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Application of SARSAC for Arsenic-Polluted Water in Prek Chrey Khnong of Kandal, Cambodia

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Abstract: *Situated in Kandal province of Cambodia with lower Bassac river as a border with Vietnam, a village of Koh Thom district called Prek Chrey Khnong with a population of several hundred families faces lack of drinking water sources especially during dry season due to the existence of elevated arsenic level (3–53 times higher than CDWQS) in pipe well water and the presence of bacteria in surface water. To solve this problem, a sustainable arsenic removal system for affected communities (SARSAC) which has been used to remove arsenic and other trace metals successfully in India was installed in this village to provide safe drinking water from arsenic and bacteria to its residents. After passing through the system, initial levels of arsenic (450 ppb), iron (1,560 ppb), manganese (1,981 ppb), E-coli (7 cfu/100mL), and total coliform (13 cfu/100mL) in the water were reduced to the levels lower than the CDWQS and WHO guidelines. The consecutive mechanisms responsible for this removal are 1). filtratration of bacteria, color and taste in the gravel-sand tank; 2). oxidation of arsenic, iron, manganese via aeration pipe connected to the tank and column; 3). adsorption of arsenic to the surface area of iron oxides impregnated with resin beads in the column; and 4). co-precipitation of arsenic with iron and manganese. With a preferred flow rate of 9–12 L/min, an estimated discharge of safe water of 4,000–5,000 L per 8 operating hours can supply as many as 200–250 families within 3–5 days' period. It is necessary that the system should be monthly monitored for water quality and for maintenance to gain the residents' trust and to assure sustainable use of safe water in the village.*

Keywords: Arsenic; SARSAC; Drinking water; Bacteria; Prek Chrey Khnong

1. INTRODUCTION

The presence of naturally occurring arsenic in groundwater utiilized as a source of drinking water has become a concern to Cambodia since the year 2000 (Polya et al., 2003); Phan et al., 2010). Groundwater arsenic is found in many provinces of Cambodia, for instance Kandal, Prey Veng, Kratie, Kampot (Buschmann et al., 2007; Luu et al., 2009). Amongst these provinces, Kandal has been comphrehended as the most affected area since it covers the Mekong delta which includes the areas along the Bassac and Mekong Rivers where As-bearing sediments transport from the upper Mekong River are deposited by a fluvial process. As a result, amongst the population of 1.1 million in this province up to 2 in 1000 people who have been using arsenic-contaminated groundwater are believed to be at risk of arsenicosis, owing to the lack of surface

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water and their poor living condition (Sthiannopkao et al., 2002).

Currently, the governmental agencies and non-governmental organizations (NGOs) are paying much attention to this province by educating the people about the impact of arsenic, providing accessibility of purchased water to rural areas, and introducing a certain type of arsenic treatment facilities. However, yet some treatment facilities are reported to perform an incomplete removal of arsenic due to degradation of adsorbing materials and differences in groundwater composition.

In the meantime, the hybrid anion exchanger (HAIXs) resins, which were developed by SenGupta's group and have been effectively used throughout India for provision of safe drinking water (Sarkar et al., 2007), were introduced to Kandal province, Cambodia as adsorbents for removal of arsenic and other contaminants from pipe-well waters. The system which includes a column storing the resins is called SARSAC (Sustainable Arsenic Removal System in Affected Communities).

Therefore, the purpose of this study is: (1) to apply the HAIX resin SARSAC to Cambodian arsenic-polluted groundwater; and (2) to provide safe drinking water to the Cambodian local residents in Kandal province.

2. METHODOLOGY

2.1 Sample collection and analysis

Kandal province was selected as a prioritized province for SARSAC installation with Prek Chrey Khnong village of Koh Thom district being the target to solve the problem of arsenic-polluted water for the residents. To assure whether the waters of Prek Chrey Khnong are polluted with arsenic, 20 water samples were randomly collected and analyzed for arsenic, iron, and mangenses with an atomic absorption spectrophotometer (AAS) at the chemical laboratory of the Department of Chemical Engineering and Food Technology, Institute of Technology of Cambodia. Prior to the collection, the water was pumped out for several minutes to remove oxic surface water. The water was fully placed into a 50mL bottle and added with nitric acid to avoid precipitation during the transport to Phnom Penh.

Detailed tests and analysis were conducted for only the water sample from at the selected location where the SARSAC is installed. Parameters such as pH, oxidation-reduction potential (ORP), temperature, turbidity, and total dissolved solid (TDS) were measured on site, whereas Escherichia coli (*E-coli*) and total coliform were analyzed in the lab.

2.2 Location for SARSAC installation

Since only one system would be installed in the Prek Chrey Khnong village of Kandal in this study, three criteria were considered to choose the location of installation as follows: (1) Accessibility: the location can be more easily assessed by most residents in the village; (2) Responsible person: the person in-charge of the system and maintenance should be kind and strong enough and always available when needed; and (3) Arsenic concentration: relatively low arsenic in the pipe-well/tube-well water is preferred for long life-span of the system.

2.3 System and materials

The SARSAC system is divided into two major parts, a tank for elimination of bacteria, color, and turbidity (filtration process) and a steel column for removal of arsenic and other trace metals (oxidative-precipitation process). The tank contains gravels (1–2 cm grain size) of 15 cm thickness at the bottom followed up by coarse sands (0.5–1 cm grain size) of 30 cm thickness and then by fine sands (1.5–3 mm grain size) of 50 cm thickness, while the column contains gravel (1–2 cm) of 10 cm thickness at the bottom followed up by coarse sands (0.5–1 cm) of 30 cm thickness with HAIX resins of 60 cm thickness being stored at the top.

The system was designed with the desired flow of 9–12 L/min. Washing of the tank and column is achieved by reversing the direction of flow of the water and the velocity of the counter-flow water is limited because of possible losses of material. Moreover, it enables to increase air-flow turbulence to effectively loosen particles attached to the grains of sand. The circulation of air inside the column help oxidize the zero valent iron to hydrated ferric oxides (HFOs) with a high capacity of arsenic adsorption due to its high affinity to both As(III) and As(V) since air is a significant oxidizer. The tank and column with their accessories were preferrably fabricated and purchased in Cambodia, whereas the hybrid anion exchanger (HAIX) resins were provided by Lehigh University, America. The HAIX resin beads are impregnated with hydrated ferric oxides (HFOs).

3. RESULTS AND DISCUSSION

3.1 Major elements of Prek Chrey Khnong village waters

The groundwater of Prek Chrey Khnong village exhibited significant concentrations of arsenic, iron, and manganese, as seen in Table 1. The arsenic concentration varied between 156–2,656 ppb (with average of 746 ppb), with 100% samples exceeding the Cambodian drinking water quality standard (CDWQS) of 50 ppb (3–53 times higher) and WHO of 10 ppb (16–266 times higher). Consumption of low arsenic over long period of time may result in chronic arsenic poinsoning or arsenicosis and long exposure to arsenic would lead to skin disorder, numbness, dizziness, fatigue, and abnormal pain (Lianfang and Shenling, 2003).

Table 1. Major elements in waters of Prek Chrey Khnong village, Koh Thom, Cambodia.

Samples	Fe (ppb)	Mn (ppb)	As (ppb)
PC-01	-	462	295
PC-02	-	317	298
PC-03	-	833	235
PC-04	-	538	352
PC-05	-	881	156
PC-06	1,560	1,981	450
PC-07	-	50	1,159
PC-08	5,561	65	2,656
PC-09	-	64	1,623
PC-10	2,580	574	786
PC-11	2,773	1,177	706
PC-12	4,489	3,309	298
PC-13	3,845	3,106	968
PC-14	3,449	1,795	1,056
PC-15	12,573	740	928
PC-16	8,327	1,633	298
PC-17	3,803	1,284	304
PC-18	4,221	1,417	329
PC-19	19,008	1,209	833
PC-20	3,916	1,245	1,181
Minumum	-	50	156
Average	3,793	1,134	746
Maximum	19,008	3,309	2,656

Note: (-) not detected

The iron concentrations displayed between not detected–19,008 ppb (with average of 3,805 ppb), with 65% surpassing the CDWQS of 300 ppb (0–63 times higher) and WHO of 1,000 ppb (0–19 times higher). It is remarked that the iron concentration of 19,008 ppb is relatively high compared with previous findings (Feldman et al., 2007) and there was a significant gap between not detected iron and the lowest iron (1,560 ppb), suggesting there was a quick precipitation at the field since most low arsenic samples were also observed together with no-iron samples. The concern of high concentration of iron in water is generally related with aesthetic properties (noticeable taste or undesired color) (Feldman et al., 2007).

Manganese was present between 50–3,309 ppb (with average of 1,134 ppb) in groundwater was typical to other places of Kandal province. The samples as much as 80% consisted higher manganese than that of the CDWQS of 400 ppb (0–8 times higher) and WHO of 500 ppb (0–7 times higher). Long-term exposure to high concentrations of manganese via oral intake may result in neurological disorders (WHO, 2004).

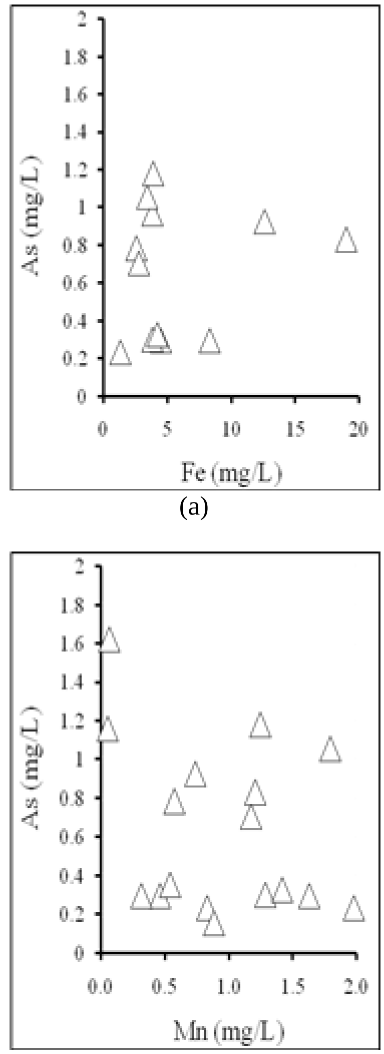

Figure 1. No significant relationships between (a) arsenic and iron; (b) arsenic and manganese.

The presence of high arsenic with high iron indicates that arsenic may be released to groundwater by dissolution of iron oxides (Rowland et al., 2008), but additional field parameters should be considered meanwhile. However, no significant correlation of arsenic and iron was found (Fig. 1a). The highest arsenic (2,656 ppb) with slightly high iron (5,561 ppb) was found in sample PC-08 and the highest iron (19,008 ppb) with slightly high arsenic (833 ppb) for sample PC-19. This may be due to the scale of study area with only a village, suggesting that groundwater arsenic in extensive area should be integrated. If dissolution of iron oxide as a main mechanism of arsenic release may be proven, it is convenient to apply the HAIX resin to readsorp and to coprecipate arsenic after As(III) and Fe^0 are oxidized to As(V) and iron oxides, respectively. There is also no correlation of arsenic with manganese (Fig. 1b). However, raw water with high iron and manganese can be also removed by the HAIX system (Sarkar et al., 2010).

Figure 2. SARSAC system installed at Prek Chrey Khnong village of Kandal province, Cambodia.

3.2 Installation and performance of SARSAC system

After discussion with local residents and authorities of the Prek Chrey Khnong village, the SARSAC system was installed at a selected house (Fig. 2), corresponding to the sample PC-06 (Table 1) with an agreement and collaboration from the house owner. The residents use rain water they can collect during rainy season for dry season and normally purchase purified water from Vietnamese sellers at 2,000–2,500 KHR/20L. The purchased water can be used for drinking up to 3–5 days for a small family. Some residents use surface water or dug well water for drinking after boiling it since it is costless and available nearby.

Table 2. Comparison of water chemistry before and after treatment with Cambodian Drinking Water Quality Standard (CDWQS) and WHO guideline for case of Prek Chrey Khnong village, Kandal province, Cambodia.

Samples	Raw water	Treated water	CDWQS	WHO
As (ppb)	450	5	50	10
Fe (ppb)	1,560	214	300	1,000
Mn (ppb)	1.981	158	400	500
ORP (mV)	–23	5	n/a	n/a
pH	7.4	7.11	6.5–8.5	n/a
Temp (°C)	29.5	30.6	n/a	n/a
Turbidity (NTU)	0.5	0.38	5	n/a
TDS (ppm)	976	117	800	n/a
Total coliform (cfu/100mL)	13	0	0	0
E-coli (cfu/100mL)	7	0	0	0

Note: n/a: not available

The comparision of the initial raw water chemistry from the pipe well at the inlet and the terminal treated water chemistry after passing through the system at the outlet is shown in Table 2. After treatment with SARSAC system, initial arsenic of 450 ppb is reduced to less than the CDWQS and WHO guidelines. Meanwhile, other co-existing elements such as iron and manganese also reduced to less than both guidelines. The value of oxidation reduction potential (ORP) for raw water was –23 mV which increased to 5 mV after the water comes into contact with surface air. This indicates change of water condition from reducing to oxidizing condition. The total dissolved solid (TDS) also reduced from 976 ppm to 117 ppm below the CDWQS of 800 ppm, being indicative of loss in dissolved solids such as dissolved Fe, As, and Mn to the system. The initial total coliform and *E-coli* which were present at 7 cfu/100mL and 13 cfu/100mL, respectively, were completely removed from the water. The presence of this coliform bactria may be due to contamination from surface water since most of the pipe wells in this village were 20–30 m deep and Prek Chrey Khnong village is normally surrounded by floods during rainy season. However, the surface water is also harmful to the residents' healths due to the presence of bacteria, causing vomit and stomachache.

The contact/residence time of raw water with surface area of HFO-impregnated resins together with aeration system allow step-by-step oxidation, adsorption, and precipitation. First, dissolved Fe(II) and As(III) in raw water are oxidized to Fe(III) and As(V), respectively; Fe(0) on resins is oxided to HFOs, increasing more surface areas for adsorption. Therefore, flow rate is necessary to vary between 9–12 L/min. With this flow rate, an estimated volume of 4,000–5,000 L safe water can be produced from the system within 8 hours; which can supply as many as 200–250 families (roughly half of the Prek Chrey Khnong village) within 3–5 days.

4. CONCLUSIONS

As a result of this research, the HAIX SARSAC can remove As, Fe, Mn, total coliform, and *E-coli* from the arsenic-polluted waters in Prek Chrey Khnong village of Kandal province, Cambodia. Therefore, the SARSAC is also thought to be practically applicable in other places of Cambodia with waters exposing similar chemistry to those in this study. With the SARSAC being installed, local residents of Prek Chrey Khnong village can consume arsenic-safe pipe well water at much lower price; however, monthly monitoring of water quality and SARSAC maintenance should be taken measure.

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