron nails get exposed to air and water, they rust and produce ferric hydroxide particles to which arsenic present in the water is quickly adsorbed. Some of the arsenic-loaded particles get flushed down but become trapped within a few centimeters in the fine sand layer. As the outer iron surfaces scale off, new surfaces are exposed and the adsorption process is repeated. By these continuous mechanisms, arsenic is retained in the filter components and filtered water is potable. The KAF is also shown to be effective in removing pathogens from water as a result of four mechanisms: physical straining, adsorption of pathogens to the filter components, predation of pathogen by biofilm (algae, bacteria, protozoa, and small invertebrates) that become established within a few weeks in the sand, and natural die-off of pathogens.

METHODS

Study area

Study sites were selected in the program areas of Filters for Families (FFF), an organization involved in arsenic mitigation and research. At the time of the study, FFF was running arsenic mitigation programs using KAF for more than 2,000 households in several communities/areas of the district. Our sampling areas were Ramgram municipality and five other villages – Jahada, Pratappur, Sarawal, Sunawal, and Sukrauli. These areas had already been prescreened by FFF as well as other organizations to have unsafe arsenic concentrations by kit testing. From these areas we chose 62 households by simple random sampling where KAFs were running at least for 6 months. The numbers of households sampled in the areas were 5, 3, 35, 3, 14, and 2 from Jahada, Pratappur, Ramgram, Sarawal, Sukrauli, and Sunawal, respectively. A limitation of this study is that we did not collect information about filter maintenance and handling which play important roles in efficiency of KAFs and our finding is not a representation of the overall scenario in the FFF program areas.

Water sampling and assessment of arsenic concentration

From each household, we collected influent and effluent water samples in 150 mL pre-acid washed plastic bottles, the former after pumping the tubewell for 15–20 times, and the latter after pouring fresh tubewell water over the basin. One milliliter of concentrated hydrochloric acid (HCl) was then added to each water sample for preservation and the samples were stored at $-20\,^{\circ}$C until arsenic assessment.

Arsenic concentration of the water samples was assessed by Hydride-Generation Atomic Absorption Spectrophotometer (HG-AAS) (SOLAAR 969AA Spectrometer, Thermo Elemental, UK). Briefly, 25 mL of water was treated with pre-reductants HCl and sodium iodide (NaI) and allowed to react for 30 min to convert all forms of arsenic into trivalent state. Then the sample was fed into HG-AAS for measurement of arsenic concentration. Sodium borate (NaBH4) and HCl were used for generating arsenic hydride. Arsenic concentration in the water sample was determined after calibrating the instrument with trivalent arsenic (III) standard solution which had gone through the same process as the sample. The detection limit of the HG-AAS for water was 5 μg/L.

RESULTS

Among 62 household tubewell waters evaluated, 21 and six tubewells had arsenic concentrations below NDWQS and WHO standards, respectively (Table 1). In all households having functional KAFs, flow rates of the KAFs were fairly good: we noticed that KAFs were well used and people responded that they were getting enough water for drinking (data not shown). Sixty-six percent (41/62) and 90% (56/62) of tubewell water samples had arsenic concentrations above the NDWQS and WHO standards, respectively. The mean and median arsenic concentrations for influent water samples were 133.13 and 74 μg/L, and for effluent water

Table 1 | Distribution of arsenic concentration in study areas

	NDWQS standard		WHO standard	
VDC/ municipality	<50 μg/l (safe)	≥50 μg/l (unsafe)	<10 μg/l (safe)	≥10 μg/l (unsafe)
Jahada	4	1	0	5
Pratappur	0	3	0	3
Ramgram	7	28	1	34
Sarawal	0	3	0	3
Sukrauli	8	6	4	10
Sunawal	2	0	1	1
Total	21	41	6	56

samples, they were 56.45 and 25 μg/L, respectively (data not shown).

Of 62 tubewells, 21 and 41 tubewells had arsenic concentrations <50 and ≥50 μg/L, respectively (Table 2). Of the 41 tubewells having arsenic concentrations ≥50 μg/L, KAFs reduced arsenic concentration to <50 μg/L for only 22 (43 – 21: # effluent water samples having arsenic concentration <50 – # influent water samples having arsenic concentration <50 μg/L) tubewells, an efficacy of 54%. Similarly, six and 56 tubewells had arsenic levels <10 and ≥10 μg/L, respectively. Of the 56 tubewells having arsenic concentrations ≥10 μg/L, KAFs reduced arsenic concentration to <10 μg/L for only 13 (19 – 6: # effluent water samples having arsenic concentration <10 μg/L – # influent water samples having arsenic concentration<10 μg/L) tubewells, an efficacy of 23%.

By single mean test, effluent water samples did not have a significantly different mean arsenic concentration than the NDWQS value, 50 μg/L. In contrast, influent as well as effluent water samples had a significantly higher mean arsenic concentration than the WHO standard, 10 μg/L. No effluent water sample from a KAF had a higher arsenic concentration than the influent water.

DISCUSSION

Groundwater arsenic contamination has become a significant public health concern in lowland regions of Nepal, Nawalparasi district being the most severely affected. In 2003, after KAF was developed and tested to be efficient, it became popular for arsenic mitigation programs in Nepal. The effectiveness of KAF was last evaluated in 2005 by a pilot study that tested 1,034 households from arsenic affected areas that had a wide variation of arsenic, and the effectiveness of KAFs was found to be 90% (Ngai *et al.* 2007). We studied the efficacy of KAFs that were in use for more than 6 months in field areas of FFF by measuring arsenic concentrations in influent and effluent waters.

Interestingly, influent arsenic concentrations in 21 households were below the NDWQS value but they were using KAFs. KAFs were provided to these households based on blanket testing via kit method. This difference in arsenic concentrations at different times could be due to the lower specificity and sensitivity of the kit method than AAS method and/or temporal variation of groundwater arsenic (BGS 2001; Karagas *et al.* 2001; Steinmaus *et al.* 2005).

Under field conditions of actual use, we did not find significant efficacy of KAFs in reducing elevated arsenic concentration to the safe level (NDWQS or WHO standard). Assessment of influent and effluent water samples from 62 households showed that only 54% of KAFs reduced the elevated arsenic concentration to <50 μg/L. The effectiveness was even lower when tested for the WHO standard. Single mean test also showed that the average effluent arsenic concentration was not significantly different (or lower) than the NDWQS value which further supports a low efficacy of KAF. Similarly, average influent and effluent arsenic concentrations were significantly higher than the WHO standard value ($p < 0.001$). These findings clearly indicated that, under *in situ* field conditions, effectiveness

Table 2 | Efficacy measurements of KAF by standard arsenic levels

	<50 μg/l	≥50 μg/l	*P*-value[a]	<10 μg/l	≥10 μg/l	*P*-value
Before filtration	21 (34%)	41 (66%)	<0.001	6 (9%)	56 (90%)	<0.001
After filtration	43 (69%)	19 (30%)	<0.05	19 (31%)	43 (69%)	<0.001

[a] *P*-value calculated for influent and effluent waters by single mean test using NDWQS and WHO standards.

of KAFs was not satisfactorily high: only 44% KAFs reduced elevated arsenic to below the NDWQS standard. Our concomitant study in the same area also noted the biological evidence of arsenic exposure among people consuming the KAF-filtered water (Maden *et al.* 2012). In case of high arsenic influent concentrations, iron nails used in the KAFs should be replaced on a yearly basis for optimum function (CAWST 2011). Many KAFs we assessed were run for more than a year but we did not observe such a practice in all households. This could be a main reason why a significantly high number of filters we assessed were not functioning properly. In addition, water parameters which can vary geographically and lack of proper maintenance and handling can be reasons for lower efficiency of KAFs. Efficiency could be increased by the following measures: a silt layer from the well water that accumulates on the sand and in the biofilm should be cleaned monthly, the factors affecting the efficacy of the KAF should be examined and then necessary adjustments should be made, and household members should be trained for proper monitoring and handling of the KAF.

CONCLUSION

Under field conditions, only half of the KAFs tested were able to reduce elevated groundwater arsenic concentration to the safe level. Therefore, as long as a KAF is operated, regular assessment of influent and effluent arsenic concentrations are required that will help to make necessary adjustments to factors affecting its efficiency or repairs to the KAF.

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