Research Journal of Recent Sciences _____ ISSN 2277-2502
Vol. 3**(ISC-2013),** 7-13 **(2014)** *Res. J. Recent. Sci.*

Review Paper

Arsenic-21st Century Calamity- A Short Review

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Available online at: www.isca.in
Received 11th January 2014, revised 19th February 2014, accepted 13th March 2014

Abstract

Arsenic, since its isolation in 1250 A.D by Albertus Magnus, has been a continuous centre of controversy. It belongs to the metalloid group of elements and known as a major contaminant in the environment. The source of occurrence of arsenic in the groundwater is natural as well as anthropogenic. The new EPA standard is 0.01 ppm on the recommendation of National Academy of Science. The first major case of arsenicosis was reported from Argentina in 1920's and afterward it was reported from India in 1983 and soon it becomes a serious calamity in Bangladesh. Hitherto, more than 137 million people are suffering from arsenicosis. Arsenic is a protoplastic poison due to its effect on sulphydryl group of cells interfering with cell enzymes, cell respiration and mitosis. This is very important issue but much less discussed. The present study was conducted to review the studies conducted on arsenic and its mitigation. From a comprehensive literature review it was found that arsenicosis is a slow poison which manifest itself over a period of 5-20 years. This short review highlights and provides an overview of arsenic, its impact on health and available mitigation techniques. Conclusions have been drawn from the literature reviewed, and suggestions for future research are proposed.

Keywords: Arsenicosis, toxicity, drinking water, adsorbent, technique.

Introduction

Arsenic was first documented by Albertus Magnus in 1250 A.D[1]. Arsenic in drinking water has been reported as the most widespread geogenic contaminant in water sources worldwide. The discovery of arsenic in drinking water in many areas of the world has caused widespread public health concern[2]. Arsenic is reported to be a major calamity of 20th -21st century. In groundwater arsenic is present mainly in nonionic trivalent (As III) and ionic pentavalent (As V) inorganic form in different proportions depending on the environmental condition of the aquifer. The solubility of arsenic in water is usually controlled by redox condition, pH, biological activity and adsorption reaction. The reducing condition at low Eh value converts arsenic into a more mobile arsenite form, whereas at high Eh value arsenate is the major arsenic species. Arsenite (As III) is more toxic than arsenate (As V) and difficult to remove from water by most technique[3].

Background: The first major case of arsenic pollution was recognized first in Cardoba Province of Argentina in 1920s. The next major case came in 1960s in alluvial wells in Taiwan and Andean river in Chile. Both cases resulted in major causalities. In modern era, the major outbreak was reported from West Bengal, India in 1983, and soon the major calamity was reported from Bangladesh. Up to 1995 arsenic pollution had been identified in 14 countries, but since 1996, arsenic pollution has been reported from more than seventy countries on six continents so far[4].

Among 70 countries in different parts of the world affected by groundwater arsenic contamination, the largest population at risk is in Bangladesh followed by West Bengal in India[5]. High concentration of arsenic in drinking water are found in various parts of the world including, Argentina, Bangladesh, Chile, China, Hungary, India, Mexico, Nepal, Pakistan, Thailand, USA, Vietnam and Combodia.

The first footprint of arsenic contamination in India was reported in Punjab, Haryana, Himachal Pradesh, and Uttar Pradesh. In modern era, the first case was reported from West Bengal in 1983. In 2002, arsenic contamination located in Bihar in middle Ganga plain and at the same time apprehended contamination in Uttar Pradesh lying in middle and upper Ganga plain. In 2004, 17 villages of the Sahebganj district of Jharkhand, in the middle Ganga plain reported to be affected. Simultaneously in Assam, two districts had an arsenic concentration above permissible limit. All the States and Countries surveyed in the Ganga-Meghan-Brahmaputra (GMB) plain, which has an area of approximately 500,000 square kilometer and a population over 500 million, are at risk from groundwater arsenic contamination reported by Chaurasia et. al[6]. In this paper, impact of arsenic on health and various mitigation techniques available are discussed and recommendation for future research work is given based on literature reviewed.

Maximum Contaminant level for Arsenic in Drinking water: In 1975, under Safe Drinking Water Act (SDWA), Environmental Protection Agency (EPA) established a

maximum contaminant level for arsenic at 0.05 ppm based on a Public Health Service standard originally established in 1942. Since that time, revision of maximum contaminant level has been considered a number of times[7]. The Safe Drinking Water Act of 1994 mandates that the US EPA identifies and regulates drinking water contaminants that may have an adverse human health effect and that are known or anticipated to occur in public water supply system. The SDWA was amended in 1996 and these amendments required that the EPA develop an Arsenic Research Strategy and publish a proposal to revise the Arsenic maximum contaminant level by January 2000. A draft of Arsenic Research Plan was prepared by EPA in December 1996 and was finalized in February 1998 based upon a technique review by the EPA's Board of Scientific Counselor[8].A March 1999 report by the National Academy of Sciences (NAS) concluded that the current standard of 0.05 ppm does not achieve EPA's goal of protecting public health and should be lowered as soon as possible. On January 22, 2001 EPA adopted a new standard for arsenic in drinking water at 10 ppb or 0.01 ppm, replacing the old standard of 50 ppb or 0.05 ppm. The rule becomes effective on February 22, 2002. The date by which it came into force[9] is January 23, 2006.

Impact of Arsenic on Human Health

Arsenic is a metalloid with a name derived from the Greek word '*Arsenikon*', meaning potent[10]. Arsenic continues to be one of the most extensive environmental poisonous elements throughout the world. Since 1983, major outbreak in West Bengal, India, millions of people have been exposed to dangerous levels in their drinking water, thus spurring a high level of activity in all public health efforts for the treatment and prevention of arsenic related illness.

The effects of arsenic on the human body have been known for over four millennia; its legacy as a toxic substance, both intentionally, accidentally, has been documented in history. Humans are exposed to arsenic poisoning primarily from air, food and water. However, elevated arsenic level in drinking water is the major cause of arsenic toxicity in the world[11]. Acute and sub-acute poisoning results from ingestion of large quantities of arsenic with lower exposure time, whereas chronic poisoning occurs due to consumption of arsenic contaminated water for a long period of time. Figure 1, indicates the manifestation of arsenic poisoning or arsenicosis in form of melanosis, leucomelanosis and keratosis.

Human health effects of chronic arsenic toxicity are designated by the term '*Arsenicosis*' which was first coined by Guha et. al,[12]and later used by WHO[13] to imply a chronic disease caused by prolonged exposure in humans to arsenic. Previously the condition was described as Arseniasis, Arsenism, Arsenicism, etc. The symptoms of chronic arsenic toxicity are insidious in onset and are dependent on the magnitude of the dose and duration of its exposure. In India, cases of arsenic toxicity including liver fibrosis due to drinking of arsenic contaminated water were reported from Chandigarh[14] in early 1978. In 1984, large number of cases of arsenic induced skin lesions were reported from Kolkatta, West Bengal, India[15]. Since then incidences of chronic arsenic toxicity have been reported in the most states adjoining the upper, middle and lower Ganga and Brahmaputra Plain.

Several studies were conducted to know the possible effect of arsenic on human health by various researchers throughout the world. The most detailed studies were conducted by Chakraborti and others[16], IARC[2], Guha and others[12,17,11], WHO[13], Saha[18], Tay[19], Ahmad and others[20,21], Milton and others[22], Ehrenstein and others[23,24], Sun and others[25], Rahman and others[26],Santra and others[27], Oshikawa and others[28], ATSDR[29],Ahsan and others[30,31], Andrew and others[32,33,34], Agusa and others[35],Chen and others[36], Chung and others[37], Drobha and others[38], Druwe and others[39], Argos and others[40], Hughes and others[41].

Arsenic poisoning and its effect: Arsenic is a protoplastic poison due to its effect on sulphydryl group of cells interfering with cell enzyme, cell respiration and mitosis[42]. Arsenic enters the human body through ingestion, inhalation or skin absorption. Most ingested and inhalated arsenic is well absorbed through the gastrointestinal tract and lung into the blood stream. Studies link inorganic arsenic ingestion to a number of health effects. These health effects include;

Figure-1
Arsenicosis Manifestations

Cancerous Effects: Skin, bladder, lung, kidney, nasal passages, liver and prostate cancer; and Non-Cancerous Effects: Cardiovascular, pulmonary, immunological, neurological and endocrine effects[9].

Respiratory Effects: Effects of Arsenic on the human respiratory system have been reported both from occupational exposure as well as from tube well water arsenic toxicity. Exposure to arsenic results in laryngitis, bronchitis, and tracheobronchitis causing stuffy nose, sore throat, hoarseness and chronic cough etc[43]. Chronic asthmatic bronchitis and asthma is a common complication of groundwater arsenic toxicity [44].

Cardiovascular Effects: Axelson and others[45], Lee[46], and Wall[47] reported that chronic inhalation of arsenic trioxide can increase the risk of death in humans from cardiovascular disease. Zaldivar[48] accounted several cases of myocardial infarction and arterial thickening in children who consumed water containing about 0.6 mg/l arsenic. Arsenic ingestion through food or water may have serious effects on the human cardiovascular system. Both acute and chronic arsenic exposure cause altered myocardial depolarization and cardiac arrhythmias that may lead to heart failure [49, 50].

Gastrointestinal Effects: Gastrointestinal symptoms are common in acute poisoning but not in chronic like groundwater arsenicosis. EPA[9], Goebel and others[51], reported that clinical signs of gastrointestinal irritation from acute arsenic poisoning include burning lips, painful swallowing, thirst, nausea and abdominal colic. The most likely mechanism of gastrointestinal toxicity is damage to the epithelial cells, with resulting irritation.

Hematological Effects: The hematopoietic system is also affected by both short and long term arsenic exposure. Anemia and leucopenia are common effects of poisoning and have been reported as resulting from acute[52], intermediate[53], and chronic oral exposures[54]. These effects may be due to direct haemolytic or cytotoxic effects on the blood cells. High concentration of arsine up to 10 ppm can cause death within hours due to RBC haemolysis[55].

Hepatic Effects: Arsenic was the first chemical agent to which liver disease was attributed in humans. Since the liver tends to accumulate arsenic with repeated exposures, hepatic involvement has been reported most commonly as a complication of chronic exposures over period of months or year[56].

Renal Effects: Like the liver, the Kidneys will accumulate arsenic in the presence of repeated exposure. The Kidneys are the major route of arsenic excretion, as well as major sites of conversion of pentavalent arsenic into the more toxic and less soluble trivalent arsenic. Sites of arsenic damage in the kidney include capillaries, tubules and glomeruli[57, 58].Arsine is likely to cause tubular necrosis with partial or complete renal failure, requiring hemodialysis for removal of the hemoglobin bound arsenic[59].

Dermal Effects: Skin disorders have been documented in several epidemiological studies in which people consumed drinking water that contained arsenic. Characteristic effects of arsenic ingestion included generalized hyperkeratosis, warts or corn on the palms and soles, and areas of hyper-pigmentation interspersed with small areas of hypo-pigmentation on the face, neck and back [60].

Neurological Effects: Pershagen and others[61] reported that ingestion of inorganic arsenic can result in neural injury. Like the cardiovascular system, both the peripheral and central components of the nervous system can be damaged by arsenic. In acute high exposure often causes encephalopathy with such symptoms as headache, lethargy, mental confusion hallucination, seizures and coma[62].

Developmental Effects: Nordstrom and others[63] found that babies born to women exposed to arsenic dusts during pregnancy had a higher than expected incidence of congenital malformations. The average birth weight of the babies was slightly below average. In chronic arsenicosis from groundwater, no development defect has been reported[64].

Mutagenic Effects: Mutagenesis includes the induction of DNA damage and a wide variety of genetic alterations, which can range from simple gene mutations. Some of these changes may cause genetic damage transmissible to subsequent generations, and / or some may cause cancer or their problems in the exposed generations[65]. Arsenic has long been known to cause chromosomal damage, but most investigators have been unable to induce direct gene mutation[66,57]. Barrett and others[67], Nakamuro and Sayato[68], Nordenson and others[69], reported that the comparisons of chromosome aberration frequencies induced by trivalent and pentavalent arsenic have indicated that the trivalent forms are far more potent and genotoxic than the pentavalent forms.

Diabetes: Guha[11] reported that Chronic Arsenic Toxicity may induce diabetes mellitus in humans by his research conducted in Bangladesh which suggests significantly increased prevalence of diabetes mellitus due to drinking arsenic contaminated water among subjects with keratosis compared with subjects who did not have such lesions. A significant trend in risk between an approximate time –weighted arsenic exposure and the prevalence of diabetes mellitus strengthened the possibility of a causal association[70].

Arsenicosis and Cancer: Leitch and Kennaway[71] conducted some of the first animal carcinogenicity studies with arsenic. A follow up study under similar conditions produced negative results[72].These results by Leitch and Kennaway[71], of no carcinogenic effects with arsenic in one experiment, followed

by limited positive results, are similar to what has been published up to the 1990s. Many Studies of experimental arsenic carcinogenesis using oral, dermal or parenteral administration followed over the years. These studies included mice and rats [41].

International Agency for Research on Cancer[2] evaluated data from ecological studies, cohort studies and case-control studies from many countries and observed that arsenic was potentially carcinogenic for skin cancer in humans. Malignant arsenical skin lesions may be Bowen's disease (Intraepithelial carcinoma or carcinoma in situ), basal cell carcinoma or squamous cell carcinoma. Further there is increased risk of development of urinary bladder cancer and lung cancer due to chronic exposure to arsenic. Guha[11] reported that epidemiological studies conducted in several countries involving populations with high long term exposure to arsenic found increased risk for kidney cancer also. Relative risk estimates for kidney cancer were generally lower than those for urinary bladder cancer, and no studies have reported dose-response relationships on the basis of the individual exposure data. IARC[2] further reported excess mortality from prostate cancer in south-west Taiwan. Inconsistent findings were reported for other cancers.

Mitigation Techniques for Arsenic

Several techniques or methods are available for removal of arsenic from water in large conventional treatment plants. The most commonly used processes of arsenic removal from water have been described by EPA[73], Mohan and Pittman[5], Keith, Abraham and Lili[7], Thomas and others[74], Mondal, Majumder and Mohanty[75],Cheng and others[76], Hering and others and [77,78], Kartinen and Martin[79], Shen[80], Joshi and Chaudhari[81]. A detailed review of arsenic removal technologies has been presented by Sorg and Logsdon[82]. Many of the arsenic removal technologies have been discussed in details in the AWWA reference book[83].Comprehensive reviews of arsenic removal processes have been documented by Johnston, Heijnen and Wurzel[84] and Ahmed[85].

The basic principle of arsenic removal are based on conventional technique of Oxidation, Co-precipitation, adsorption on Coagulated flocs, adsorption on Sorptive media, ion exchange and membrane filtration. Oxidation of arsenite (As III) to arsenate (As V) is needed for effective removal of arsenic from groundwater by most treatment methods. The most common arsenic removal technologies can be grouped into the four categories: Oxidation and Sedimentation; Coagulation and Filtration; Sorptive filtration and Membrane filtration [3].

According to Ngai and others[86], more than fifty treatment technologies exist worldwide. Several filters for arsenic removal were developed. Simple filters with iron in various forms, for example, fillings, nails have shown greater promises for some years in Bangladesh[87]. But many of these treatment technologies have serious drawbacks, including troublesome maintenance, high costs, insufficient treatment rate, and/or reliance on materials unavailable in remote villages[86]. Arsenic filters are realistic solution if they are suitable to the local constraints.

Management of Arsenicosis

Despite the magnitude of this potentially fatal toxicity, there is no effective therapy. Complications of moderate and severe form of arsenicosis may not be prevented even after remediation of the arsenic contaminated water. However, drinking predominantly arsenic free water increased the probability of regression of arsenicosis in patient with mild stage lesions but not in those with more advanced stage lesions. Chelation therapy is thought to be the specific therapy for relief of systemic clinical manifestations and reduction of arsenic stores in the body, reducing subsequent cancer risk reported by Guha[11]. Further, the use of antioxidants like vitamin A, C and E found to improve the condition of arsenicosis patient in Bangladesh reported by Ahmad[88].

Conclusion

Arsenic is a major global problem affecting more than 500 millions of population all over the world. Arsenic enters the human body through ingestion, inhalation or skin absorption. Arsenicosis develops after six months to two year or more depending on the amount of intake of arsenic laden groundwater and arsenic concentration in the water. A wide variety of adverse health effects, including severe skin lesions, cardiovascular, neurological, hematological and cancerous effects have been attributed to chronic arsenic exposure, primarily from drinking water. Taking it as a serious note, various studies were conducted to find out the technique for mitigation of arsenic from drinking water but all of these are not free from drawbacks. Though arsenic filters are realistic solution if they are suitable to the local constraints. Further, for the treatment of arsenicosis patient, Chelation therapy and use of antioxidants are applied but the best way is to stop drinking arsenic contaminated water. This is concluded that arsenic contamination is a serious problem but hitherto there is neither effective treatment technologies are present nor effective medicines are available for the treatment of arsenicosis patient. Thus, this study recommends future research for the effective sustainable arsenic filter technology and effective therapy.

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