

Groundwater Arsenic in South-East Asia: Extent, Effects and Solutions

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Abstract: Groundwater is a clean source of drinking water. However, the presence of elevated concentrations of inorganic arsenic in groundwater, particularly in the regions of Bangladesh and the eastern part of India, is a cause for concern. Most people residing in this geographic location have no alternative but to drink arsenic contaminated groundwater, which has arsenic concentrations above the permissible limit (0.01 mg/L). As a result, approximately 123 million people in India and Bangladesh face higher risk of cancer, as well as risk other cardiovascular and neurologic diseases. Many techniques for getting rid of arsenic from drinking water are available. In this paper, we focus on the region of eastern India and Bangladesh to examine the extent of arsenic contamination and its toxic effects on humans, explore the sources of arsenic in this geography, and compare and contrast the technologies of arsenic removal.

Key words: Arsenic, health hazards, groundwater, agriculture, Bangladesh, India.

Introduction

The contamination of surface and groundwater by industrial and agricultural by-products, heavy metals, mining and radioactive wastes, and chlorinated solvents has become one of the global concerns. Dissolved chemicals (such as fluoride, nitrate, pesticides), heavy metals (such as lead, mercury, zinc, arsenic, cadmium, nickel), and non-aqueous phase liquids and bio-colloids can contaminate and pollute natural water resources (Mandal and Sengupta, 2005; Wilkin et al., 2005; Huang et al., 2010). Arsenic (As) contamination is a big threat in South-east Asian countries, where large stretches of deltaic aquifers containing inorganic arsenic have been identified (Figure 1). A recent study highlighted that approximately 80 million people in Bangladesh and 43

million people in Eastern India are afflicted by diseases that can be attributed to arsenic (SOS, 2010). It has been asserted that the high level of arsenic in groundwater in this region (>0.01 mg/L) is the primary cause of this large scale epidemic, since groundwater is the primary source of drinking water in the Gangetic floodplain areas of West Bengal, India and Bangladesh (Dhar et al., 1997; Smedley and Kinniburgh, 2002; Chakraborti et al., 2002; Mukherjee et al., 2006; Samadder and Subbara, 2007; Brammer and Ravenscroft, 2009).

The purpose of this article is to provide an improved understanding of the arsenic contaminated areas, the effects of arsenic toxicity, the source and detection of arsenic, and the ongoing remedial measures for reducing arsenic contamination in Bangladesh and eastern part of India. We explore the traditional and

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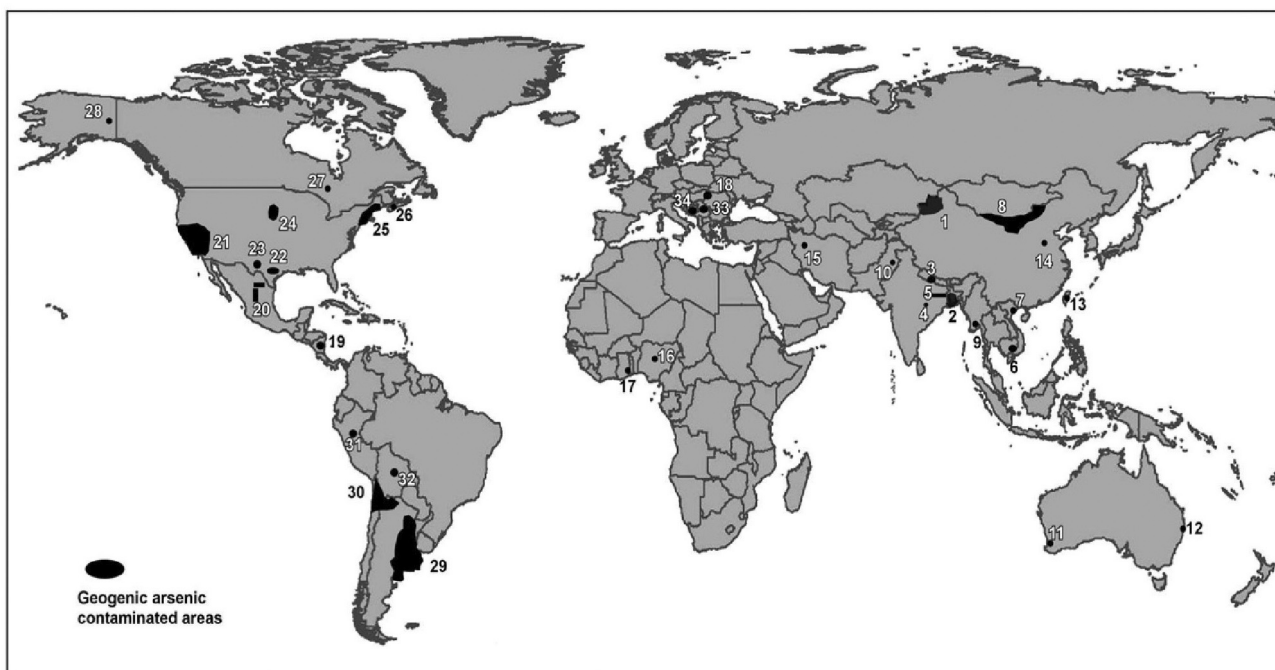


Figure 1: World map showing the major areas contaminated with naturally occurring arsenic (modified from Mukherjee et al., 2008).

1. Xinjiang, China, 2. Bengal Basin, India and Bangladesh, 3. Terai plains, Nepal, 4. Donargarh rift zone, central India, 5. Middle Gangetic plain, India, 6. Mekong plain and delta, Cambodia, Vietnam and Laos, 7. Red river delta, Vietnam, 8. Yellow river plain, Inner Mongolia, 9. Irrawady delta, Myanmar, 10. Indus alluvial plains, Pakistan, 11. Perth, Australia, 12. Stuart Point, New South Wales, Australia, 13. Taiwan, 14. Shanxi, China, 15. Kurdistan, Iran, 16. Nigeria, 17. Ghana, 18. Great Hungarian Plain, Hungary and Romania, 19. Nicaragua, 20. Lagunera region, northern Mexico, 21. Southwestern USA, 22. Gulf Coastal Plain, southern Texas, USA, 23. Southern High Plains, northern Texas, USA, 24. Inner Plains, Dakota and Minnesota, USA, 25. New England, USA, 26. Nova Scotia, Canada, 27. Ontario, Canada, 28. Fairbanks, Alaska, USA, 29. Chaco-Pampean plain, Argentina, 30. Atacama dessert area, northern Chile and Argentina, 31. El Zapote, Peru, 32. Andean highlands, Bolivia, 33. Serbia and 34. Albania.

current methodologies of arsenic removal in order to analyze their efficiencies, cost effectiveness and ease of use. This review will help policy planners with a focussed insight into the problems and extent of arsenic contamination, the effect on the general populace, and the proposed solutions.

The Extent of Arsenic Contamination

Arsenic contamination is particularly prominent in India and Bangladesh in terms of magnitude of health problems and the size of population are being affected by it. The problem is acute – the maximum arsenic concentration in these regions, particularly near Kolkata in India, and near Noakhali in Bangladesh, were recorded as 3.7 mg/L and 4.73 mg/L respectively (Chakraborti et al., 2010; Brammer and Ravenscroft, 2009; Vu et al., 2003; Baruah et al., 2003; Magalhaes, 2002). In Bangladesh, groundwater of 60 (out of 64) districts

has been identified as having arsenic contamination above the standard levels ($As > 0.01$ mg/L). The most vulnerable areas are located in Satkhira, Munshiganj, Chandpur, Laksmipur and Noakhali, where 70-90% of the analyzed samples show an arsenic concentration of more than 0.1 mg/L (Jiang et al., 2013). The current drinking water standard for arsenic is 0.05 mg/L in India and Bangladesh (The World Health Organization standard is 0.01 mg/L). It was during the 1970s when groundwater arsenic contamination was identified as being above the permissible limit in West Bengal and Bangladesh (Chakraborty and Saha, 1987; UNICEF, 2008; UNICEF, 2010; Blacksmith Institute, 2010). The recently released Indian standard IS 10500:2012 (the previous one was published in 1983) has revised the acceptable limit to 0.01 mg/L which can be relaxed to 0.05 mg/L in absence of an alternate source. Incidentally, in the affected areas, groundwater was not only being used for drinking purposes but also for irrigated farming

of rice and vegetables, thus leading to occurrence of a higher level of arsenic in these crops (Brammer and Ravenscroft, 2009).

Arsenic in saturated and unsaturated subsurface zones can not only move with water in dissolved form but also can be absorbed with finer soil particles (colloids), and mobilized with groundwater, can flow to longer distance as shown in Figure 2. In Bangladesh and eastern part of India, it is most likely that the inorganic arsenic had transported further in saturated as well as partially-saturated zones along with mobile soil colloids (arsenic attached with particle size $<10^{-5}$ m and $>10^{-7}$ m) (Izabela et al., 2009; Sharma et al., 2011). Recent studies have shown that the colloidal particles would move longer than expected with the water flow (Sen and Khilar, 2006; Sharma et al., 2008b).

The presence of air-water interface in the unsaturated zone (a common scenario in the event of groundwater pumping and rainfall/infiltration events) can also play a critical role in the mobilization of colloidal particles from the sediment/soil surfaces (Sharma et al., 2008a; Sharma et al., 2008c). The force generated by moving air-water interfaces could be strong enough to detach the colloidal particles and allow further transportation (Izabela et al., 2009; Sharma et al., 2011). The constant withdrawal of groundwater from the contaminated/uncontaminated aquifers for drinking and irrigation purposes in the arsenic affected areas lowers the water table (which creates a pressure difference) and increases the transport of contaminant attached colloids with water flow (at the air-water interfaces and in suspension) towards the uncontaminated aquifers (vertically) or to a new location (horizontally).

Studies on groundwater flow simulations suggest that the deeper aquifers (>150 m deep) of Bengal Basin are highly vulnerable to downward migration of high-As groundwater from shallow aquifers due to increased withdrawals of deep groundwater for irrigation (Radloff et al., 2011). As a result, new aquifers are getting contaminated and at the same time the arsenic contaminated areas are gradually expanding. However, a detailed investigation is needed to identify the role of colloidal particles for attachment of arsenic with them and transported/relocated in the subsurface system.

A study by Chakraborti et al. (2002), which was based on several government reports and local newspapers in the 1980s-90s, showed that the West Bengal government Health Directorate was totally unaware about the mitigation measures of arsenic contamination. Recently, some surveys of tubewells for their contamination level (by abandoning the arsenic producing wells) have helped in the remedial measures for the people affected by arsenic problem in Bangladesh and India (Mathieu et al., 2010; Akter and Ali, 2011; Mudhoo et al., 2011). Few other programmes like Sanitation, Hygiene Education and Water Supply in Bangladesh (SHEWA-B, Arsenic Mitigation in Bangladesh – Unicef), Joint Plan of Action have been initiated by the two governments with the help of private agencies for identification and mitigation of arsenic problem in Bangladesh and India (Mathieu et al., 2010; Akter and Ali, 2011; UNICEF, 2008; UNICEF, 2010; Blacksmith Institute, 2010). Approximately, five million tubewells were tested for arsenic contamination to check the permissible arsenic contamination level (0.05 mg/L)

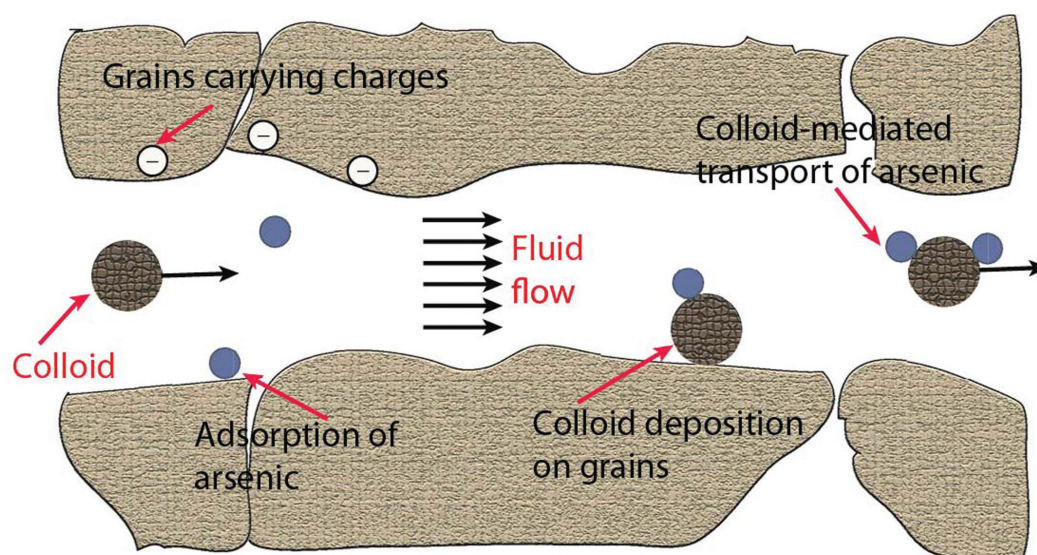


Figure 2: Flow and transport of colloidal particles attached with arsenic.

in Bangladesh. The government officials marked the high concentration arsenic producing tube-wells with red colour (>0.05 mg/L) and the low concentration arsenic producing tube-wells with green colour (<0.05 mg/L). But, till date, no concrete arrangement on As-free drinking water supply has been made to keep the people safe from this natural calamity (Mathieu et al., 2010; Akter and Ali, 2011; UNICEF, 2008; UNICEF, 2010; Blacksmith Institute, 2010; World Bank, 2005). In addition, many workshops, seminars, symposiums, and discussion sessions were organized to initiate the arsenic mitigation options.

The Effects of Arsenic Contamination

A vast body of literature has reported the severe health consequences when arsenic is taken beyond the permissible limits (0.05 mg/L). Commonly occurring diseases due to ingestion of high level of arsenic through digestive system are melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsum, gangrene, and skin cancer including cancers of liver, lung, bladder, or kidney (Dhar et al., 1997; Smith et al., 1992; Kazi et al., 2009). Arsenic intake to human body may occur either directly (by drinking or by cooking foods with arsenic rich water) or indirectly via food chain (i.e. through crops grown from arsenic contaminated water and arsenic rich sewage). This phenomenon is described in Figure 3.

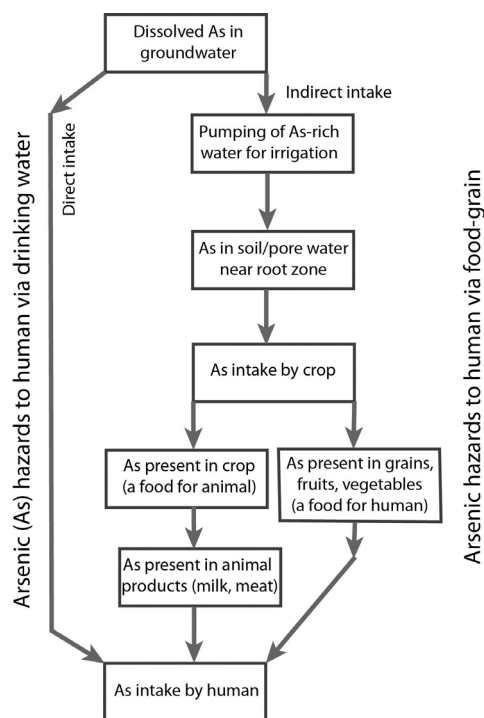


Figure 3: Pathways of arsenic intake by human.

Direct Effects of Arsenic Intake

A continuous exposure to arsenic via drinking water leads to serious chronic diseases. Long-term intake of arsenic at even lower rates (<0.01 mg/L) in drinking water can adversely affect human health and lead to arsenic induced cancer (Liao et al., 2009). A comparative study showed that people drinking arsenic contaminated water had higher arsenic level in their hair and blood samples compared to those drinking arsenic-free water (Kazi et al., 2009). Arsenic in drinking water can impair the immune response to microbial infection (Kozul et al., 2009). Moreover, epidemiologic studies suggested that arsenic in drinking water may affect pregnancy and infant health (Rahman et al., 2010). These studies further demonstrated that the number of stillbirth and infant mortality rate tends to increase constantly among pregnant women who were drinking water with higher levels of arsenic.

Indirect Effects of Arsenic Intake

Arsenic contaminated groundwater used for irrigation increases the arsenic level in crops (such as rice, wheat, vegetables) and the consumption of these agriculture products can cause severe health problems (Brammer and Ravenscroft, 2009; Williams et al., 2006; Zhu et al., 2008; Bhattacharya et al., 2010; Hua et al., 2011). Table 1 shows the incidence of arsenic content in crops commonly grown in arsenic affected area of West Bengal, India (Bhattacharya et al., 2010). Rahman and Hasegawa (2011) showed that by using arsenic-contaminated groundwater with 0.318 – 0.643 mg As/L in water for irrigating crop lands, an initial arsenic level of 5.7 – 9.7 mg/kg in soil may rise up to 83 mg/kg. Bhattacharya et al. (2010) reported the highest arsenic content in potato (0.654 mg/kg) and the lowest in turmeric (0.003 mg/kg) as compared to other crops in Table 1, although the arsenic concentration limit for these crops was within the food hygiene concentration limit of 1.0 mg/kg (Abedin et al. 2002; WHO). In arsenic-affected area of Bangladesh, vegetables were found with arsenic content between 0.07 and 3.99 mg/kg, and average arsenic content in rice (an important cereal for the people of this region) was found to be 0.496 mg/kg (Jiang et al., 2013; Das et al., 2004; Meharg and Mazibur, 2003).

Brammer and Ravenscroft (2009), in their excellent review on arsenic contents in agricultural crops, asserted that among all the crops, paddy/rice was the most affected crop by arsenic contamination because it is a commonly grown crop in the arsenic affected area and at the same time requires standing water (which

Table 1: Mean arsenic content of crops grown in arsenic affected area of West Bengal, India

<i>Crops</i>	<i>Number of samples</i>	<i>Mean arsenic content (mg/kg)</i>
Brinjal (eggplant)	16	0.279
Cabbage	14	0.209
Cauliflower	22	0.257
Garlic	18	0.126
Green chilli	29	0.085
Lemon	30	0.012
Lentil	14	0.096
Mustard seed	18	0.198
Onion bulb	23	0.162
Papaya	26	0.258
Pea	23	0.141
Potato tuber	23	0.654
Radish	21	0.344
Rice grain (Aman)	18	0.324
Rice grain (Boro)	21	0.451
Spinach	22	0.257
Tomato	29	0.084
Turmeric	14	0.003
Wheat	8	0.129

Modified from Bhattacharya et al., 2010.

is generally arsenic contaminated) throughout the crop growth period.

The indirect effects of arsenic contamination are important because even if the drinking water is not contaminated, the consumption of contaminated food can lead to arsenic related diseases. For example, in Bangladesh and West Bengal, an average person consumes about 450 gms of rice per day. With arsenic level of >0.08 mg/kg, food intake becomes a dominant alternative way of arsenic poisoning for populations exposed to low or no arsenic in drinking water (Marchiset-Ferlay et al., 2012; Mondal and Polya, 2008).

The Sources of Arsenic

The upper layer (70-100 m) of the ground's subsurface system is the most affected part polluted by arsenic in

Bangladesh and India (Van Geen et al., 2003; Chakraborti et al., 2010; Mudhoo et al., 2011; Magalhaes, 2002; Baruah et al., 2003). Arsenic retention in soil/sediment also depends on the presence of iron and aluminum oxides, redox-potential, pH and the type of soil in the subsurface (Magalhaes, 2002; Baruah et al., 2003). Geochemical reactions such as oxidation-reduction, precipitation-dissolution, and adsorption-desorption are also responsible for the presence of arsenic in groundwater (Wilkie and Hering, 1996; Nickson et al., 2000; Magalhaes, 2002; Baruah et al., 2003). The possible sources and routes of arsenic in subsurface systems are summarized in Table 2. Interestingly, in India (the West Bengal and part of Chhattisgarh) and Bangladesh, the presence of arsenic in groundwater is not due to mining, industrial, or thermal activities, rather, it can be attributed to the geochemical reactions of aquifer sediment (such as pyrite and arsenopyrite) under aerobic conditions and by reductive dissolution of sorbed arsenic from ferric-oxyhydroxide (Vu et al., 2003; Acharyya et al., 1999; Nickson et al., 2000). Arsenic present in alluvial Ganges river aquifers was reported to be derived from oxidation of arsenic-rich pyrite in aquifer sediment. Arsenic concentration has also been observed to vary with the depth from ground surface (Acharyya et al., 1999).

Acharyya (2002) asserted that the source of arsenic in the Gangetic plain of West Bengal was not from locally present sulphide but from weathered acid magmatic rocks of the Dongargarh rift belt (as the arsenic-rich pyrite was not present there or occurred in minuscule quantity). In the arsenic contaminated area of Dongargarh rift belt, iron concentrations were low in shallow and deep tube wells (0.01-0.5 mg/L), which reduced the arsenic mobilization in groundwater. So, arsenic was mainly released from weathering and decomposition of arsenic enriched rocks of Dongargarh rift belt, but it was likely that the released arsenic attached with mobile colloids (Chakraborty and Saha, 1987; Mathieu et al., 2010; Akter and Ali, 2011; UNICEF, 2008; UNICEF, 2010; Blacksmith Institute, 2010; World Bank, 2005; Sharma et al., 2011) or

Table 2: Major sources and pathways of arsenic in subsurface systems

<i>Anthropogenic</i>			<i>Geogenic</i>	<i>Biogenic</i>
<i>1. Agriculture</i>	<i>2. Industry</i>	<i>3. Other</i>		
Pesticides	Timber treatment	Sewage	Geothermal activities	Plants
Insecticides	Toners	Smelting	Volcanic activities	Agricultural organisms
Seed treatment	Paints		Rock and mineral weathering	Micro and aquatic biota
Cattle dip	Electro plastic			
Fertilizers	Chemicals			

remained adsorbed in iron-oxyhydroxide and only mobilized to groundwater by their reductive dissolution under a conductive environment (Acharyya, 2002). In Bangladesh, microbially mediated reductive dissolution of Fe(III)-oxyhydroxides, facilitated by electron donors, e.g. organic matter and/or dissolved organic carbon (DOC), under moderate to strong reducing conditions was reported widely as primary mechanism of releasing arsenic in groundwater (Jiang et al., 2013). Human activity (heavy pumping of groundwater for drinking or irrigation and excavation of ponds) has also been suggested as being responsible for the presence of arsenic over a range of well depths (Neumann et al., 2009; Benner, 2010).

Locally grown crops also affect the presence of arsenic. The major crop grown in our focal areas is rice, which needs standing water in the fields. The inundation of water in the rice field restricts the aeration which permits arsenic to remain in soluble and mobile forms (As^{3+}) for plant uptake. Other major crops such as wheat and maize do not require flooded water and thus have sufficient aeration. During the aeration process, arsenic transforms to a solid form of arsenate (As^{5+}) which is not readily available for uptake by crops like wheat and maize. The presence of these factors depends on geographic location which is further influenced by years of agriculture operations (Brammer and Ravenscroft, 2009).

Overall, the predominant source and mobilization of arsenic into the groundwater in the focal area seems to be due to the transport and mobilization with river flows, and subsequent deposition with sediment to the river plain, following its infiltration into the groundwater gradually by mobilization mechanisms. However, the behaviour of arsenic in agricultural crops and food chain is not well understood. The effect of crops grown in areas of higher arsenic levels on human health is an open area for further research.

Detecting Arsenic

Arsenic can occur in many different forms, depending on the chemical properties of water and sediment. Depending on pH and redox potential, arsenic could be found as arsenate (As^{5+}) and arsenite (As^{3+}). Both forms of arsenic can easily occur in the environment, but As^{5+} is abundant in oxygenated surface water and As^{3+} can be abundant in reducing groundwater environment (Smedley and Kinniburgh, 2002; Vu et al., 2003). Arsenite is about 60 times more toxic than arsenate and tends to be more mobile in the environment (Vu

et al., 2003; Jain and Ali, 2000). Arsenic detection is predominantly based on the reaction of arsine gas with some chemical agent to form a coloured complex (Arora et al., 2009; Diesel et al., 2009; Joshi et al., 2010). The colour intensity is visually compared by colour-coded charts which allow a quick measurement of the arsenic contamination level at any site. To detect arsenic concentration as low as 0.05 mg/L, bacteria based biosensor is a potential alternative to the abiotic sensor (Diesel et al., 2009). Recently, Joshi et al. (2010) developed an arsenic field test kit based on whole-cell biosensors with change in pH. Although, a range of arsenic detection techniques and instruments have been successfully used for a while, the general populace still needs a concrete solution which can help alleviate the problem of drinking arsenic contaminated water. The subsequent section highlights some of the commonly used methods for the treatment of arsenic contaminated water.

Treatment of Arsenic Contaminated Water

A number of techniques have been developed for removing arsenic from drinking water. These are based on coagulation (Hansen et al., 2006; Balasubramanian et al., 2009), membrane filtration (Lohokare et al., 2008; Han et al., 2002), chemical precipitation (Borho and Wilderer, 1996; Zaw and Emett, 2002; Dutta et al., 2005), ion exchange (Kim and Benjamin, 2004; Baciocchi et al., 2005), adsorption using various adsorbents such as iron oxide, nano zero-valent iron (nZVI) supported on activated carbon, activated alumina, naturally available red or laterite soil (Lien and Wilkin, 2005; Henderson and Demond, 2007; Mohan and Pittman, 2007; Ko et al., 2007; De et al., 2009; Jovanovic and Rajakovic, 2010; Chowdhury and Yanful, 2011; Choudhury, 2011; Wu et al., 2011; Jain and Singh, 2012), and bio-sorption techniques (Mondal et al., 2008; Boddu et al., 2008). Arsenate (As^{5+}) can be removed more efficiently at relatively low cost by coagulation method using durable chemical powder, although it produces toxic sludge. Membrane filtration is another efficient method capable of removing arsenic of any form without producing toxic waste (Mohan and Pittman, 2007), but demands high maintenance and operation cost. Arsenic can also be removed by *in situ* oxidation/precipitation processes at low-cost, but it is relatively a slow process and removes mainly the arsenate (As^{5+}) form of arsenic. Arsenate can also be removed from water by ion exchange process which is relatively expensive. Adsorption has also been asserted

as an effective technique for groundwater arsenic removal (Mohan and Pittman, 2007).

Several types of biological (e.g. biomass, macroalgae, cellulose sponge, chitin) and chemical adsorbents (e.g. iron and iron compounds, activated alumina, activated carbon) are also being used for arsenic removal. Macroalgae can also be used for household treatment purpose and it can remove up to 80-90% of arsenic (Bundschuh et al., 2010). Iron loaded vegetable biomass has also been suggested as a good option for arsenic removal (Silva et al., 2009), however drying and grinding of biomass adds an additional cost (and an additional effluent to be treated). Iron or its compound such as zero-valent iron (ZVI), iron oxides, hydroxides, and oxyhydroxides are the most widely used inexpensive adsorbents with higher arsenic removal efficiencies (Mohan and Pittman, 2007). ZVI is normally used as permeable reactive barrier for treatment of arsenic contaminated water from the subsurface zone (Lien and Wilkin, 2005; Henderson and Demond, 2007) and also used in small-scale drinking water system in the rural area (Lackovic et al., 2000).

These studies showed that ZVI has high arsenic removal efficiency for field operation. The permeable reactive barriers are also effective for arsenic removal at low influent pH, low redox potential, and low influent concentration of nitrate, chloride, and alkalinity (Henderson and Demond, 2007). Factors such as aerobic condition and low pH are more favourable for removing arsenate than that of arsenite (Sun et al., 2006; Tanboonchuy et al., 2011). Although, formation of the corrosion products of iron plays a critical role in arsenic removal mechanism (Manning et al., 2002), the main disadvantage of using ZVI is that it is time consuming, i.e. the reaction time is of the order of several days for complete removal of arsenic (Biterna et al., 2010). Recently, nZVI or activated carbon adsorbent was introduced by loading nZVI on activated carbon and this modification showed higher removal efficiency for arsenite than arsenate at neutral pH. The presence of Ca^{2+} and Mg^{2+} in water further enhances the arsenate removal, but Fe^{2+} decreases the arsenite removal efficiency (Choudhury, 2011).

Traditionally used low cost treatment processes for arsenic removal include wood charcoal and sand, sedimentation, coagulation process, lime-softening, natural inorganic gradient and household arsenic filter. Several other community level devices have also been reported for the treatment of arsenic contaminated water in Bangladesh and India (Kumar et al., 2008;

Rott and Kauffmann, 2008). In addition to the above mentioned treatment processes of arsenic contaminated water, other economically viable techniques to access arsenic-free water in the affected parts of South-east Asia can be extracting arsenic-free water from deeper aquifers, harvesting natural rainwater, or supplying the purified arsenic-free river water (Islam et al., 2011). A comparison of important treatment processes, for a pH variation 6 to 8 is shown in Figure 4 (Mondal et al., 2006; Duarte et al., 2009). Figure 3 shows that As^{3+} removal by nZVI is the most effective method to treat arsenic contaminated water. Removal of As^{5+} was relatively easier and higher than the removal of As^{3+} for most of the technologies.

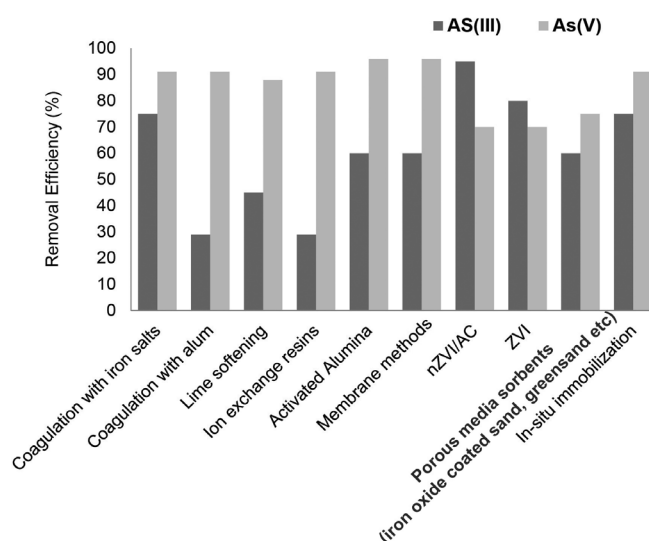


Figure 4: Comparison among arsenic removal technologies.

Conclusions and Future Directions

In South-east Asia, while research institutions and government organizations have been combating the effect of arsenic for more than three decades, yet very little progress is visible towards the mitigation of arsenic hazards for the affected people. Even today, in the Bengal Basin, more than 50 million people are consuming water characterized with higher arsenic levels of >0.05 mg/L. Moreover, there is an increasing trend of arsenic affected areas due to the changes in hydrological and geochemical regime causing further contamination of the extremely limited safe freshwater aquifers available. Therefore, a renewed interest in the study of arsenic, and a focus on how arsenic can be treated is necessary. Our study is aimed at partially fulfilling this need.

Studies show that the flow and transport of the arsenic attached colloidal particles could play an important role in contaminating adjacent locations in the subsurface system. Although methods for detection of arsenic contaminated waters (for aquifers and drinking water supplies), and removal technologies have been developed, very few of them are currently being used in affected locations of the South-east Asia because of limitations of use, as well as economic and political constraints. Several remediation measures (e.g. colour coding of hand pumps, emphasis on rain water harvesting, use of surface water) have been adopted for peoples in the concerned areas, but these are not effective in remedying the problem of arsenic. As a result, inhabitants in arsenic affected areas are at increased risk of cancer, cardiovascular, neurologic, and other diseases. Therefore, future research should be directed to the development and implementation of feasible arsenic removal technologies with establishment of necessary infrastructure and legislative framework in order to eradicate the menace of arsenic pollution in the affected areas.

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