



Review Article

## STATUS AND MITIGATION OF ARSENIC CONTAMINATION IN GROUNDWATER IN INDIA

C. P. Kumar<sup>1</sup>

<sup>1</sup>National Institute of Hydrology, Roorkee – 247667 (Uttarakhand) India

Correspondence should be addressed to C. P. Kumar

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### ABSTRACT

High arsenic concentrations in groundwater in different states of India have become a major cause of concern in recent years. The groundwater in the past was considered to be safe for drinking purposes, but now it is recognized that many shallow tube wells contain arsenic at concentrations higher than the safe limit set for drinking purpose by WHO (1993). It is becoming an emerging issue in the water supply and health related sectors of India. The purpose of this paper is to review the recent status of arsenic in groundwater in India and present various methods suitable to be adopted in mitigating its adverse effects on human health.

**KEY WORDS:** Arsenic, Contamination, Groundwater, Mitigation, Geogenic, Anthropogenic

### INTRODUCTION

Arsenic (As) is a metalloid element (atomic number 33) with one naturally occurring isotope of atomic mass 75, and four oxidation states (-3, 0, +3, and +5). In the aqueous environment, the +3 and +5 oxidation states are most prevalent, as the oxyanions arsenite ( $\text{H}_3\text{AsO}_3$  or  $\text{H}_2\text{AsO}_3^-$  at pH ~9-11) and arsenate ( $\text{H}_2\text{AsO}_4^-$  and  $\text{HAsO}_4^{2-}$  at pH ~4-10) (Smedley and Kinniburgh, 2002). Arsenic is widely distributed in nature and principally occurs in the form of inorganic or organic compounds. In soils, arsine gases may be generated by fungi and other related micro-organisms. Different forms of arsenic have different toxicities, with arsine gas being the most toxic form of the inorganic oxyanions, arsenite are the most toxic forms and arsenate, the less toxic forms. The organic (methylated) arsenic forms are considered least toxic. Exposure to inorganic compounds may occur in a number of ways through certain industrial effluents, pesticides, chemical alloys, combustion of fossil fuels, wood preservative agents, occupational hazards in mining and dissolution in drinking water. The most commonly found arsenic compounds in drinking water are arsenate or arsenite. However, groundwater is notoriously prone to chemical and other types of contamination from natural sources or by anthropogenic activities.

Arsenic contamination is a worldwide health problem due to its toxicity and the fact that it occurs at unhealthful levels in water supplies, particularly groundwater, in more than 70 countries (Ravenscroft et al., 2009) on six continents. Arsenic contamination of drinking water is a worldwide problem due to its damaging effects on health. These effects range from skin ailments to serious and dangerous diseases such as cancer. Continuing exposure to arsenic can cause damage to the human cardiovascular, gastrointestinal, dermal, hepatic, pulmonary, renal, neurological (ATSDR, 2000), reproductive system and respiratory systems (ATSDR, 2000; Mandal and Suzuki, 2002).

Reliable information on arsenic vulnerability and health effects are seldom available, but it is clear that in many nations of the world, arsenic in drinking water has been observed at concentrations greater than the WHO guideline value i.e. 10 µg/l (0.01 mg/l) or the prevailing national standards. The major issue of arsenic contaminated water is to find out the level of

contamination and it is not so easy because of no colour, no odour and no taste even in the highly contaminated water. Arsenite is more toxic (approximately ten times) than the arsenate due to the former's ability to react with sulfhydryl groups thereby increasing the residence time (Nagarnaik et al., 2002). Although there is no widely accepted mechanism of the release of arsenic in groundwater, but it has been accepted that majority including North-Eastern states of India is of natural, geological origin. The arsenic is considered to be closely linked with the oxidation-reduction process of pyrite and iron oxide.

The most important mitigation measure is prevention of further exposure by providing safe drinking water. Several schemes have been executed to contain and remove arsenic from groundwater used for household activities as well as irrigation and other uses.

### SOURCES OF ARSENIC CONTAMINATION

Arsenic is a natural constituent of the earth's crust and is the 20<sup>th</sup> most abundant element. The average concentration of arsenic in the continental crust is 1–2 mg/kg (Taylor and McLennan, 1985). Arsenic is released into the environment through natural processes such as weathering and volcanic eruptions, and may be transported over long distances as suspended particulates and aerosols through water or air. A range of arsenic compounds, both organic and inorganic, are introduced into the environment through geological (geogenic) and anthropogenic (human activities) sources (Figure 1). Small amounts of arsenic also enter the soil and water through various biological sources (biogenic) that are rich in arsenic. Although the anthropogenic source of arsenic contamination is increasingly becoming important, it should be pointed out that the recent episode of extensive arsenic contamination of groundwater in Bangladesh and West Bengal is of geological origin, transported by rivers from sedimentary rocks in the Himalayas over tens of thousands of years, rather than anthropogenic.

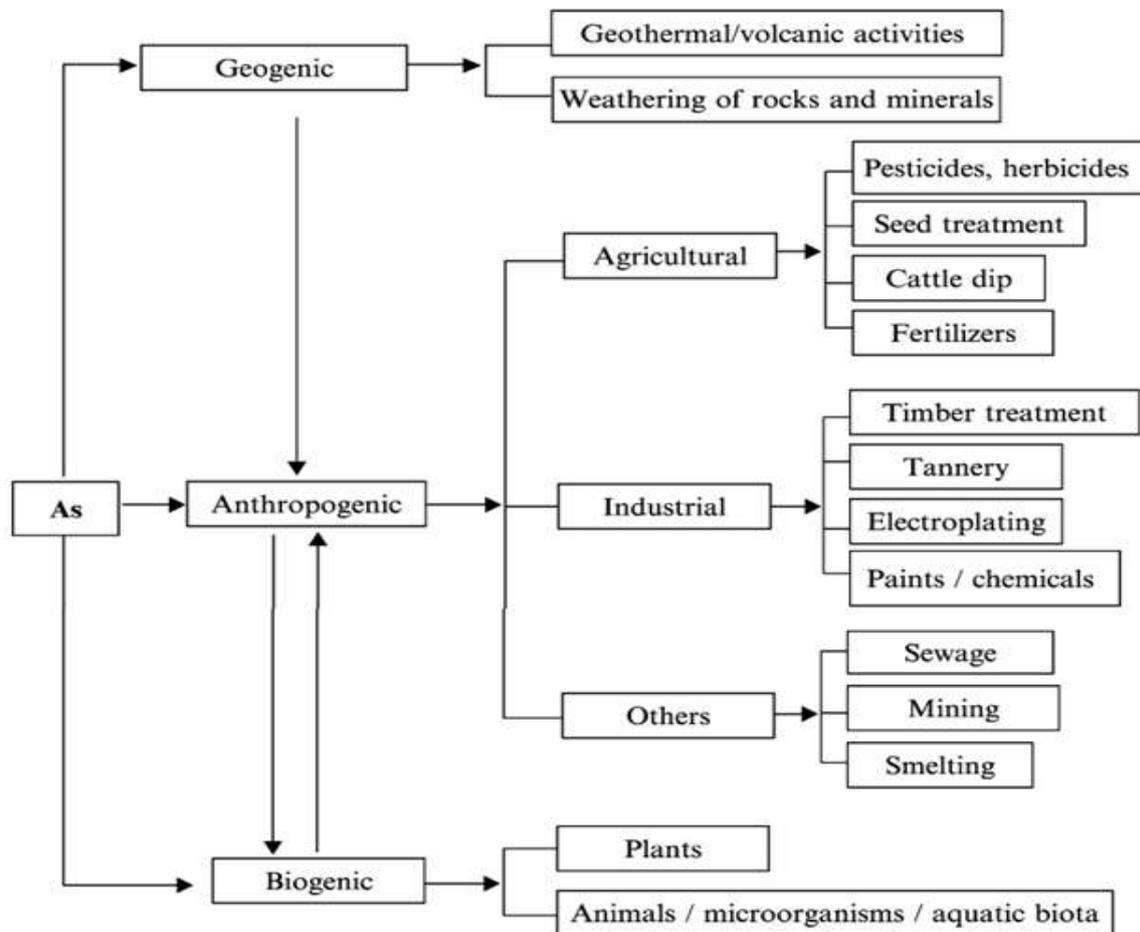


Figure 1: Major Sources of Arsenic

#### 2 Geologic Source

Arsenic is extensively distributed in geological materials, but with variable concentrations. An average concentration of arsenic in the continental crust of the earth is 1.5 to 2.0 mg/kg. The mean concentrations of arsenic in igneous rocks are 1.5 to 3.0 mg/kg and in sedimentary rocks, it ranges from 1.7 to 400 mg/kg (Smith et al., 1998). Arsenic ranks 52<sup>nd</sup> in crustal abundance and is a major constituent in more than 245 minerals (O'Neill, 1995). Arsenic is introduced into soil and water

during the weathering of rocks and minerals followed by subsequent leaching and runoff. Therefore, the primary source of arsenic in soil is the parent (or rock) materials from which it is derived (Yan-Chu, 1994).

### Anthropogenic Sources

Arsenic is introduced into the environment through numerous anthropogenic happenings. These sources release arsenic compounds that differ greatly in chemical nature and bioavailability. Major sources of arsenic discharged onto land originate from commercial wastes (40%), coal ash (22%), mining industry (16%), and the atmospheric fallout from the steel industry (13%) (Eisler, 2004). Arsenic trioxide ( $As_2O_3$ ) is used extensively in the manufacturing of ceramic and glass, electronics, pigments and antifouling agents, cosmetics, fireworks, and Cu-based alloys (Leonard, 1991). Arsenic-containing pesticides and herbicides release arsenic containing liquid and solid wastes that, upon disposal, are likely to contaminate water bodies and soil.

### Biogenic Sources

Biological sources contribute only small amounts of arsenic into soil and water ecosystems. However, plants and micro- and macro-organisms affect the redistribution of arsenic through their bioaccumulation (e.g., biosorption), biotransformation (e.g., bio-methylation), and transfer (e.g., volatilization).

### Status of Arsenic Contamination in India

The presence of arsenic in groundwater in India is the most serious health hazard. According to the North Eastern Regional Institute of Water and Land Management (NERIWALM), a staggering 32,077 water sources have been contaminated with naturally occurring inorganic materials like arsenic, iron and fluoride (Chakraborty, 2007). A recent study shows that out of three blocks of Golaghat district of Assam, Podumoni shows maximum 67.57% groundwater contamination by arsenic followed by Kathalguri block 44.45%. Currently, the groundwater arsenic contamination has spread to 16 districts, threatening more than 10 million people in Bihar.

Many areas within the north-eastern states with arsenic concentration greater than 0.05 mg/l, imply that millions of people are at serious risk of arsenic poisoning. According to a report, the concentration of arsenic generally varies from 0.02 to 0.9 mg/l (exceeding the WHO standard of 0.01 mg/l and Bureau of Indian Standard (BIS) of 0.05 mg/l). While As and iron pose individual problems in the aqueous environment, their association in groundwater have the potential of providing a simple means of removing arsenic by co-precipitation and adsorption. About 95% of the area of the north-eastern region contains dissolved iron in excess of 2 mg/l, and the iron concentration is as high as 15 mg/l in many areas (Singh, 2004). The North Eastern Regional Institute of Water and Land Management (NERIWALM) report (Chakraborty, 2007) indicated that arsenic levels in Assam, Manipur, Tripura and Arunachal Pradesh were above 300 parts per billion (ppb). According to the World Health Organisation (WHO), consumption of water contaminated with arsenic levels of over 50 ppb can cause skin lesions and even cancer.

Singh and Ghosh (2012) indicated that there is a very high health risk in the arsenic contaminated areas in Maner blocks of the Patna district. They found that the cancer risk and hazard quotient owing to drinking arsenic contaminated groundwater was as high as 192. In that area, an average of 142  $\mu\text{g/l}$  of arsenic was detected with the highest value of 498  $\mu\text{g/l}$  of As measured in the Haldichapra Panchayat of Maner block, Patna. However, the highest level of 2182  $\mu\text{g/l}$  of arsenic was reported in the Buxar district of Bihar (SOES, 2012). Other arsenic affected areas of Bihar, where the level of arsenic in drinking water exceeded 1000  $\mu\text{g/l}$  are Bhojpur, Patna, Samastipur, and Bhagalpur districts. More than 50  $\mu\text{g/l}$  of arsenic were detected in Vaishali, Saran, Begusarai, Khagaria, Munger, and Katihar districts. However, other districts like Siwan, Lakhisarai, Darbhanga, Supaul, and Kishanganj were below India's standard of 50  $\mu\text{g/l}$  of arsenic in drinking water. State wise names of the districts (partly affected) from where arsenic (above 0.05 mg/l) groundwater contamination has been reported is presented in Table 1.

**Table 1:** State wise names of the districts (partly affected) from where Arsenic (above 0.05 mg/l) groundwater contamination has been reported (Source: Central Groundwater Board)

Sr. #	States	Districts
1.	Assam	Sivsagar, Jorhat, Golaghat, Sonitpur, Lakhimpur, Dhemaji, Hailakandi, Karimganj, Cachar, Barpeta, Bongaigaon, Goalpara, Dhubri, Nalbari, Nagaon, Morigaon, Darrang & Baksha
2.	Bihar	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Patna, Purnea, Samastipur, Saran, Vaishali
3.	Chhattisgarh	Rajnandgaon
4.	Haryana	Ambala, Bhiwani, Faridabad, Fatehabad, Hissar, Jhajjar, Jind, Karnal, Panipat, Rohtak, Sirsa, Sonapat, Yamunanagar.
5.	Jharkhand	Sahebganj

6.	Karnataka	R aichur and Yadgir district
7.	Manipur	Bishnupur, Thoubal
8.	Punjab	Mansa, Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, Ropar.
9.	Uttar Pradesh	Bahraich, Balia, Balrampur, Bareilly, Basti, Bijnor, Chandauli, Ghazipur, Gonda, Gorakhpur, Lakhimpur Kheri, Meerut, Mirzapur, Muradabad, Rai Bareilly, Sant Kabir Nagar, Shajahanpur, Siddarthnagar, Sant Ravidas Nagar, Unnao
10.	West Bengal	Bardhaman, Hooghly, Howrah, Malda, Murshidabad, Nadia, N-24 Parganas, S- 24 Parganas.

## Mitigation Measures

Elevated arsenic content in groundwater is one of the most serious concerns as it affects large unconsolidated aquifers along many alluvial and deltaic plains of the world particularly in southern, south-eastern and eastern parts of Asia. The problem is compounded because the drinking water supply of these thickly populated parts is dependent on shallow aquifers which are found to be contaminated. In India, approximately 40 million people are residing within the risk zone of arsenic contamination (Acharyya, 2005 and Saha, 2009).

Major source of arsenic in groundwater is of geogenic origin and is intricately linked to the aquifer geometry and groundwater flow regime. Its effective mitigation warrants understanding of physico-chemical processes in groundwater and aquifer framework, lithology and groundwater flow regime of the area. The mitigation measures include variety of options, ranging from removing arsenic from groundwater after it is extracted, searching alternative aquifers, reducing the level within the aquifer itself, dilution of the contaminants by artificial recharge, blending with potable water etc.

## Ex-Situ Arsenic Removal

This method primarily targets to lower the concentration of arsenic after the water is extracted from aquifers. Following measures are adopted for this method.

### 1. Precipitation Processes

This process includes coagulation/filtration, direct filtration, coagulation assisted microfiltration, enhanced coagulation, lime softening, and enhanced lime softening. Adsorption co-precipitation with hydrolysing metals such as  $Al^{3+}$  and  $Fe^{3+}$  is the most common treatment technique for removing arsenic from water. Sedimentation followed by rapid sand filtration or direct filtration or microfiltration is used to remove the precipitate. Coagulation with iron and aluminium salts and lime softening is the most effective treatment process. To improve efficiency of this method, a priory oxidation of  $As^{3+}$  to  $As^{5+}$  is necessary. Hypochlorite and permanganate are commonly used for the oxidation. Atmospheric oxygen can also be used, but the reaction is very slow. The major techniques based on this process include; Bucket treatment unit, Fill and draw treatment unit, Tube well-attached arsenic treatment unit and Iron arsenic treatment unit.

### 2. Adsorptive Processes

It includes adsorption onto activated alumina, activated carbon and iron/manganese oxide based or coated filter media. Adsorptive processes involve the passage of water through a contact bed where arsenic is removed by surface chemical reactions. The activated alumina-based sorptive media are being used in Bangladesh and India. No chemicals are added during treatment and the process relies mainly on the active surface of the media for adsorption. Granular ferric hydroxide is a highly effective adsorbent used for the adsorptive removal of arsenate, arsenite, and phosphorous from natural water. In the Sono 3-Kolshi filter, used in Bangladesh and India, zero valent iron fillings, sand, brick chips and wood coke are used as adsorbent to remove arsenic and other trace elements from groundwater.

### 3. Ion-exchange Processes

This is similar to that of activated alumina, however, in this method the medium is synthetic resin of relatively well defined ion exchange capacity. In these processes, ions held electrostatically on the surface of a solid phase are exchanged for ions of similar charge dissolved in water. Usually, a synthetic anion exchange resin is used as a solid. Ion exchange removes only negatively charged As (V) species. If As (III) is present, it is necessary to oxidise it.

### 4. Membrane Processes

This includes nano-filtration, ultra-filtration, reverse osmosis and electrodialysis which uses synthetic membranes for removal of many contaminants including arsenic. They remove arsenic through filtration, electric repulsion, and adsorption of arsenic-bearing compounds. A few emerging techniques based on the above processes are given below.

### **Manganese Greensand**

Greensand is a granular material composed of the mineral glauconite, which has been coated with manganese oxide. It is a natural zeolite (microporous mineral), and has strong ion exchange properties, and has been found effective in removing iron, manganese, arsenic, sulphide, and many other anions (Water & Wastes, 2003). Greensand surface is strongly oxidizing, and is thus able to remove both arsenite and arsenate.

### **Coagulation Assisted Microfiltration**

In this, microfiltration is used in a manner similar to a conventional gravity filter. The advantages of microfiltration over conventional filtration are a more effective microorganism barrier, removal of smaller floc sizes and an increased plant capacity (EPA, 2000; Wachinski et al., 2006). The microfiltration membrane system works to remove arsenic from water by the addition of an iron-based coagulant, such as ferric chloride, to the water. The arsenic is adsorbed onto positively charged ferric hydroxide particles, which are then removed by microfiltration.

### **Enhanced Coagulation (aka electrocoagulation, electroflotation)**

In this technique, soluble anodes made from iron or aluminum are used. Reported advantages are the in-situ oxidation of As (III) to As (V), and exhibits better removal efficiencies than with classical coagulation. Organic arsenic, fluoride and dissolved metals are also removed by this method. An additional advantage of enhanced coagulation is the reported removal of natural organic matter.

### **Solar Oxidation and Removal of Arsenic (SORAS)**

It is a simple method that uses irradiation of water with sunlight in PET or other UV transparent bottles to reduce arsenic level from drinking water (Wegelin et al., 2000). The method is based on photochemical oxidation of As(III) followed by precipitation or filtration of As(V) adsorbed on Fe(III) oxides. Field tests in Bangladesh show removal efficiency between 45-78% with an average of 67%.

### **Iron Oxide Coated Sand (IOCS)**

UNESCO-IHE developed an arsenic removal method based on adsorption on iron oxide coated sand (IOCS). IOCS is a byproduct from groundwater treatment plants and consequently very cheap. This technique is efficient for both As(III) and As(V). Different family scale removal filters were tested in Bangladesh and also a large scale centralized application was tested in Greece and Hungary (Petrusevski et al., 2007).

Majority of low cost methods rely on precipitation or adsorption. They are frequently capable of successfully treating a wide range of arsenic-contaminated influent concentrations to achieve or surpass drinking water standards.

## **Arsenic Safe Alternate Aquifers**

This technique advocates to tap safe alternate aquifers right within the affected areas. In India except at Rajnandgaon in Chhattisgarh state, the vast affected areas in the Gangetic Plains covering Bihar and Uttar Pradesh as well as Deltaic Plains in West Bengal are marked by multi-aquifer system (CGWB 1999, Acharyya 2005, Saha 2009, Shah 2007). The sedimentary sequence is made up of quaternary deposits, where the aquifers made up of unconsolidated sands separated by clay/sandy clay, making the deeper aquifer/aquifers semi-confined to confined.

The contamination is confined in the upper slice of the sediments, within 80 m and affecting the shallow aquifer system (CGWB 1999, Saha et al. 2009). At places, like Maldah district of West Bengal, single aquifer exists till the bed rock is encountered at 70-120 m below ground level (bgl). Detailed CGWB exploration, isotope and hydrochemical modeling carried out by CGWB along with other agencies like BARC has indicated that the deep aquifers (>100 m bgl) underneath the contaminated shallow aquifer, have been normally found as arsenic free. Long duration pumping tests and isotopic studies in West Bengal and Bihar have indicated that there is limited hydraulic connection between the contaminated shallow and contamination free deep aquifers and the groundwater belong to different age groups having different recharge mechanisms (CGWB 1999, Saha et al. 2010, 2011, CGWB and BARC 2009).

The deep aquifers in West Bengal, Bihar and Uttar Pradesh have the potential to be used for community-based water supply. However, if a single aquifer system exists, as found in Malda district of West Bengal, this technique may not be useful. The generalized schematic diagram showing the distribution of arsenic in multi-layered alluvial aquifers and design of a deep-tubewell tapping the deeper aquifer system (Talukdar and Ghosh, 2009) are shown in Figures 2 and 3 respectively.



Figure 2: Distribution of Arsenic in Multi-Layered Alluvial Aquifer

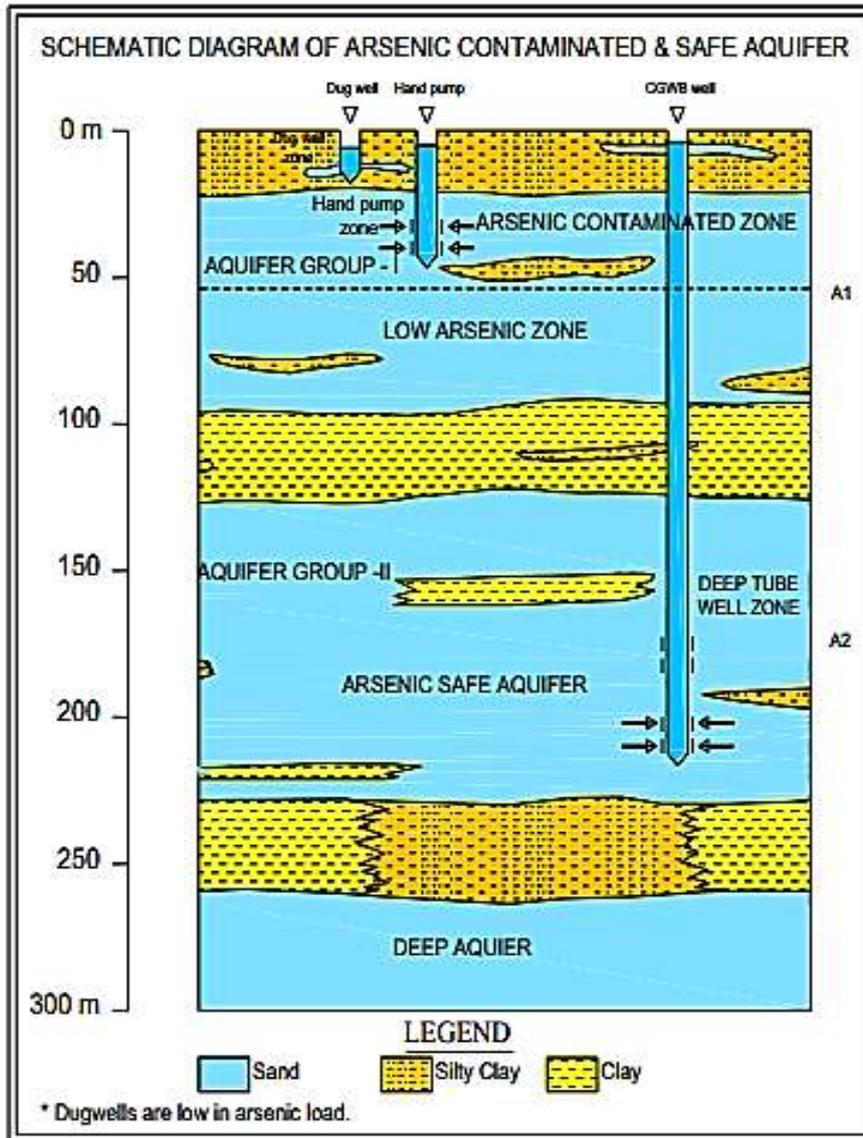
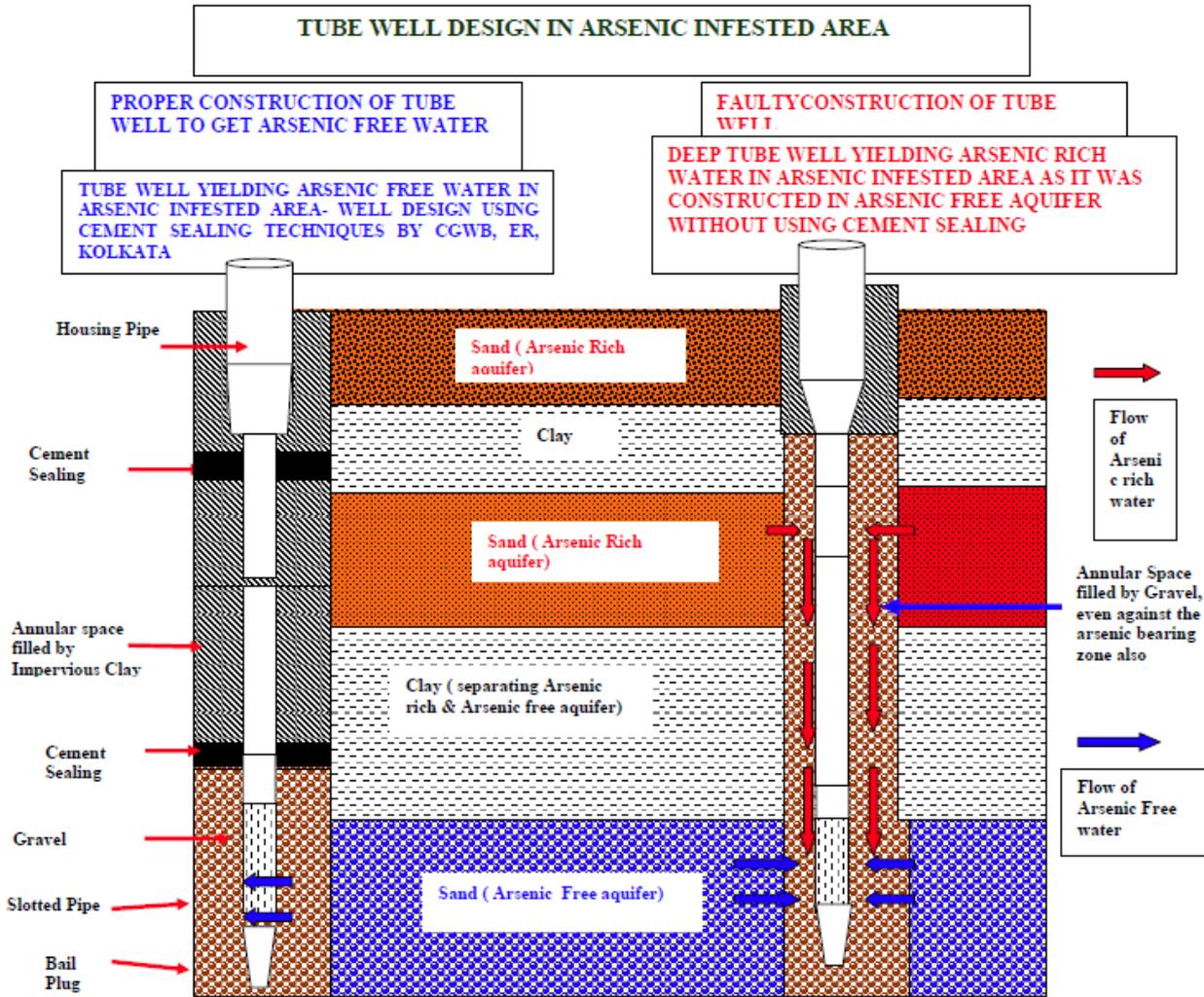


Figure 3: Tube-well Design for Tapping Arsenic Safe Deeper Aquifer



### IN-SITU (SUB-SURFACE) ARSENIC TREATMENT

In-situ remediation refers to all such techniques that make arsenic immobilization possible within the aquifer itself. As arsenic is mobilized in groundwater under reducing conditions, it is also possible to immobilize the arsenic by creating oxidized conditions in the subsurface.

#### 1. Use of Atmospheric O<sub>2</sub> for Iron and Arsenic Rich Water

In-situ treatment for the removal of arsenic, iron, manganese, or combination thereof, has been successfully applied to water wells. In the United States, in-situ remediation of other trace-elements, such as chromium, is gaining regulatory acceptance. In-situ remediation is generally thought to be less expensive than above-ground treatment. The concept of in-situ remediation of Fe(II) has been practiced in Europe for decades where concentrations are lowered through introduction of atmospheric O<sub>2</sub> to Fe(II) rich water. The process is commonly cyclic, with a period of injection followed by a period of pumping. Beside Fe(II), Mn and As concentrations have also been reduced. The efficiency of removal has been noted to increase after continued cycles. In addition, even after operation of such systems for decades, clogging of wells or aquifer materials has not been reported.

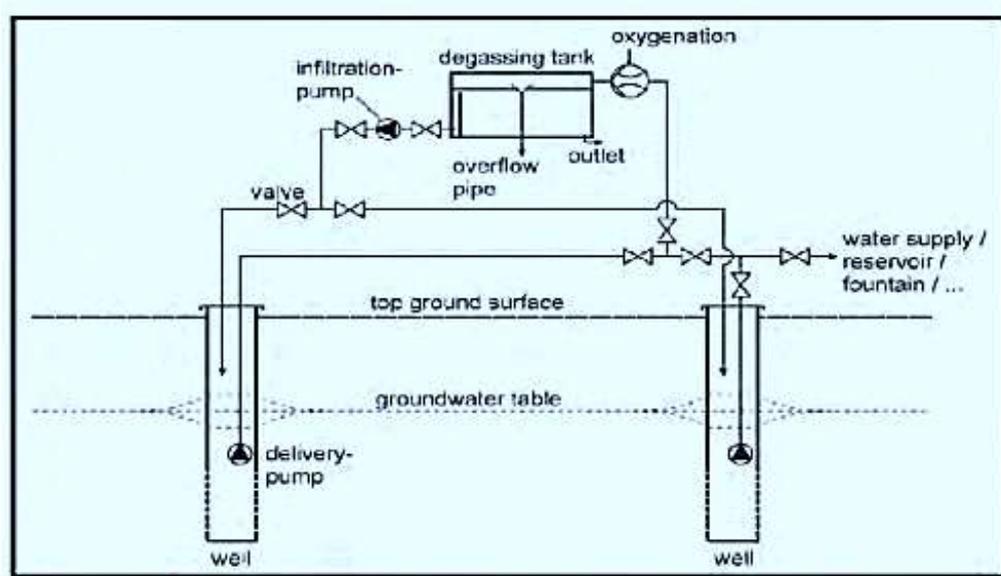
#### 2. Use of Atmospheric O<sub>2</sub> and Ferrous Chloride for Low Iron and Arsenic Rich Water

This removal technique has been demonstrated successfully from alkaline water (pH>8) with low iron load at Carson Valley, USA. The low dissolved Fe content limits development of significant iron oxide and the high pH limits arsenic adsorption onto iron oxide. In this case, dissolved O<sub>2</sub>, Fe(II), and HCl are added to water and injected into the aquifer to form iron oxide and lower the pH to remove arsenic.

### Sub-Terranean Arsenic Removal (SAR)

The SAR Technology developed by a consortium of European and Indian scientists was demonstrated at a location near Kolkata during 2005-06 as a demonstration of in-situ technology. This technology was subsequently replicated successfully in arsenic affected areas in West Bengal through World Bank Development program. In this technique (Figure 4), the aerated water is stored in feed water tanks and released back into the aquifers through the tubewell by opening a valve in a pipe connecting the water tank to the tubewell pipe under the pump head. A number of different physical, chemical and biological processes are intensified in the surrounding area of the well screen section, the so called oxidation zone. Because of the input of oxygen, the redox potential of the water is increased. The dissolved oxygen in aerated water oxidizes arsenite to less-mobile arsenate, the ferrous iron to ferric iron and Manganese(II) to Manganese(III), followed by adsorption of arsenate on iron(III) and Manganese(III) resulting in a reduction of the arsenic content in tube well water.

Figure 4: SAR Technology for In-situ Arsenic Remediation



### Permeable Reactive Barriers (PRB) Technology

In this in-situ technique, walls containing reactive media are installed across the path of a contaminated groundwater plume to intercept the plume. The barrier allows water to pass through the media which removes the components by precipitation, degradation, adsorption, or ion-exchange. This method is reported to have lower operation and maintenance costs than ex-situ (pump and treat) methods. PRBs are already commercially available and are being used to treat groundwater containing arsenic at a full scale at two sites in the USA, although arsenic is not the primary target. Four types of materials have been used in the construction of permeable reactive barriers (PRB) used in the treatment of arsenic contaminated groundwater - zero valent iron (ZVI), furnace slag, sorbents and composite materials (organic + ZVI or a sorbent). It has been observed that iron based sorbents (IBS) can remove efficiently both the As(III), As(V) and their mixtures. As(V) is removed easier than As(III). Iron oxide-bearing minerals (iron-oxide coated sand) have long been recognized as an effective reactive media for arsenic-contaminated groundwater remediation. Based on it, technique has been developed to facilitate in-situ oxidative precipitation of  $Fe^{3+}$  in a soil (sand) media for generating a reactive barrier that could immobilize arsenic (As) and other dissolved metals in groundwater.

### 3. Electrokinetic Treatment

Electrokinetic treatment is an emerging in-situ remediation method designed to remove heavy metal contaminants from soil and groundwater. The method is most applicable to soils with small particle sizes, such as clay. However, its applications for treating arsenic contaminated groundwater are not of practical interest as treatment is limited by the depth to which the electrodes can be placed.

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Of the various in-situ remediation techniques, in India, only the SAR technology (as described above) has been demonstrated successfully in parts of West Bengal. Even though, in-situ immobilization has the great advantage of not producing any wastes that must be disposed of, however, experience is limited, and the technique should be considered with caution.

## **MITIGATION WORKING PLAN IN INDIA**

There are different options for remediation of arsenic. As a short term measure, various types of ex-situ removal techniques are adopted, in house-hold scale or community scale. Use of dug wells which are found to be arsenic free are also proposed. As medium and long term measures, alternate arsenic free deeper aquifers (hydro geologically suitable ones) and surface water based supply may be adopted. Artificial recharge and rain water harvesting is also a viable option for arsenic remediation as it dilutes the concentration. Presently, emphasis is given to adopt in-situ removal of arsenic as it is environment friendly because no sludge is produced. However, the success of any arsenic mitigation measure depends upon awareness creation and capacity building of the people residing in the affected areas.

### **West Bengal**

The initiative to combat the menace of arsenic hazards, in true sense, came into existence in the year 1992. From 1992 onwards, Government of West Bengal and Central Government, along with several academic Institutions and Non-Governmental Organizations, have initiated a number of restorative and substituting measures coupled with action plan. Their main focus was on the detailed investigations to understand the physio-chemical process and mechanism, alternate arrangement to supply arsenic free water to the affected populace and development of devices for arsenic removal and their implementation at the field. The state government of West Bengal has operationalized a number of schemes. The research studies have been focused towards identifying: (i) extent and nature of arsenic contamination in groundwater, (ii) causes and mobilization, (iii) mitigation strategies, and (iv) devising cost effective remediation techniques and developing sustainable groundwater resources management strategies. Various type of ex-situ removal techniques have been adopted and in-situ methods have been as pilot study.

### **Bihar**

Groundwater arsenic contamination in Bihar first surfaced in the year 2002 from two villages, Barisbhan and Semaria Ojhapatti in the Bhojpur district located in the flood-prone belt of Sone-Ganga. A number of scientific studies, focusing mainly on physico-chemical analyses of arsenic contaminated groundwater, assessment of extent, mobilization pathways, and possibility of tapping deeper aquifers, arsenic in food chains and its effect on health, were initiated by state and central government organizations and by different academic institutions working in the state. In addition to R & D studies and exhaustive investigations, government of Bihar has started a number of schemes as the precautionary measures to ensure supply of risk-free potable groundwater, particularly in community based localities, and as counteractive steps to combat probable arsenic related threats. As an outcome of scientific investigations and surveys, by 2008, out of 38 districts in the state, 15 districts covering 57 blocks, were identified with groundwater arsenic contamination above 50 µg/l. Arsenic mitigation strategies need to further explored and implemented.

## **CONCLUDING REMARKS**

This review has attempted to summarize the harmful effects of arsenic along with incidents of arsenic contamination in groundwater in various states of India. There are many sources of arsenic that contaminate the groundwater. It possesses a significant risk to public health. Therefore, the first priority to remediate the crisis should be early identification of the affected sources, and the next hurdle is to provide arsenic-safe water to the affected masses. It is necessary to seal the highly contaminated tube wells to protect the non-contaminated aquifers and provide the good biosand filters to the rural regions.

The arsenic-mitigation strategy should be location-specific. Any method suitable for a specific area may not be generalized for other affected regions due to (a) geographical and geomorphological variations and (b) differing socio-economic and literacy conditions of people. But whatever be the approach, for success at field level, the people should be made aware of the arsenic problem and its effects, and their whole-hearted participation is also needed to contain the situation. Ex-situ methods are used successfully. After adopting the suitable mitigation strategies, we can hopefully provide arsenic free water for drinking, irrigation and other purposes.

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