

Effect of Arsenic Contamination in Potable Water and Its Removal Techniques

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Abstract

Thousands and thousands of people are suffering from the toxic effect of arsenic in many countries. It is due to natural ground water contamination as well as industrial hazards waste and drainage problems. Permissible level of arsenic in water is 0.01 ppb defined by World Health Organization. The delta region of Brahmaputra and Ganga is one of the world's most affected areas. The central portion of Argentina is affected by arsenic-contaminated groundwater. Specifically, the La Pampa produces water containing 4-5300 microgram as per litre. There are many public water supply systems in United State of America. Their water supply from groundwater had met the old 50 ppb arsenic standard but exceeded the new 10 ppb. China, Australia, Japan, Nepal and many more countries in all over the world are facing problem of ground water contamination of arsenic. There are lot of effort has been made by WHO, NGOs and governments of different countries. But still several cases are found in all over the world. Bangladesh is a most affected country among all of ground water contamination of arsenic.

To make water portable for human consumption, there were several techniques used to remove contamination. Use of chlorine, ozone etc. and physical method such as UV treatment, other filtration techniques such as reverse osmosis, membrane filtration, flocculation, adsorption etc. are some of the effective methods for removal of contamination from water. In this review, some of the most effective arsenic removal techniques will have been discussed.

Keywords: Arsenic; Contamination; Filtration; Selectivity; Adsorption

Introduction

Arsenic that has the symbol 'As', and atomic number 33, atomic weight 74.92 is often referred to as a metal but, it is classified chemically as non-metal or metalloid belonging to Group-15 of the periodic table. The most common oxidation states for arsenic are: -3 (Arsenide: usually alloy like intermetallic compounds), +3 (arsenite (As (III))), and most organ arsenic compounds), and +5 (Arsenates (As (V)): the most stable inorganic arsenic oxy compounds). Arsenic is always present as compounds with oxygen, chlorine, sulphur, carbon and hydrogen on one hand, and with lead, gold and iron on the other [1]. It can exist in inorganic or organic form; inorganic arsenic is more toxic than organic arsenic. Inorganic arsenic occurs naturally in many kinds of rocks and it is most commonly found with sulphide ores as arsenopyrite. Inorganic arsenic compounds are known to be human carcinogenic and organic compounds are typically white to colourless powders. Elemental form of arsenic is insoluble in water. It can only soluble in oxidized form [1].

Arsenic, being a normal component of human body is transported by the blood to different organs in the body mainly in the form of mono methyl arsenic (MMA) after ingestion [2]. It causes variety of adverse health effect to human after acute and chronic exposures such as dermal changes (pigmentation, hyperkeratosis, and ulceration), respiratory, pulmonary, cardiovascular, gastrointestinal, haematological, reproductive, immunologic, Geno toxic, mutagenic, and carcinogenic effects [3].

Many countries all over the world are facing problem of arsenic contamination. There are 19 states in India having arsenic contaminated water including Rajasthan, Bihar, Bengal, Utter Pradesh, Orissa, and Gujarat. Severe problems due to arsenic contamination in water have been seen in Rajasthan, Jharkhand, West Bengal and Chhattisgarh [1].

The worst situation of arsenic contamination has been seen in delta region of Brahmaputra and Ganga rivers. Bangladesh is grappling with the largest mass poisoning of a population in history because groundwater used for drinking has been contaminated with naturally occurring inorganic arsenic. It is estimated that of the 125 million inhabitants of Bangladesh between 35 million to 77 million are at risk of drinking contaminated water [4]. The scale of this environmental disaster is greater than any seen before; it is beyond the accidents at Bhopal, India, in 1984, and Chernobyl, Ukraine, in 1986. The effect of arsenic contaminated water as a drinking water on health of human beings in India has been shown in Figure 1 [5]. The situation of this contamination of arsenic in groundwater is not only found in Asian countries but also in Europe, Africa, North America, and Australia.

In this review paper, all the sources of ground water contamination with arsenic has been observed and marked. Affected regions of arsenic contaminated groundwater have also been seen with their effect on human health. Different techniques for arsenic removal from ground water contamination have also been reviewed with their pros and cons. There is lot of techniques are available for the purification of water since very past. But very few are having better efficiency for arsenic removal from contaminated drinking water. Some of those techniques have been mentioned in this review paper like Reverse Osmosis, Activated Alumina, Ferric Activated Carbon, Coagulation and flocculation, Membrane Filtration, Solar Oxidation Technique and FeO nanoparticles. These techniques are having good result against arsenic contaminated water along with the problem of disposal of their hazards residual. In some of the countries, these hazards residuals with arsenic contamination have been used in buildings of roads and in bricks manufacturing [6].



Figure 1: Shows the effect of arsenic infection on human health

Contamination

Most of the cases of arsenic toxicity in the medieval and early modern age were due to arsenic intake through medicine, smelting or genocide activities. Around the middle of 20th century arsenic poisoning surfaced from some countries where people ingested arsenic contaminated water [7]. The toxicity manifested on mass scale rather than the mere individual cases. The major affected countries were Argentina, Chile, Mexico, and Taiwan. Close to the end of 20th century groundwater arsenic contamination and sufferings of people came to the lime light from three more Asian countries (West-Bengal- India, China and Bangladesh). The source of arsenic was contaminated hand tube wells. In global arsenic contamination scenario 38 countries are affected at present [8]. In Asia alone 13 countries are arsenic affected and Asian countries are worse arsenic affected in global scenario. In Bangladesh alone out of its 64 districts, 60 districts have groundwater arsenic contamination above WHO guideline value (10 ppb) [7]. In India, flood plain regions belonging to Ganga and Brahmaputra rivers are arsenic affected. There are major three types of contamination of groundwater in all over the world; which are given below in Figure 2. On the other hand, affected groundwater regions were given in figure 3. The coloured spot in Figure 3 [9] has specified as three different types of sources of contamination.

Human added contamination

Participation of human activities in the contamination level of arsenic in groundwater is increasing day by day. Now in the present scenario of 21st century, human activities are also playing a major role. The major sources of human activities are use of pesticides for crops, medicines, waste product of factories, drainage and thermal power plants etc. A recent example of contamination in this category has found in Rajghat and Badarpur area of Delhi NCR (India) [10,11]. Arsenic contamination located in parts of Delhi NCR, the capital of India in the vicinity of Rajghat and Badarpur coal based thermal power plant with total generation capacity of 1085 Mega Watt. Arsenic, being a very coalphile element, has strong affinity to coal matter. There are instance of major dust pollution around power stations from fly ash dispersal. The main method of disposal of flies ash from the power stations by mixing with water; the resultant slurry is pumped through pipes to ash disposal ponds [12]. An example of human added contamination or anthropogenic contamination has been shown in Figure 4 [13] and Figure 5 [14]. The waste hazards materials from industries were exposed to environments. These hazards disposals are having long time effect on environment equilibrium [15].

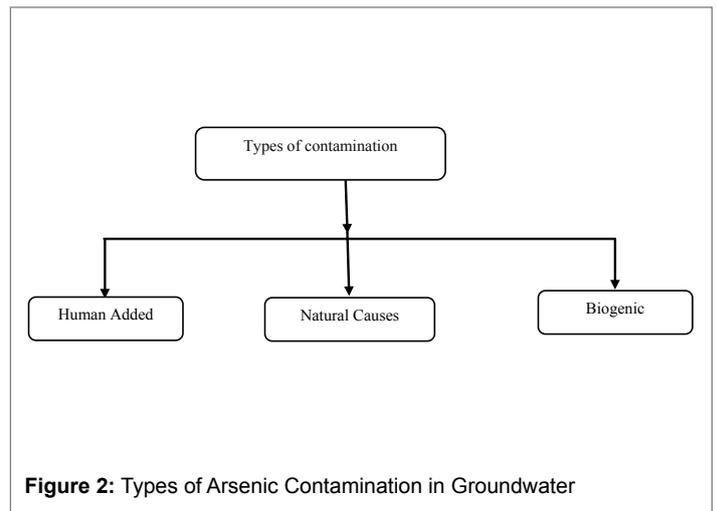


Figure 2: Types of Arsenic Contamination in Groundwater



Figure 3: Shows the types of groundwater arsenic contamination and their sources

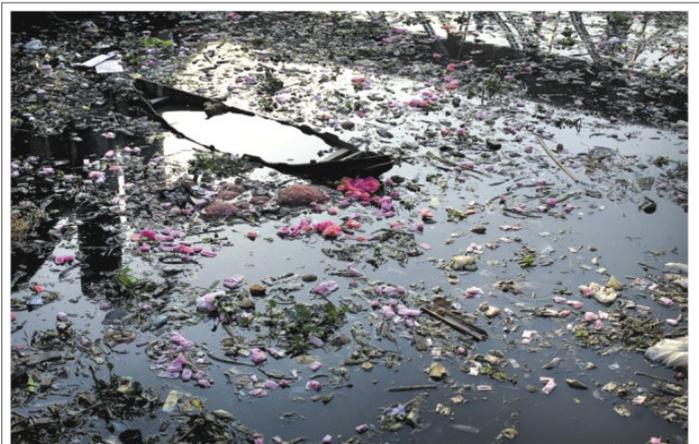


Figure 4: Shows an example of anthropogenic contamination of arsenic

In some countries, waste materials from factories flows to rivers without any proper filtration [8]. These are one of the main causes in increasing of arsenic contamination in rivers water and later on it contaminates groundwater of delta regions of that river.

Threats to water quality are divided among agriculture, spills, leaking underground storage tanks and septic systems, urban runoff, mining, and industrial operations. California leads in agriculture, farming and ranching in United State of America, accounting for \$20 billion in revenues per year. So it is not surprising that agriculture has emerged as



Figure 5: Shows the example of arsenic disposal in air

one of the biggest source of groundwater contamination in California. California uses the most pesticides and fertilizers of all the states of United State of America et al Anthony Saramento, April, 2002 [16].

Natural causes

Geothermal activities in the Core of earth cause imbalance on the surface of Earth. These imbalances cause a lot of natural disasters on Earth's surface like volcano eruption, Tsunami, weathering of rocks and minerals, tornadoes etc. Some of these disasters activity of nature are sources of arsenic contamination in water like volcano eruption, weathering of rocks and minerals [12].

The transport and distribution of arsenic in the environment is complex. Due to the many chemical forms in which it may be present and because there is continuous cycling of different forms of arsenic through air, soil and water. Arsenic dissolved in water can be present in the different form. In well-oxygenated water and sediments, nearly all arsenic is present in the stable form of arsenate (V). In some cases arsenite (III) and arsenate (V) forms are less stable and are interchangeable, depending on the chemical and biological conditions [16]. Some chemical forms of arsenic adhere strongly to clay and organic matter, which can affect their behaviour in the environment that has shown in Figure 6 [17]. Weather rock and soil containing arsenic, may be transported by wind or water erosion. Arsenic releases in to the atmosphere by volcanic activity and attaches to particles that are dispersed by wind and fall back to the ground [18].

Water percolating through soils picks up naturally occurring minerals, salts and organic compounds. As the water migrates downward, the concentrations of dissolved minerals and salts typically increases, a process known as mineralization. In some cases, the percolating water accumulates minerals concentrations high enough that the groundwater no longer used as a water supply. This is also a way of groundwater contamination of arsenic [19,20].

Biogenic contamination

Arsenic undergoes a series of biological transformation in the aquatic environment, yielding a large number of compounds, especially organo-arsenicals [21]. Certain reactions, such as oxidation of As (III) to As (V), may occur both in presence and absence of microorganism, whereas other reactions such as methylation, are not thermodynamically favourable in water and can occur only in presence of organism, which indicates that many aquatic organism are capable of accumulating arsenic and may catalyse the oxidation of As (III) to As (V). Biological transformation is significantly important in marine ecology.

Affected Regions of World

In Figure 7 [22], the scenario of contamination and level of arsenic contamination in all over the world has been shown. The intensity of the contamination is increasing year by year due to high need of water consumption to compete the population growth. Levels of arsenic in rice



Figure 6: Shows contamination of air and water due to volcano eruption

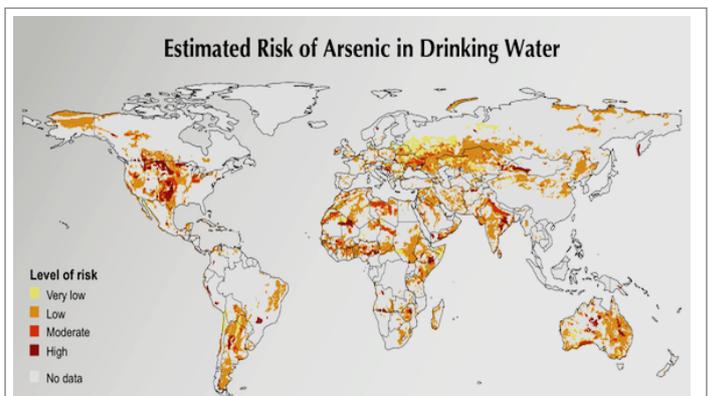


Figure 7: Shows the arsenic affected regions of World

grain are typically 0.05-0.4 ppb for North America, Europe, and Taiwan [23].

Asia

The digging of tube-wells for drinking water supply into aquifers elevated in arsenic in Bangladesh and West Bengal has been described as the greatest mass poisoning in human history, with 36 million people exposed to elevated arsenic in their drinking water [24]. In Bangladesh, arsenic contamination level in groundwater is up to 2 ppm. Groundwater is used extensively to irrigate rice crops in Bangladesh, particularly during the dry season with 75% of the total cropped area are for rice cultivation and 83% of the total irrigated area used for rice cultivation only. Background levels of arsenic in soils from limited surveys conducted in Bangladesh rice paddy field ranges from 4 to 8 mg of arsenic kg⁻¹ [23,25].

There has been considerable investigation into drinking water contamination in Bangladesh/West Bengal, with increasing numbers of epidemiological studies. However, to date, no studies have been published which consider other potential arsenic exposure routes to these populations [26,27]. Food surveys on the daily arsenic intake in the United States and Europe showed that fish products and rice are major dietary source of arsenic. In countries that have a rice subsistence diet, the importance of dietary exposure to arsenic through rice could be considerable. Arsenic levels in rice grain reached 0.7 ppb in rice grown on paddy soils containing 68 ppb arsenic in China, showing the potential for arsenic contamination of rice grain from contaminated paddy soils [28,29].

In Japan, arsenic levels were found to be high in geothermal waters and springs first time in 1950s, and arsenic contamination of groundwater

was noted in 1994. Exposure to arsenic from industrial sources was noted in early 1950s. In Iran, chronic arsenic poisoning was noticed and subsequent well-water sampling revealed concentrations exceeding 1,000 ppb in 1981 AD [30].

In India arsenic contamination first foot print are reported in Panjab, Haryana, and Himachal Pradesh. Chandigarh (India) and its surrounding area were first highlighted in 1976 AD as arsenic contaminated ground water. In 1984 AD ground water arsenic contamination was identify in lower Ganga plain of West Bengal. In 1992 AD arsenic groundwater contamination in lower plain area (Terai) of Nepal came to notice [30]. In 2002 June, arsenic contamination located in Bihar in middle Ganga plain and at the same time apprehended contamination in Utter Pradesh lying in middle and upper Ganga plain. During October 2003 AD to August 2005 AD three districts of Utter Pradesh namely, Ballia, Gazipur and Vranashi are present in hit list [25].

In January 2004 AD, 17 villages of Sahebganj district of Jharkhand state of India, in the middle Ganga plain are reported affected. Simultaneously January-February 2004 AD in Assam state of India two districts had an arsenic concentration above 50 ppb. All the states and countries surveyed in the Ganga-Meghan-Brahmaputra (GMB) plain, which has an area of approximately 500,000 Km² and a population over 500 million, are at risk from ground water arsenic contamination [31].

Arsenic exposed states of India

Bihar: Initially detected in the year of 2002 AD from Semaria-Ojhapatia village of Bhojpur districts. 57 blocks in 15 districts are under high arsenic contamination risk [32,33].

Chhattisgarh: Arsenic contamination in groundwater is reported along North-South trending 80 Km stretch of Kotri lineament from Chhattisgarh State. The severity is found in certain part of Ambagarh Chowk block of Rajnandgaon [32].

Jharkhand: Arsenic in water (>0.05 ppm) are reported from 3 blocks of Sahebganj district of Jharkhand. Most affected regions of Jharkhand are Rajmahal, Udohwa and Sahebganj districts. These districts have reported high level of arsenic contamination in groundwater.

Arsenic contamination in India is mainly geogenic and mostly occurs in unconsolidated sediments except in Chhattisgarh. In Chhattisgarh, it occurs in aquifers in Precambrian rocks [34].

Europe

The discoveries of arsenic contamination of groundwater have occurred over a span of nearly 100 years, the most recent within the last decade. Observations of health problems first led to the realization that arsenic was being inadvertently ingested. Arsenic poisoning in humans in Argentina was recognized as early as 1913 AD, and attributed to the drinking of groundwater. A possible connection between skin cancers and drinking water was recognized in Taiwan during the 1930s. In the 1940s, arsenic contamination of well water in the Pannonian Basin in Romania and adjacent Hungary was discovered [35]. Recognition of similar occurrences in other European countries such as south-western England, Germany, Greece, and Spain followed, and groundwater with As concentrations that exceed standards are now observed in more than 70 countries worldwide (Nordstrom, 2002; Ravenscroft et al., 2009) [35].

The European guideline for arsenic in drinking water is in accordance with the WHO guideline of 10 ppb. In their background document, the WHO states that the 10 ppb guideline is based on practical considerations (detection limit and feasibility/cost of arsenic removal) instead of the health effects [36]. Arsenic in drinking water supply has never been a matter of interest in most European countries because the standard of 10 ppb is hardly ever exceeded. Nevertheless, in countries such as Hungary,

Serbia, Croatia, Greece, Italy and Spain, elevated arsenic concentrations have been detected and special treatment steps are needed to reduce the arsenic to acceptable levels [37]. Arsenic exposure in Hungary, Romania and Slovakia was extensively studied and elevated arsenic exposure via drinking water was found prevalent in some of the studied countries. The median lifetime concentrations were estimated to be 13.3 ppb in Hungary, 0.7 ppb in Romania and 0.8 ppb in Slovakia. Overall 25% of the population was found to have average concentrations over 10 ppb and 8% with exposure over 50 ppb [38].

North America

During the mid-20th century, instances of Arsenic contamination of groundwater were reported for the western USA and Alaska, but were not fully recognized in the states of Oklahoma, Texas, and Arkansas and in the Midwest and North-eastern parts of the country until the 1980s [37]. Most recently, groundwater containing arsenic in excess of USA Federal and State MCLs was found in parts of the Atlantic Coastal Plain. In Canada, arsenic contaminated groundwater in New Brunswick and Nova Scotia were noted in the 1970s, and instances in western Canada were noted in the 1960s and 1980s [39].

United States of America, Millard County, Utah

West Millard County is a desert area of Utah with a low density of population; around 250 people have been drinking well-water with arsenic concentrations of 180-210 ppb, the predominant arsenic species being As (V) (86%) [39]. Researchers were examined for specific signs of arsenic toxicity, including dermal signs. Typical signs and symptoms of arsenic intoxication were not found in any study participants. Participants from Deseret had the highest average concentration of arsenic in urine at 211 ppb and that of Hinckley participants had 175 ppb compared to controls from the Delta (48 ppb) [40]. The highest average concentration of arsenic in hair was 1,210 µg/kg from the Hinckley residents and that of Deseret residents was 1,090 µg/kg compared to controls from the Delta (320 µg/kg). It was reported hypertensive heart disease, nephritis, neprosis, and prostate cancer among the people of the arsenic affected areas in Utah. Western Oregon Wells in Eugene, Creswell, and Grove districts in Central Lane County, known to yield arsenic-rich groundwater, are in an area underlain by a particular group of sedimentary and volcanic rocks, which geologists have named the Fisher Formation [41]. Lassen County, California in Lassen County, California, arsenic poisoning by well water containing arsenic in the range of 50-1,400 ppb was reported during 1970 ppb. It was found that, for drinking-water with arsenic exceeding 50 (± 30) ppb, there was an increase of arsenic content in hair, indicating body burden due to arsenic exposure. The literature reveals that the health of these people who were exposed to arsenic was not adversely affected. In New Hampshire, concentrations of arsenic were measured in 992 drinking-water samples collected from randomly-selected New Hampshire households. Concentrations of arsenic up to 180 ppb were found, with water from domestic wells containing significantly more arsenic than that from municipal sources [42]. Water samples from drilled bedrock wells had the highest concentrations of arsenic, while samples from surface wells had the lowest concentrations. The arsenic in groundwater of New Hampshire was derived from weathering of bedrock materials and not from anthropogenic contamination. Analysis of rock digests indicates concentrations of arsenic upto 60,000 µg/kg in pegmatite with much lower values in surrounding schist and granites rocks. Arsenic concentration was found higher 50 ppb in well-water and springs of Fairbanks, Alaska [43]. A study was initiated to evaluate the arsenic content of streams and groundwater of the Pedro Dome summit area, about 30 km north of Fairbanks, Alaska, in the heart of the historic Fairbanks mining district. Arsenic was associated with gold mineralization and is believed to reach the groundwater through weathering of arsenic containing rocks [44].

Arsenic pollution of glacial and fluvio-glacial aquifers is well-known in the USA, Canada and Finland, but largely unrecognised in other glaciated regions. However, the majority of cases come from stable continental regions. Wells drilled on deposits of the youngest glacial advance in the USA (the Wisconsin) were much more likely to be polluted in Minnesota, Iowa and the Dakotas [45]. In Finland, arsenic polluted groundwater was correlated with arsenic anomalies in glacial sediment. However, in most countries of interest here, the requisite geochemical atlases probably do not exist, and it would be simpler, and far more reliable, to survey groundwater directly [46].

Australia

Australia is a country rich in minerals that constitute a significant source of arsenic contamination to the environment, in addition to anthropogenic sources, such as mining activities and pesticide usage [47]. In 1991, survey data revealed elevated levels of arsenic in surface water and groundwater of Victoria, mostly around the gold-mining regions. In that area, concentrations of arsenic in groundwater varied from 1 to 300,000 ppb while in surface water these were in range of 1 to 28,300 ppb. In a follow-up study in the same area in the mid-1990s, concentrations of arsenic were 1-12 ppb in groundwater samples, 1-220 ppb in surface water samples, and 1-73 ppb in drinking-water samples [47].

In Australia, old stocks of lead arsenate used as pesticides before 1970 AD remained in sheds and caused chronic arsenic poisoning among workers. Recently, Smith et al. summarized the environmental behaviour of arsenic, with particular emphasis on sources, distribution, and accumulation of arsenic in the Australian environment. They reported the presence of both anthropogenic and naturally-occurring arsenic [48].

Africa

In Brazil, concerns were raised about reports of human exposure to arsenic in drinking-water as a result of gold-mining in the zone of Minas-Gerais in south-eastern Brazil [49]. In 1998 AD, urinary arsenic was measured in 126 school children, and a mean concentration of 25.7 (range 2.2-106) ppb was noted. Environmental investigations in the surrounding regions found that the mean level of arsenic in surface water was 30.5 (range 0.4-350) ppb; levels of arsenic in soil ranged from 200 to 860 mg/kg, and sediments had a mean concentration of 350 (range 22-3,200) mg/kg [50].

Methods for Arsenic Removal

Several techniques are available in the present scenario of 21st century. All the available techniques are having their own pros and cons as well. Some of them found more practical to use frequently among the mass of arsenic contaminated people. Microbial contamination from water consumption, there are several techniques are used to remove contamination like use of chlorine, ozone etc., physical method such as UV treatment, other filtration techniques such as reverse osmosis, membrane filtration, flocculation, adsorption etc. Some efficient and practical techniques for the purpose of arsenic removal from drinking water will have discussed in this section [6].

Membrane filtration

This work addresses pressure driven membrane separation processes. Pressure driven processes can be divided into four overlapping categories of increasing selectivity: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and hyper-filtration or reverse osmosis (RO). It should be noted that, in general, driving pressure increases as selectivity increases [51]. Clearly it is desirable to achieve the required degree of separation (rejection) at the maximum specific flux (membrane flux/driving pressure). In general, separation is accomplished by MF membranes and UF membranes via mechanical sieving, while capillary flow or

solution diffusion is responsible for separation in NF membranes and RO membranes. However membrane composition combined with solvent and solute characteristics can influence rejection via electrostatic double layer interactions or other hindrances [52].

When a solution containing ions is brought in contact with membranes possessing a fixed surface charge, the passage of ions possessing the same charge as the membrane (co-ion) can be inhibited. This condition is termed Donnan Exclusion. More specifically, when a solution with anionic arsenate is brought in contact with a membrane possessing a fixed negative charge, the rejection of arsenate may be greater than if the membrane was uncharged [53]. Hence, the selection of a membrane possessing a slight negative charge may be advantageous for the removal of arsenic from drinking water. This is a particularly fortunate set of circumstances, since most NF and UF membranes possess a slight negative charge, and the speciation of arsenic in natural waters is primarily in the anionic arsenate form [51]. If the barrier (membrane) is intact, no particles larger than the membranes pore size can pass through the filter. This is illustrated in Figure 8 [54].

Ferric activated carbon composites adsorbents

In this method, the activated carbon (AC) (AC12 × 40, China Calgon) was used in this study. This kind of AC has moisture content of 1.2%, ash content of 10.3%, iodine values of AC adsorption of 1029 mg/g, the hardness of 96.2%, and the density of 480 g/L. Grain sizes of AC were: less than 1.7 mm in diameter (less than 12 US mesh sieve; less than 1.8% by mass) and more than 0.425 mm in diameter (more than 40 US mesh sieve; less than 1.9% by mass) [55]. The virgin activated carbon was firstly rinsed with distilled water to remove dirties, and then was washed by 0.001 M HCl solution to remove all salts precipitated in its pores. Then, the AC was repeatedly washed with the distilled water to remove all traces of the acid. Subsequently, the washed AC was oven-dried at 85°C for 24 h to volatilize the organic impurities, and then was modified by 1 N HNO₃ for 5 h at the room temperature [56,57].

FeO/AC adsorbent was prepared by mixing FeCl₃/FeSO₄ (molar ratio 2:1) and 5 mol NaOH and remaining for 10 min at the temperature of 70°C and pH value of 9.5, along with the gentle stirring (60 rpm), and then was impregnated into the modified AC [58,59]. The obtained materials were dried in an oven at 100°C for 3 h. The samples were analysed by X-ray diffraction (XRD) (Ni filtered Cu K, λ=1.5418 nm), X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM) and nitrogen adsorption measurements [60,61].

Another approach to produce a more efficient system for the reduction of Cr (VI) was to create highly dispersed Fe phases on the surface of activated carbon. These Fe/AC composites show some innovative aspects:-

- 1) The high surface area carbon support significantly increases the amount of reactive Fe-bearing chemical species, dispersed as very small particles [62].
- 2) After deactivation, the oxidised iron in the composite can be regenerated by a simple thermal treatment in which Fe³⁺ species react with carbon to regenerate the reduced active phases Fe and Fe₃O₄ (Figure 9) [63].

Reverse osmosis systems

The most cost-effective method for removing arsenic from a private water supply appears to be reverse osmosis, commonly called RO. RO can be thought of as filtration at a molecular level. It works by forcing water through a special, selective membrane [64].

Reverse osmosis remove total dissolved solids by forcing the water, under pressure, through a synthetic membrane. The membrane contains microscopic pores which will allow only molecules smaller than 0.0001 micron to pass through. Since the molecules of dissolved metals and salts

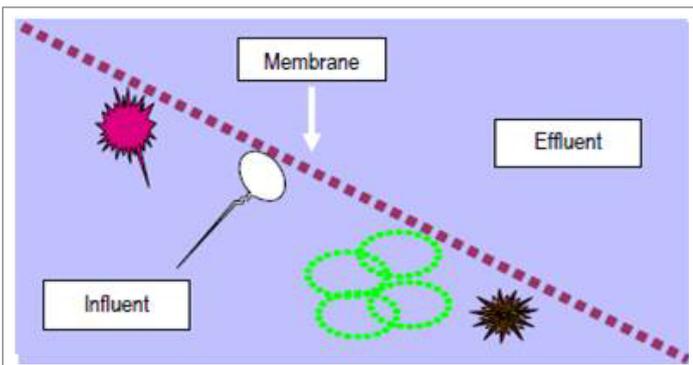


Figure 8: Represents the Membrane Filtration Mechanism

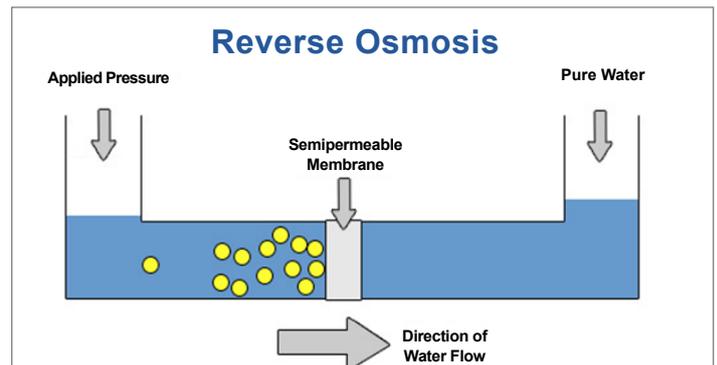


Figure 10: Represents the mechanism of reverse osmosis

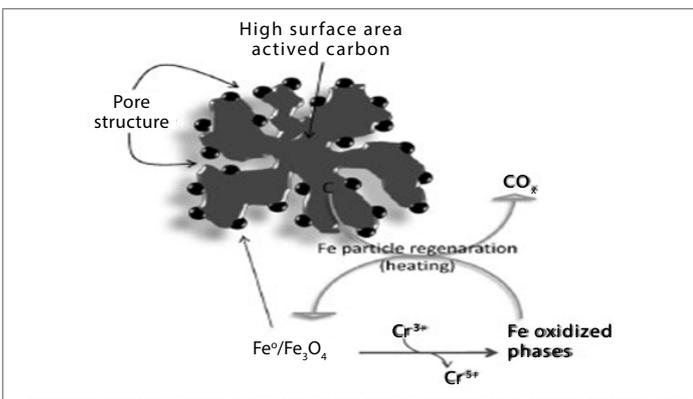


Figure 9: Shows schematic representation of the Fe phases on the surface of activated carbon and process of Cr reduction and Fe oxidized phase regenerations.

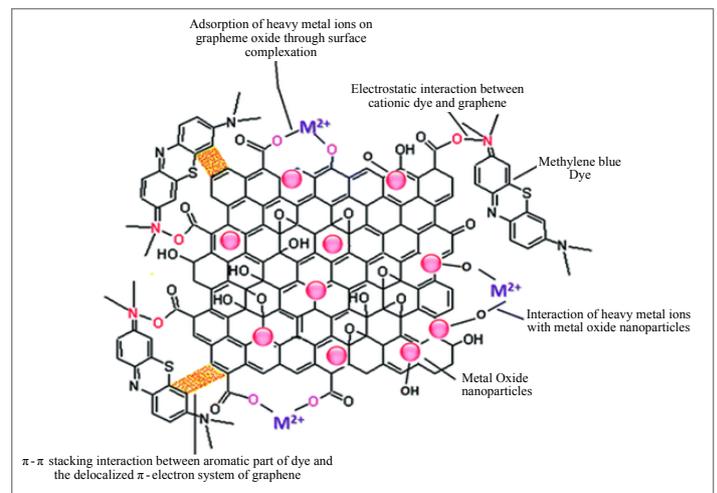


Figure 11: Shows different types of interactions is involved in the adsorption of pollutants on metal oxide/graphene oxide

are large compared to the water molecules, the water will squeeze through the membrane leaving the metals and salts behind [65]. A professional Reverse Osmosis system is capable of removing 90-99% of the dissolved mineral salts from water. The mechanism of reverse osmosis has been well described in Figure 10 [66].

Nano Iron Oxide based Absorbents

Magnetite reduced graphene oxide: Magnetite-reduced graphene oxide (M-RGO) composites (via a chemical reaction with magnetite particle size average of ~10 nm) show very good response against arsenic removal from contaminated water. M-RGO composites are superparamagnetic at room temperature and can be separated by an external magnetic field [67]. These composites show high binding capacity for As (III) and As (V), due to increased adsorption sites in the presence of reduced graphene oxide. The composites show near complete (over 99.9%) arsenic removal within 1 ppb. Thus, they are practically usable for arsenic separation from water [68]. Figure 11 [69] shows different types of interactions in the adsorption of pollutants on metal oxide/graphene oxide [69].

Iron oxide coated sand and limestone: A method for removal of iron and arsenic (III) from contaminated water using iron oxide-coated sand and limestone has been developed for drinking water. Sand was coated with ferric chloride and used as filtering media. Limestone was added onto the coated sand and the effect of limestone addition on removal efficiency of iron and arsenic has enhanced drastically. Maximum removal was found 97.5% with a coated sand dosage of 5 gram/100 ml with limestone by Reshmi and Iohborlang et al December, 2012, [70].

Ferrihydrite, granular ferric hydroxide, and hydrous ferric oxide are the most widely explored iron oxides and hydroxides for the removal of

arsenic yielding promising results for both As (III) and As (V) removals [71-76]. In the last decade, removal of arsenic using zero valent iron (ZVI) or Fe (0) for removal of as has been widely explored by several research groups both in the laboratory [77-79] and in the field [80-84]. The removal mechanisms for arsenic and other contaminants using ZVI have been reviewed by Noubactec in great detail [85, 86].

Arsenic removal via electrocoagulation

The mechanism of electrocoagulation has been the subject of continual review. The coagulation is brought about primarily by the reduction of the net surface charge to a point where the colloidal particle (previously stabilized by the electrostatic repulsion) can approach closely enough for Van der Waals forces to hold them together and allow aggregation [87]. The reduction of the surface charge is a consequence of the decrease of the repulsive potential of the electrical double layer by the presence of an electrolyte having opposite electric charge. In this process, the coagulant is generated in situ by electrolytic oxidation of an opposite anode material [88]. Charge ionic species arsenic, metals or other components are removed from wastewater by allowing it to react with an ion having an opposite charge or with floc of metallic hydroxides generated within the effluent [89].

The electro coagulation process operates on the principle that the cations produced electrolytically from iron and/or aluminium anodes enhance the coagulation of contaminants from an aqueous medium [90]. Electrophoretic motion tends to concentrate negatively charged particles in the region of the anode and positively charged ions in the region of the cathode. The consumable, or sacrificial, metal anodes are

used to continuously produce polyvalent metal cations in the vicinity of the anode. These cations neutralize the negative charge of the particles carried toward the anodes by electrophoretic motion, thereby facilitating coagulation [91]. In the flowing EC techniques, the production of polyvalent cations from the oxidation of the sacrificial anodes (Fe and Al) and the electrolysis gases (H_2 and O_2) works in combination to flocculate the coagulant materials [92]. Even inert electrodes, such as titanium and the passage of an alternating current have also been observed to remove metal ions from solutions and to initiate the coagulation of suspended solids. As mentioned above, gas bubbles produced by the electrolysis carry the pollutant to the top of the solution where it is concentrated collected and removed [93]. The removal mechanisms in EC may involve oxidation, reduction, decomposition, deposition, coagulation, absorption, adsorption, precipitation and flotation [94]. Figure 12 shows electro coagulation process [95].

Solar oxidation technique

Solar oxidation in individual units (SORAS) was explored by Garcia *et al.* [19] as alternative technology to treat arsenic from the groundwater. The process is based on photochemical oxidation of As (III) followed by precipitation or filtration of As (V) adsorbed on Fe (III) oxides. Their findings show that the underlying chemistry is very complex, and the removal efficiency is affected by the changes in the chemical matrix, or by changes in the operative conditions. Eawag, Swiss Federal Institute of Aquatic Science and Technology has currently developed SORAS in its laboratory and field tested in the WATSAN Partnership Project in Bangladesh [96]. However, more studies are requested before this technology is feasible in practical uses of arsenic removal [95]. SORAS reduce arsenic contents to approximately 50 to 80%. The method is conceived for usage at household level to treat small quantities of drinking water at virtually no cost. The working principle of SORAS has been shown in Figure 13 [96].

Activated alumina (AA)

A liquid and/or solid residual may be produced from an AA system depending on the type of operation. If the system is regenerated, a liquid waste is produced from the backwash, caustic regeneration, neutralization, and rinse steps. In some instances, sludge may be generated from the regeneration and neutralization streams because some alumina dissolves during the regeneration step and may be precipitated as aluminium hydroxide [97]. If aluminium based sludge is produced because of lowering the pH of the liquid residual, this sludge will contain a high amount of arsenic because of its arsenic adsorption characteristics. This sludge and the remaining liquid fraction of the solution will require disposal [98]. Because both residuals contain arsenic, their disposal may be subject to disposal requirements. When the AA has reached the end of its useful life, the media itself will also become a solid residual that must be disposed [99]. Because of its high arsenic removal capacity, an activated alumina system may be operated on a media throwaway basis rather than a media regeneration basis. When operated on a throw-away basis, the exhausted AA media will be the principal residual produced. This media has the potential of being classified as a hazardous waste because of its high arsenic content. A TCLP (Toxicity Characteristic Leaching Procedure) test is necessary, therefore, to determine its classification and ultimate disposal restrictions [100]. Because the AA media will filter out particulate material in the source water, the media bed will occasionally require backwashing. This backwash water will likely contain some arsenic attached to either the particulate material or the very fine AA material that is removed during backwashing. Consequently, the disposal of the backwash water may also be subject to the disposal requirements [101,102].

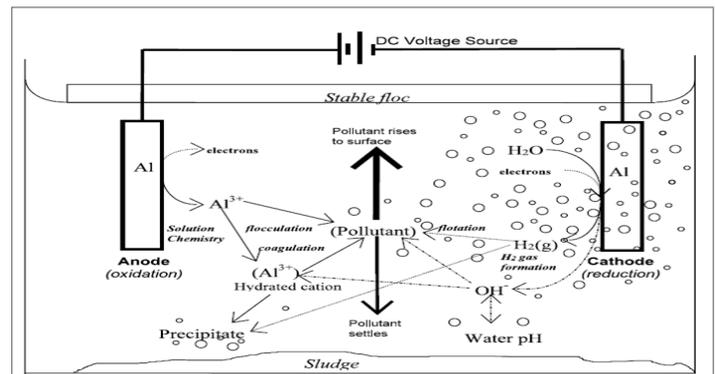


Figure 12: Shows the process of electro coagulation

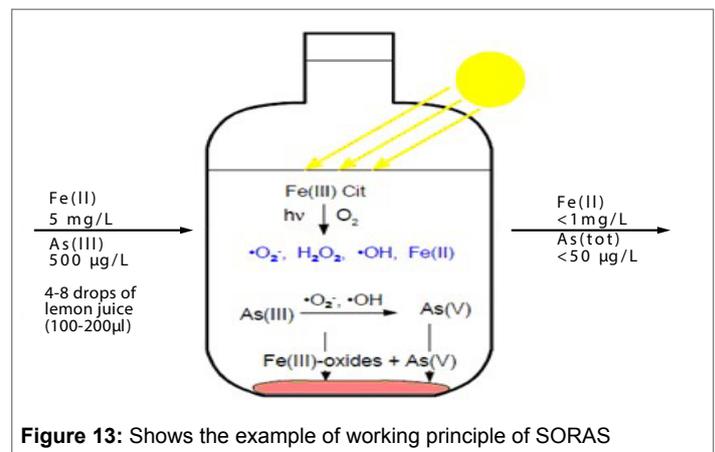


Figure 13: Shows the example of working principle of SORAS

Nano filtration

Nano filtration is also a kind of membrane filtration works on reverse osmosis. It removes molecules and ions effectively. The removal is achieved by the large difference in solution-diffusion rate of water and solute. RO is mainly used for producing desalinated water. Along with harmful ions, it also retains useful minerals. Nano-filtration (NF) process retains large and multivalent ions. NF is also known as “loose RO membranes” due to their relative high water flux [103].

Latest Advancement

Recently, some of researchers have worked on some more effective methods of arsenic removal. Zhang and Sun, 2013 [104,105], invented multifunctional micro/nanostructured MnO_2 spheres successfully and applied them in the removal process of arsenic species from groundwater. As (III) species can be effectively oxidized by the synthesized MnO_2 followed by the adsorption of As (V) species [106]. The synthesized material is repudiated with good adsorption and oxidative capacity required for the removal of arsenic species under controlled conditions.

Cui *et al.* [107], synthesized highly porous, nanostructure ZrO_2 spheres from amorphous ZrO_2 nanoparticles with the help of a food-safe additive, agar powder, which yielded a simple, cheaper, and safer process for the synthesis of ZrO_2 spheres. These ZrO_2 spheres displayed good adsorption capacity on As (III) and As (V) at near neutral pH, without the requirement of pre-oxidation and/or pH adjustment of the arsenic contaminated water.

Comparison between Different Techniques

There are a lot of techniques available and a lot more about to discover for the removal of arsenic from portable water. Every technique has their own pros and cons too. The comparison of suitability, percentage of

arsenic removal and cost effective like matters have been discussed for these available techniques of arsenic removal. Table 1 has well described the comparison of some effective available techniques.

Conclusion

The problem of arsenic contamination of groundwater in all over the world; from Japan to USA and from Sri Lanka to Russia, are visible and not ignorable. There different types of sources for the arsenic contamination of groundwater. Anthropogenic sources are getting more effective day by day in modern ways of development all over the world. Some countries like Bangladesh, India, Nepal and North American countries are having severe condition of arsenic contamination. A lot of effort has been made by so many Governments and WHO in number of location of World to improve the condition of contaminated groundwater and its severe effect on human health. But mass infected conditions like Bangladesh are not in control and it is going bad day by day. In this review, we have discussed causes of arsenic infection in human food chain.

The best arsenic treatment technique for a given utility will depend on arsenic concentration and the species in source water, other constituents in the water, existing treatment processes, treatment costs, and handling

of residuals. Laying techniques where mentioned and discussed in section 4. Some techniques have their benefits along with their back image. For example, Activated Alumina is having good efficiency against arsenic removal from infected water. But the disposal of its hazards residual is prime concern. Reverse Osmosis is good technique. Many of the manufacturing companies of water purifier are using this. But while talking about the mass infected people, it seems that it is unable to fulfil the requirement.

The drinking water contamination is a question on life supporting elements of nature. In this situation the impact will always visible on mass of the people.

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Techniques	Removal Efficiency of As (III)	Removal Efficiency As (V)	Relative costs	Advantages	Disadvantages
Coagulation/Co-Precipitation	Less than 30%	Greater Than 90%	Low	Monitoring is not required. Low costs. Chemicals are easy to manufacture.	Toxic sludge disposal. Skilled operators are required.
Alum Coagulation	Less than 30%	Greater Than 90%	Low	Chemicals are having low cost.	Low efficiency against As (III). Toxic sludge disposal.
Iron Coagulation	60% to 90%	Greater than 90%	Low	Low cost. Good efficiency. Very simple operation. Common chemicals.	Medium removal of As (III). Pre-oxidation may be required.
Enhanced Coagulation	60% to 90%	Greater than 90%	Low to Medium	High removal efficiency of Arsenic as well as organic matter and metal hydroxides.	Emerging technique, not proven on practical scale
Activated Alumina	60% to 90%	Greater than 90%	Medium	Commercially available. High efficiency. Low maintenance cost. No daily sludge disposal.	Every time re-adjustment of pH is required. Hazards residue disposal is quite challenging.
Iron based Sorbents (IBS)	30% to 60%	Greater than 90%	Low to Medium	Plenty of possibilities. There is no re generation.	It requires pH control, replacement of media after exhausting and regular testing to provide safe operation.
Reverse Osmosis	60% to 90%	60% to 90%	High	High removal efficiency. No solid waste. Removes other contamination too. Chemicals are not required.	High running costs. Regular maintenance is required. Re-adjustment of water quality is required.
Nano-filtration	60% to 90%	60% to 90%	High	High removal efficiency.	Large capital is needed. High running costs.

Table 1: Comparison of available arsenic removal techniques of arsenic contaminated water

References

- Bhu-Jal News quarterly journal of central groundwater board (2009) Arsenic in groundwater in India. Ministry of water resources, Government of India 24.
- Barringer JL, Reilly PA (2013) Arsenic in Groundwater: A Summary of Sources and the Biogeochemical and Hydrogeologic Factors Affecting Arsenic Occurrence and Mobility. In: Current perspectives in contaminant hydrology and water resources sustainability. InTech Publishers, New Jersey Water Science Center 83-116.
- Abernathy CO, Calderon RL, Chappell WR (1997) ARSENIC exposure and health effects. Chapman and Hall.
- Meharg AA, Md Rahman M (2003) Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. *Environ Sci Technol* 37: 229-234.
- <http://www.premierwatermn.com/water-quality/water-contaminants/arsenic/>
- Shiv Shankar, Uma Shankar, Shikha (2014) Arsenic Contamination of Groundwater: A Review of Sources, Prevalence, Health Risk, and Strategies for Mitigation. *The Scientific World Journal* 2014: 18 pages.
- Mukherjee A, Mrinal KS, Hossain MA, Ahamed S, Bhaskar Das, et al. (2006) Arsenic Contamination in Groundwater: A Global Perspective with Emphasis on the Asian Scenario. *J HEALTH POPUL NUTR* 24: 142-163.
- Ravenscroft P (2007) Predicting the Global Extent of Arsenic Pollution of Groundwater and its Potential Impact on Human Health. UNICEF, New York.
- <http://www.hydratelife.org/wp-content/uploads/2014/03/via-world-bank.jpg>
- Dubey CS, Mishra BK, Shukla DP, Singh RP, Tajbakhsh M, et al. (2011) Anthropogenic arsenic menace in Delhi Yamuna flood plain. *Environ Earth Sci* 65: 131-139.
- Lalwani S, Dogra TD, Bhardwaj DN, Sharma RK, Murty OP, et al. (2004) Study on arsenic level in groundwater of Delhi using hydride generator accessory coupled with atomic adsorption spectrophotometer. *Indian J Clin Biochem* 19: 135-140.
- Chaurasia N, Mishra A, Pandey SK (2012) Finger Print of Arsenic Contaminated Water in India-A Review. *J Forensic Res* 3:172.
- <http://www.sos-arsenic.net/english/source/>
- <http://www.slideshare.net/sangohanfly/arsenic-groundwater-contamination-in-bangladesh> (slide 11).
- Jha A, Nagrath K, Vijaya Lakshmi K (2001) Access to safe water: Approaches for nanotechnology benefits to reach the bottom of the pyramid. Final Technical Report May 2011. Development alternatives group, New Delhi.
- Chen HW, Frey MM, Clifford D, McNeill NS, Edwards M (1999) Arsenic Treatment Considerations. *Journal of the American Water Works Association* 91: 74-85.
- <http://azzamqonita.blogspot.in/>
- Balakrishna G, Pervez S, Bisht DS (2011) Source apportionment of arsenic in atmospheric dust fall out in an urban residential area, Raipur, Central India. *Atmospheric Chemistry and Physics* 11: 5141-5151.
- Radloff KA, Zheng Y, Michael HA, Stute M, Bostick BC, et al. (2011) Arsenic migration to deep groundwater in Bangladesh influenced by adsorption and water demand. *Nat Geosci* 4: 793-798.
- Lenny HEW, Trang PTK, Lan VM, Stengel C, Amini M, et al. (2011) Arsenic Pollution of Groundwater in Vietnam Exacerbated by Deep Aquifer Exploitation for More Than a Century. *P Natl Acad Sci (PNAS)* 108:1246-1251.
- GaoY, Qui YL, Tain FJ (2011) Organs Distribution of Arsenic in Rat Exposed to Low-Level Arsenic through Drinking Water. *Journal of Environment and Health*.
- Schwarzenbach RP, Egli T, Hofstetter TB, von Gunten Urs, Wehrli B (2010) Global Water Pollution and Human Health. *Annual Review of Environment and Resources* 35: 109-136.
- Appelo CAJ, Drijver B, Hekkenberg R, de Jonge M (1999) Modeling In Situ Iron Removal from Ground Water. *Groundwater* 37: 811-817.
- Argos M, Kalra T, Pierce BL, Chen Y, Islam T, et al. (2011) A Prospective Study of Arsenic Exposure From Drinking Water and Incidence of Skin Lesions in Bangladesh. *Am J Epidemiol* 174: 185-194.
- Van Geen A, Ahmed KM, Akita Y, Alam MJ, Culligan PJ, et al. (2011) Fecal contamination of shallow tubewells in Bangladesh inversely related to arsenic. *Environ Sci Technol* 45: 1199-1205.
- National Institute of Hydrology Roorkee Central Ground Water Board, New Delhi (2010) Mitigation and Remedy of Groundwater Arsenic Menace in India: A Vision Document. Under the aegis of: Ministry of Water Resources, Government of India, New Delhi.
- Acharyya SK, Chakraborty P, Lahiri S, Raymahashay BC, Guha S, Et al. (1999) Arsenic poisoning in the Ganges delta. *Nature* 401: 545-546.
- Dhar RK, Zheng Y, Saltikov CW, Radloff KA, Mailloux BJ, et al. (2011) Microbes enhance mobility of arsenic in Pleistocene aquifer sand from Bangladesh. *Environ Sci Technol* 45: 2648-2654.
- Mahmood, Halder AK (2011) The socioeconomic impact of Arsenic poisoning in Bangladesh. *Journal of Toxicology and Environmental Health Sciences* 3:65-73.
- Mandal BK, Suzuki TK (2002) Arsenic round the world: a review. *Talanta* 58: 201-235.
- USEPA (1993) Treatment and occurrence—arsenic in potable water supplies. Prepared by Malcolm Pirnie, for the Office of Ground Water and Drinking Water, Washington, DC.
- Hira-Smith MM, Yuan Y, Savarimuthu X, Liaw J, Hira A, et al. (2007) Arsenic concentrations and bacterial contamination in a pilot shallow dugwell program in West Bengal, India. *J Environ Sci Health A Tox Hazard Subst Environ Eng* 42: 89-95.
- Hoque MA, Burgess WG (2012) 14C dating of deep groundwater in the Bengal Aquifer System, Bangladesh: implications for aquifer anisotropy, recharge sources and sustainability. *Journal of Hydrology* 444-445: 209-220.
- National Academy of Sciences (1977) Medical & Biological Effects of Environmental Pollutants: Arsenic. Washington DC.
- WS Atkins International Limited (2001) Rapid Assessment of Household Level Arsenic Removal Technologies, Phase-I and Phase-II, Final Report.
- Hughes MF, Beck BD, Chen Y, Lewis AS, Thomas DJ (2011) Arsenic Exposure and Toxicology: A Historical Perspective. *Toxicol Sci* 123: 305-332.
- AWWA (1999) Water Quality and Treatment: a handbook of community water supplies. McGraw- Hill, New York.
- Sorg TJ (2000) Regulations on the disposal of arsenic residuals from drinking water treatment plants. EPA.
- Budinova T, Savova D, Tsyntsarski B, Ania CO, Cabal B, et al. (2009) Biomass waste-derived activated carbon for the removal of arsenic and manganese ions from aqueous solutions. *Applied Surface Science* 255: 4650-4657.
- Cornell RW, Schwertmann U (1996) The Iron Oxides. 1st edition, Wiley-VCH: New York.
- Lemley AT, Wang Q, Saltmiras DA, (2003) In Pesticide Decontamination and Detoxification, ACS Symposium Series, No. 863; Gan JJ, Zhu

- PC, Aust SD, Lemley AT(eds) Oxford University Press: USA, 65-83.
42. Moura FCC, Oliveira GC, Araujo MH, Ardisson JD, Macedo WAA, et al. (2006) Highly reactive species formed by interface reaction between FeO–iron oxides particles: An efficient electron transfer system for environmental applications. *Appl Catal A: General* 307: 195-204.
 43. Costa RCC, Lelis MFF, Oliveira LCA, Fabris JD, Ardisson JD, et al. (2006) Novel active heterogeneous Fenton system based on $Fe_{3-x}M_xO_4$ (Fe, Co, Mn, Ni): The role of M^{2+} species on the reactivity towards H_2O_2 reactions. *J Hazard Mater B* 129: 171-178.
 44. Costa RCC, Moura FCC, Ardisson JD, Fabris JD, Lago RM (2008) Highly active heterogeneous Fenton-like systems based on FeO/Fe₃O₄ composites prepared by controlled reduction of iron oxides. *Appl Catal B Environ* 83: 131-139.
 45. Coelho F, Ardisson JD, Moura FCC, Lago RM, Murad E, et al. (2008) Potential application of highly reactive Fe(0)/Fe₃O₄ composites for the reduction of Cr(VI) environmental contaminants. *Chemosphere* 71: 90-96.
 46. Moura FCC, Araujo MH, Costa RCC, Fabris JD, Ardisson JD, et al. (2005) Efficient use of Fe metal as an electron transfer agent in a heterogeneous Fenton system based on Fe⁰/Fe₃O₄ composites. *Chemosphere* 60: 1118-1123.
 47. Moura FC, Araujo MH, Dalmázio I, Alves TM, Santos LS, et al. (2006) Investigation of reaction mechanisms by electrospray ionization mass spectrometry: characterization of intermediates in the degradation of phenol by a novel iron/magnetite/hydrogen peroxide heterogeneous oxidation system. *Rapid Commun Mass Spectrom* 20: 1859-1863.
 48. Magalhães F, Moura FCC, Ardisson JD, Lago RM (2008) $LaMn_{1-x}Fe_xO_3$ and $LaMn_{0.1-x}Fe_{0.90}Mo_xO_3$ perovskites: synthesis, characterization and catalytic activity in H_2O_2 reactions. *Mater Res* 11: 307-312.
 49. Moura FCC, Araujo MH, Ardisson JD, Macedo WAA, Albuquerque AS, et al. (2007) Investigation of the solid state reaction of $LaMnO_3$ with Fe⁰ and its effect on the catalytic reactions with H_2O_2 . *J Braz Chem Soc* 18: 322-329.
 50. Choong TSY, Chuah TG, Robiah Y, Gregory Koay FL, Azni I (2007) Arsenic toxicity, health hazards and removal techniques from water: an overview. *Desalination* 217: 139-166.
 51. BAMWSP/DFID/WaterAid Bangladesh (2001) Rapid Assessment of Household Level Arsenic Removal Technologies. Phase II Report. Dhaka.
 52. Sarkar S, Greenleaf JE, Gupta A, Ghosh D, Blaney LM, et al. (2010) Evolution of community-based arsenic removal systems in remote villages in West Bengal, India: assessment of decade-long operation. *Water Res* 44: 5813-5822.
 53. Jekel M, Seith R (2000) Comparison of conventional and new techniques for the removal of arsenic in a full scale water treatment plant. *Water Supply* 18: 628-631.
 54. http://water.me.vccs.edu/exam_prep/mfiltration.html
 55. Tuna AÖA, Özdemir E, Simsek EB, Beker U (2013) Removal of As (V) from aqueous solution by activated carbon-based hybrid adsorbents: impact of experimental conditions. *Chem Eng J* 223: 116-128.
 56. Chang Q, Lin W, Ying WC (2010) Preparation of iron-impregnated granular activated carbon for arsenic removal from drinking water. *J Hazard Mater* 184: 515-522.
 57. Lodeiro P, Kwan SM, Perez JT, González LF, Gérente C, et al. (2013) Novel Fe loaded activated carbons with tailored properties for As (V) removal: adsorption study correlated with carbon surface chemistry. *Chem Eng J* 215-216: 105-112.
 58. Chen W, Parette R, Zou J, Cannon FS, Dempsey BA (2007) Arsenic removal by ironmodified activated carbon. *Water Res* 41: 1851-1858.
 59. Zhang S, Li X, Chen JP (2010) Preparation and evaluation of a magnetite-doped activated carbon fiber for enhanced arsenic removal. *Carbon* 48: 60-67.
 60. Liua Z, Zhanga FS, Sasaib R (2010) Arsenate removal from water using Fe₃O₄-loaded activated carbon prepared from waste biomass. *Chemical Engineering Journal* 160: 57-62.
 61. Yürüm A, Atakli ZÖK, Sezen M, Semiat R, YürümY (2014) Fast deposition of porous iron oxide on activated carbon by microwave heating and arsenic (V) removal from water. *Chemical Engineering Journal* 242: 321-332.
 62. Arcibar-Orozco JA, Josue DB, Hurtado JCR, Mendez JRR (2014) Influence of iron content, surface area and charge distribution in the arsenic removal by activated carbons. *Chemical Engineering Journal* 249: 201-209.
 63. Teixeira APC, Tristão JC, Araujo MH, Oliveira LCA, Moura FCC, et al. (2012) Iron: a Versatile Element to Produce Materials for Environmental Applications. *J Braz Chem Soc* 23: 1579-1593.
 64. Kartinen Jr EO, Martin CJ (1995) An overview of arsenic removal processes. *Desalination* 103: 79-88.
 65. Katsoyiannis IA, Zouboulis AI (2004) Application of biological processes for the removal of arsenic from groundwaters. *Water Research* 38: 17-26.
 66. http://www.meco.com/public/userfiles/photos/membrane_filtration/reverse-osmosis.jpg
 67. Jour Li, Weiwei Gao, Song Wu, Liqiong Qiu, Shengqiang Guo, et al. (2013) High-Density Three-Dimension Graphene Macroscopic Objects for High-Capacity Removal of Heavy Metal Ions. *Sci Rep* 3.
 68. Ruiz C, Anaya JM, Ramirez V, Alba GI, Garcia MG, et al. (2011) Soil Arsenic Removal by a Permeable Reactive Barrier of Iron Coupled to an Electrochemical Process. *Int J Electrochem Sci* 6: 548-560.
 69. Upadhyay RK, Soin N, Roy SS (2004) Role of graphene/metal oxide composites as photocatalysts, adsorbents and disinfectants in water treatment: a review. *RSC Adv* 4: 3823-3851.
 70. Rashmi RD, Iohborlang MU, Das B, Borah K, Thakur AJ, et al. (2014) Removal of iron and arsenic (III) from drinking water using iron oxide-coated sand and limestone. *Appl Water Sci* 4:175-182.
 71. Kuriakose S, Singh TS, Pant KK, (2004) Adsorption of As (III) from aqueous solution onto iron oxide impregnated activated alumina. *Water Quality Research Journal of Canada* 39: 258-266.
 72. Driehaus W, Jekel M, Hildebrandt U (1998) Granular ferric hydroxide—a new adsorbent for the removal of arsenic from natural water. *Journal of Water Supply: Research and Technology* 47: 30-35.
 73. Thirunavukkarasu OS, Viraraghavan T, Subramanian KS (2003) Arsenic removal from drinking water using granular ferric hydroxide. *Water SA* 29: 161-170.
 74. Badruzzaman M, Westerhoff P, Knappe DRU (2004) Intraparticle diffusion and adsorption of arsenate onto granular ferric hydroxide (GFH). *Water Res* 38: 4002-4012.
 75. Guan XH, Wang J, Chusuei CC (2008) Removal of arsenic from water using granular ferric hydroxide: macroscopic and microscopic studies. *J Hazard Mater* 156: 178-185.
 76. AIIH (2001) Arsenic mitigation programme for technology and park on arsenic removal devices. In Convener Director, Basu BB, Ed., *School of Fundamental Research, Kolkata, India*.
 77. Lee Y, Um IH, Yoon J (2003) Arsenic (III) oxidation by iron (VI) (ferrate) and subsequent removal of arsenic (V) by iron (III) coagulation. *Environ Sci Technol* 37: 5750-5756.
 78. Klas S, Kirk DW (2013) Advantages of low pH and limited oxygenation in arsenite removal from water by zero-valent iron. *J Hazard Mater* 252-253: 77-82.
 79. Khan AH, Rasul SB, Munir AKM, Habibuddowl M, Alauddin M, et al. (2000) Appraisal of a simple arsenic removal method for groundwater of Bangladesh. *Journal of Environmental Science and Health A: Toxic/Hazardous Substances and Environmental Engineering* 35: 1021-1041.

80. Chappell WR, Abernathy CO, Calderon RL (2001) Arsenic Exposure and Health Effects IV. In Alauddin M, Hussam A, Khan AH, Habibuddowla M, Rasul SB, (eds) et al. Critical evaluation of a simple arsenic removal method for groundwater of Bangladesh. Elsevier, USA, 441-451.
81. Hussam A, Munir AKM (2007) A simple and effective arsenic filter based on composite iron matrix: development and deployment studies for groundwater of Bangladesh. *Journal of Environmental Science and Health A Toxic/Hazardous Substances and Environmental Engineering* 42: 1869-1878.
82. Chiew H, Sampson ML, Huch S, Ken S, Bostick BC (2009) Effect of groundwater iron and phosphate on the efficacy of arsenic removal by iron-amended bios and filters. *Environmental Science and Technology* 43: 6295-6300.
83. Neumann A, Kaegi R, Voegelin A, Hussam A, Munir AKM, et al. (2013) Arsenic removal with composite iron matrix filters in Bangladesh: A field and laboratory study. *Environmental Science and Technology* 47: 4544-4554.
84. Noubactep C (2013) Metallic iron for water treatment: a critical review. *Clean-Soil Air Water* 41: 702-710.
85. Tresintsi S, Simeonidis K, Vourlias G, Stavropoulos G, Mitrakas M (2012) Kilogram-scale synthesis of iron oxy-hydroxides with improved arsenic removal capacity: study of Fe(II) oxidation-precipitation parameters. *Water Res* 46: 5255-5267.
86. Katsoyiannis IA, Ruettimann T, Hug SJ (2008) pH dependence of fenton reagent generation and As(III) oxidation and removal by corrosion of zero valent iron in aerated water. *Environ Sci Technol* 42: 7424-7430.
87. Vasudevan S, Lakshmi S, Sozhan G (2010) Studies relating to removal of arsenic by electrochemical coagulation; optimization, kinetics, coagulant characterization. *Sep Sci Technol* 45: 1313-1325.
88. Vasudevan S, Mohan S, Sozhan G, Raghavendran NS, Murugan V (2006) Studies on the oxidation of As (III) to As (V) by in-situ-generated hypochlorite. *Industrial & engineering chemistry research* 45: 7729-7732.
89. Lakshmanan D, Clifford DA, Samanta G (2010) Comparative study of arsenic removal by iron using electrocoagulation and chemical coagulation. *Water Research* 44: 5641-5652.
90. Lacasa E, Cañizares P, Sáez C, Fernández FJ, Rodrigo MA (2011) Removal of arsenic by iron and aluminium electrochemically assisted coagulation. *Separation and Purification Technology* 79: 15-19.
91. Vasudevan S, Oturan MA (2014) Electrochemistry: as cause and cure in water pollution—an overview. *Environmental chemistry letters* 12: 97-108.
92. Vasudevan S, Lakshmi J, Sozhan G (2010) Studies on the Removal of Arsenate by Electrochemical Coagulation Using Aluminum Alloy Anode. *CLEAN- Soil Air Water* 38: 506-515.
93. Vasudevan S, Lakshmi J, Sozhan G (2012) Studies on the removal of arsenate from water through electrocoagulation using direct and alternating current. *Desalination and Water Treatment* 48: 163-173.
94. Parga JR, Cocke DL, Valenzuela JL, Gomes JA, Kesmez M, et al. (2005) Arsenic removal via electrocoagulation from heavy metal contaminated groundwater in La Comarca Lagunera M'xico. *J Hazard Mater* 124: 247-254.
95. Alexandre Andrade Cerqueira and Monica Regina da Costa Marques (2012) Electrolytic Treatment of Wastewater in the Oil Industry, *New Technologies in the Oil and Gas Industry*, Dr. Jorge Salgado Gomes (Ed.), ISBN: 978-953-51-0825-2.
96. García MG, d'Hiriart J, Giullitti J, Lin H, Custo G, et al. (2004) Solar light induced removal of arsenic from contaminated groundwater: the interplay of solar energy and chemical variables. *Solar Energy* 77: 601-613.
97. Wegelin M, Gechter D, Hug S, Mahmud A, Motaleb A (2005) SORAS—a simple arsenic removal process, in *Rural and Peri-urban Water Treatment*. EAWAG.
98. Hug SJ, Canonica L, Wegelin M, Gechter D, Von Gunten U (2001) Solar Oxidation and Removal of Arsenic at Circumneutral pH in Iron Containing Waters. *Environ Sci Technol* 35: 2114-2121.
99. Lin TF, Wu JK (2001) Adsorption of arsenite and arsenate within activated alumina grains: equilibrium and kinetics. *Water Res* 35: 2049-2057.
100. Singh TS, Pant KK (2004) Equilibrium, kinetics and thermodynamic studies for adsorption of As (III) on activated alumina. *Separation and Purification Technology* 36: 139-147.
101. Tripathy SS, Raichur AM (2008) Enhanced adsorption capacity of activated alumina by impregnation with alum for removal of As(V) from water. *Chemical Engineering Journal* 138: 179-186.
102. Kunzru S, Chaudhuri M (2005) Manganese amended activated alumina for adsorption/oxidation of arsenic. *J Environ Eng* 131: 1350-1353.
103. Giles DE, Mohapatra M, Issa TB, Anand S, Singh P (2011) Iron and aluminium based adsorption strategies for removing arsenic from water. *Journal of Environmental Management* 92: 3011-3022.
104. Zhu J, Pigna M, Cozzolino V, Caporale AG, Violante A (2013) Higher sorption of arsenate versus arsenite on amorphous Al-oxide, effect of ligands. *Environmental Chemistry Letters* 11: 289-294.
105. Brandhuber P, Gary A (1998) Alternative methods for membrane filtration of arsenic from drinking water. *Desalination* 117: 1-10.
106. Zhang T, Sun DD (2013) Removal of arsenic from water using multifunctional micro-/nano-structured MnO₂ spheres and microfiltration. *Chemical Engineering Journal* 225: 271-279.
107. Cui H, Su Y, Li Q, Gao S, Shang JK (2013) Exceptional arsenic (III,V) removal performance of highly porous, nanostructured ZrO₂ spheres for fixed bed reactors and the full-scale system modeling. *Water Res* 47: 6258-6268.www