Adaptable Technologies of Arsenic Removal from Drinking Water for Arsenic Hit Areas of Pakistan

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Abstract

An elevated content of arsenic (As) in ground water in large area of Pakistan is becoming a serious threat to its inhabitants. Hi-tech technologies may not be feasible to remove As in rural and poverty hit areas of Pakistan because of being expensive and high operational costs. Some of the aboriginal technologies which involve Evaporation, co-precipitation and oxidation techniques are in use in rural areas of many regional countries like India, Bangladesh and Nepal quite successfully. These indigenous technologies have been proved to be good alternative to modern technologies. They are highly resilient and have great adaptability to our local conditions and can be used as good adaptable options in the scenario of climate change and increased water pollution. For operation of these technologies no electricity is needed and no pressure is required. No expensive chemicals, no mechanical complexity and no expensive membranes are involved in fabrication of these equipments. Yet highly productive to remove the As contents in drinking water to the desired level as per WHO standards. The purpose of the present review article is to prepare an account of such workable indigenous technologies based on evaporation, oxidation and co-precipitation techniques and fabricated locally, which could be used in the field by solution seekers in rural areas of Pakistan. These technologies can be attuned to a wide range of As contents and can be fruitfully pioneered in Pakistan with minute alteration and little training of villagers.

Key Words: Arsenic Removal; Indigenous Technology; Drinking Water

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INTRODUCTION

Arsenic metal ranks 20th in natural abundance and is ubiquitous harmful metal which occurs mainly as oxyanion compound in ground water (Smedley and Kinniburg, 2002). Though the presence of this metal ranks 12th in the human body yet its presence in drinking water can be highly lethal even in minute quantities (Mandal, 2002). Apprehensions over the occurrence of arsenic in ground water has amplified a lot in current years as it is posing a serious menace to the great many people around the world in almost all the continents including china, Bangladesh, Argentina, India, United States, Vietnam, Hungary and Pakistan. Although this problem exists in developed world too, but conditions are more worse in less develpped and thickly populated segments of population in subcontinent especially Bangladesh, Pakistan, indian part of Bengal, where about 1.749 billions of human with very little resources are exposed to the acute and chronic impacts of As (Nickson et al., 1998; Choudhary et al., 2000). According to WHO and USEPA, current limit of As contents in drinking water is 10 μg/l, but contries like pakistan and bangladesh are still striving to achieve the interim limit of 50μg/l before to stringen their limit to 10μg/l (WHO, 1993; USEPA, 2000). Exposure to As greater than the standards can cause serious ailments in the consumers like the symptoms of skin, renal, hematological, cardiovascular and respiratory disorders (Smedley and Kinniburg, 2002). More than the 90% of the remote population of Bangladesh is exposed to As contaminated water (Khan et al., 2000) and is a big menace to about 27% of the population overall (Ahmed, 2001; Smith et al., 2000).

Since 2000 Pakistan has started many programs to assess As in its drinking waters and has received shocking reports as groundwater in many parts of Pakistan are badly contaminated with As (PCRWR 2003, PCRWR 2004). Arsenic contamination levels were notoriously high in most of the areas of Pakistan. Southern Punjab usually and district

Rahimyar khan particularly were found worst hit by the As contamination. Other districts with alarming concentration of As in drinking water included Muzaffargarh, Bahawalpur, Multan, Gujranwala, Sheikhupura, Kasur and Lahore (Nickson et al., 2005). Many mitigations programs were initiated in response to this menace. Government of Pakistan in collaboration with UNICEF has started a national program for arsenic mitigation in the country (Ahmed et al., 2004; Nickson et al., 2005; Anitha, 2006). About 36% of Sindh and 20% of Punjab is exposed to the higher arsenic contents in drinking water (Islam-ul-haq et al., 2007).

CO-PRECIPITATION TECHNIQUES

Many methods are used to remove arsenic from drinking water which range from small household to a large community level plant. Principles of oxidation, coprecipitation, adsorption, membrane and ion-exchange are involved in majority of arsenic removal plants. Due to some technical reasons, hi-tech process, higher operational costs and need of well-trained staff, ion exchange & membrane purification equipment are less suitable for rural population in Pakistan. Furthermore, ion exchange plant is relatively less effective in removing As cations as there are several other competing cations are present in drinking water. Although membrane filtration technique is highly effective but its hi-tech process, higher operational costs and need of well-trained staff make it inappropriate for population in rural areas of Pakistan. So oxidation and co-precipitation techniques are the best options to be easily adopted in a third world country like Pakistan (Ravenscroft, 2001; Hering et al., 2000; Luqman et al., 2013).

In the past few years many small scale methods has been developed and successfully adopted in rural areas of India and Bangladesh and which are good options for Pakistan to be adopted for arsenic removal in rural areas.

Coagulation and flocculation

This method involves the co-precipitation and subsequent coagulation by using cheaper and locally available chemicals like Alum, iron sulphate and iron chloride. Easily and cheaply available chemical is added to the water, mixed gently and then stirred slowly. Micro flocs of hydroxides of used chemical appear instantly and grow bigger to settle down as we continue stirring. During this process, Arsenic (V) anions electrostatically get attracted and adsorbed onto the flocks. As (III) is hard to remove, needs pre-treatment of water to convert it into As (V) by using oxidants like manganese dioxide and ozone. Usually sedimentation and occasionally filtration is used to completely remove out the flocs.

Coagulation involves following chemical reactions

$$Al_2(SO_4)_3.18H_2O \longrightarrow 2Al^{+++} + 3SO_4^{--} + 18H_2O \quad (6)$$

$$2Al^{+++} + 6H_2O \longrightarrow 2Al(OH)_3 + 6H^+ \quad (7)$$

$$H2AsO4^- + Al(OH)3 \longrightarrow Al\text{-}As(complex) + Other\ Products \quad (8)$$

Similar reactions occur in case of other chemicals like $FeCl_3$

Jerry Can System (JCS)

Principles of adsorption and subsequent precipitation and sedimentation are used in jerry can system to remove As from drinking water to the desired limits. This arsenic removal system is was fabricated and tested successfully at the University of Colorado. It has variable capacity from 10-50L as per convenience and requirement. Iron fillings are used in the JCS for arsenic removal process, through which water passes and directly contact followed by vigorous shaking for 45 minutes or keeping the water stagnant for three hours. This jug can be used about 100 times before replacing iron filling to make it workable again. After successful lab tests, the JCS was failed to remove As to the desired limits in the field tests. Subsequent research has revealed that addition of iron sulphate powder along with fillings will make the system more effective and will successfully remove As to the desired limits (Hurd. 2001). Its total life time cost is about (34485 PKR) and its total production is 73000 litre, costing about 47 paisa/litre (Table 1). Its overall cost effectiveness makes it highly adaptable in rural areas of pakistan.

Arsenic Removal Using Bottom Ash (ARUBA)

In this system bottom ash is used in arsenic removal. Coal ash (waster product) is cheaply available from coal fired power plants. Particles of coal ash are layered with $Fe(OH)_3$, which makes it highly attractive for As to adsorb on to form FeAsO. This iron arsenate is insoluble in the water and precipitates, which can be filtered out. Laboratory experiments in Berkeley Lab were highly successful and they have reduced the iron contents of 100 liters of water from 500 ppb to 10 ppb by using only 30 g of the coal ash (BAAG, 2007). Aruba was highly successfully used in many areas of Bangladesh where it has reduced the As contents from 600 ppb to 10 ppb. ARUBA is a community level plant and can be used in small villages in Pakistan as central water source from where villagers can buy water at cheaper rates. Total cost of ARUBA is very low (8385 PKR) as compared to its production i.e. 73000 L, costing about only 12 paisa per litre. Its cheaper initial and total cost make it highly adaptable for our masses.

Solar Distillation

In solar distillation system, sunlight is used to cause evapaoration of the water and subsequent condensation collets the pure water. It is poor man's reverse osmosis plant. Solar still is eco-friendly trustable and promising device for our remote populations in Pakistan especially in the scenario of energy shortage and climate change. Conventional solar stills using direct sunlight may not be as effective to purify water at most of the time. But using innovative techniques to increase the energy throughput of solar light into the device makes it highly successful for arsenic removal and other contaminants. Recently lots of work has been done on this by using compound parabolic concentrators (CPCs) to direct maximum light on the device. A software has also been developed to compute out the increase in output of water due to reflectors of different heights based on the properties of reflector material and sunlight characteristics. It has also helped to develop effective solar stills. For a reflector 2.5 times the width of the still, the output per unit area per day roughly triples while increasing the cost only 10%, requiring only nominal maintenance (weekly tilts), demonstrating that CPCs are extremely economical in producing solar distilled water (Pearce and Denkenberger, 2006). Cost of arsenic free water ferom solar still is only 20 paisa/litre, which is highly attracive price for absolutely pure water and is readily compliant for our rural areas.

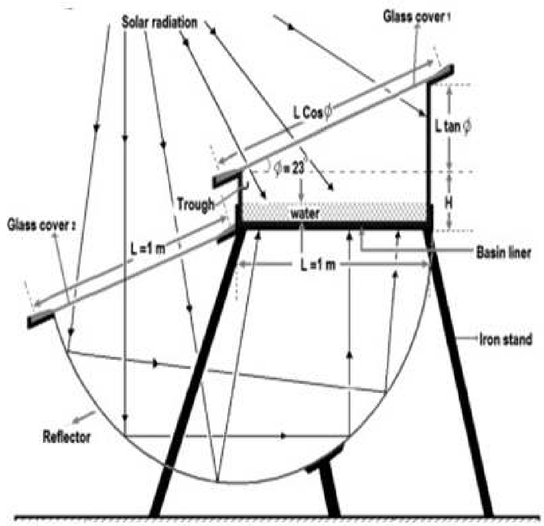

Figure1: Solar distillation using CPCs (Rahul, 2011)

Gravity Flow Arsenic Removal Filter

In this simple single step method, two plastic pitchers are used, placed on one another. In the upper pitcher filtration process is achieved while the lower one is collecting pot. In the upper pitcher a bed of silver coated sand is placed on the bottom. Above this bed different arsenic removing media can be used. Water is poured into the upper pitcher, which percolates through the media and sand bed by natural gravitational pull and passes through the bottom slits into the lower collector pitcher. This filtration system is best for those rural areas in Pakistan where there is no consistent supply of water. Different test has proved that this filtration system can remove arsenic from water for up to 25 days depending on the quality of water, filtering about 300L of water before renewal of the media and bed (Tahir, 2004). Although this method is very easy, but little bit expensive counting about the life time expense of fabrication and consumables to prtoduce 73000 L of As free water is 156050 pakistani rupees. It produces As free water at the rate of 2.13 Rupees per litre, which is little bit expensive. But this expense can be rought down by establishing bulk production of silver coated sand under government cap.

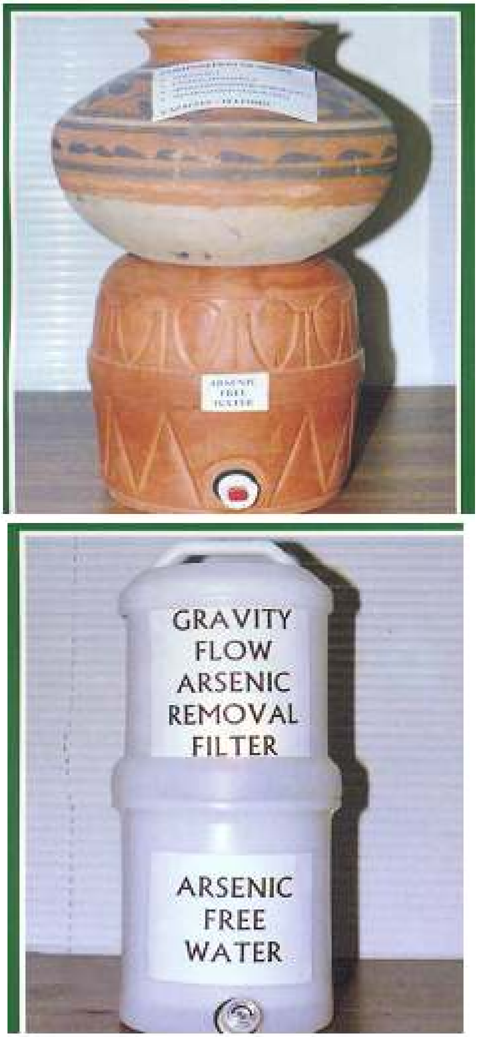

Figure 2: Gravity flow As removal filter

Kanchan Arsenic Filter

The Massachusetts Institute of Technology (MIT) has fabricated the kanchan filter after several years of research and field experiments. Iron nails, brick chips, fine sand, coarse sand and gravel filter effectively remove arsenic in single step in the Kanchan filter. Kachan filter is large bucket shaped and water is poured from the upper part of the filter and arsenic free water is collected from the bottom tap. Its capacirt is 15-20 liters/hour (Table 1). This is most cheaper way to clean As contaminated water and costs only 0.05 PKR per litre (Nagi, 2006).

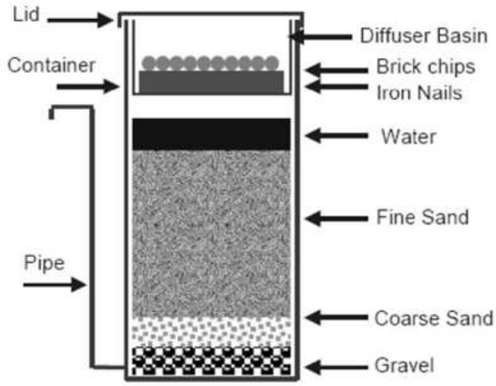

Figure 3: Cross section of Kanchan Arsenic filter

Table 1: Relative capacities and cost effectiveness of As removal technologies

Technology	Capacity (Litres)	Total lifetime cost (Rupees)	Lifetime production (Litre)	Cost of water (Rupee/Litre)	Reference
Jerry Can System	50	34485	73000	0.47	Hurd 2001
ARUBA (Arsenic Removal Using Bottom Ash)	50	8385	73000	0.12	BAAG 2007
Solar Still (long life)	50	29106	146000	0.20	Pearce and Denkenberger 2006
Gravity flow Arsenic removal filter	12	156050	73000	2.13	Tahir 2004
Kanchan Arsenic filter	20	4323	80300	0.05	Nagi 2006

CONCLUSION

These indigenous arsenic removal technmologies are highly productive in the regional conditions in India, Nepal and Bangladesh. Their suitability and eficiency varies depending upon the water quality and local conditions. These techniques can be higly valuble to be used in As hit rural parts of the Pakistan with essential alterations according to our local conditions and As contents in drinking water. The low cost of water treatment and ease of execution of the processes of these technologies will play a vital role in their adoption in Pakistan. These technologies can be prolifically kept at lower cost to make them affordable for our masses by fabricating them with locally available resources and use of commonly available chemicals like Phatkari (Alum) and Iron sulphate, where necessary. These cost effective and sustainable technologies have their own weaknesses and strengths, but can be easily modified and polished according to our own local conditions to adopt successfully in fight with As contamination.

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