Arsenic contamination, exposure routes and public health

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Natural processes such as volcanic eruptions, forest fires, and dissolution of arsenic rich minerals underground contribute to arsenic contamination in the environment. Human activities like mining, application of herbicides and pesticides, wood preservation and irrigation greatly increase levels of arsenic in the soil. Arsenic contaminated soils play a central role in As contamination in the environment. Arsenic contaminated soils may pollute the groundwater below through leaching while dust from contaminated soils may also pollute the air. Irrigation with arsenic contaminated water and atmospheric deposition can also increase As concentration in the soil. People are exposed to arsenic via diet (food chain contamination), drinking of arsenic contaminated groundwater, dermal contact, dust ingestion, and inhalation of arsenic rich dust. Children are particularly exposed to arsenic in indoor dust while playing on the floor and outdoors on playgrounds built with the wood preserving; chromate copper arsenate (CCA). Exposure to As has been associated with health problems such as cancer, cardiovascular and respiratory diseases, hearing problems, reproductive health problems in pregnant women and it affects the unborn. The health effects of As indicate the importance of combating arsenic contamination in order to protect public health.

Keywords: Arsenic; Exposure routes; Health effects; biomarkers; irrigation; pesticide; mining


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Introduction

Arsenic (As) can be found naturally in minerals, parent rocks, soil, water, atmosphere, and living organisms. In addition to its natural origin, anthropogenic activities such as mining, agriculture, wood preservation, pesticide application and military operations have increased its levels in the environment. However, most of the severe As contaminations reported in literature have been due to natural sources.

The largest and most severe As contamination in the world occurred in Bangladesh decades ago due to dissolution of arsenic rich minerals in underlying parent rocks which led to groundwater contamination. Arsenic contaminated soils and groundwater have also been reported in other countries such as Argentina, Australia, Brazil, Canada, Ghana, India, China, Nepal, Spain, Pakistan, USA, Japan, and Germany.

Elevated As concentrations exceeding regulatory limits (>10 µgL⁻¹) have been reported in groundwater at sites contaminated with As showing that As contaminated soils have the potential to pollute groundwater and surface water sources through leaching and run off. Use of As contaminated water for irrigation in farmlands has also
because As is toxic and harmful to living systems [16-17]. The environment has been associated with severe health problems of exposure and period of exposure [18]. Before we can discuss possible exposure routes and effects of exposure on public health. Hence, the aim of this paper is to provide a review on arsenic contamination in all three spheres of the environment; discuss possible exposure routes and effects of exposure on public health.

Chemistry of arsenic

Arsenic is a metalloid with atomic number 33 and mass number 74.9. There are three allotropes of arsenic; yellow As, gray As and black As though the gray one is most commonly used. Arsenic is a group V element on the periodic table with five valence electrons in the outermost electronic configuration. Common oxidation states of arsenic are +3, +5 and -3. In its natural state, arsenic is found bonded mostly with oxygen and sulfur forming many minerals in the earth crust.

Arsenic reacts with oxygen to form two oxyanions; arsenite (As III) and arsenate (As V), in aqueous solutions. Arsenite is the dominant form in anaerobic/reducing conditions while arsenate is predominant under aerobic/oxidizing conditions. The arsenate (AsO$_4^{3-}$) structure is similar to the orthophosphate anion (PO$_4^{3-}$) which causes competitive chemical behavior between the two anions [19]. Similarities between As and P is also responsible for its toxicity with As replacing P in enzyme catalyzed reactions thereby interfering in metabolic activities.

Arsenic is found in high concentrations in sulfide deposits. The most important sulfides of arsenic are realgar (As$_4$S$_4$), orpiment (As$_2$S$_3$) and arsenopyrite (FeAsS) though only realgar occurs as a natural arsenic ore [1]. Arsenic compounds and their uses

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic trioxide</td>
<td>As$_2$O$_3$</td>
<td>Industry/medicine</td>
</tr>
<tr>
<td>Lead arsenate</td>
<td>PbAsO$_4$</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Calcium arsenate</td>
<td>CaAsO$_4$</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Sodium arsenite</td>
<td>NaAsO$_3$</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Chromated copper arsenate (CCA)</td>
<td>As$_2$CrCuO$_3$</td>
<td>Wood preservative</td>
</tr>
<tr>
<td>Dimethyl arsenic acid/cacodylic acid</td>
<td>C$_2$H$_5$AsO$_2$</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Monosodium methanearsonate (MSMA)</td>
<td>CH$_3$AsNaO$_3$</td>
<td>Pesticide</td>
</tr>
<tr>
<td>Disodium methanearsonate DSMA</td>
<td>CH$_2$AsNaO$_3$</td>
<td>Pesticide</td>
</tr>
</tbody>
</table>

Long range transport of dust particles from contaminated soil by the wind may also pollute the atmosphere with As [15]. Exposure to elevated As concentrations in the environment has been associated with severe health problems because As is toxic and harmful to living systems [16-17]. The health effects of As may depend on the exposure route, level of exposure and period of exposure [18]. Before we can actually solve the problem of As pollution in the environment, we have to understand extent of contamination, the exposure routes of As in the environment and resulting health effects. Hence, the aim of this paper is to provide a review on arsenic contamination in all three spheres of the environment; discuss possible exposure routes and effects of exposure on public health.

Arsenic toxicity

Arsenic is toxic to living systems which is why it’s widely used as a rat poison and pesticide. Arsenicals used as pesticides include arsenic acid, cacodylic acid, monosodium methanearsonate (MSMA), disodium methanearsonate (DSMA), calcium arsenate, lead arsenate and sodium arsenite [1]. Arsenic trioxide (As$_2$O$_3$) has been used historically for eliminating enemies and aged relatives [19]. Arsenic can also be found in organic compounds where it’s covalently bonded with carbon and other elements. The organic arsenic compounds with the methyl group are more important in the environment (Table 1). Methylated arsenic compounds are formed by reduction of arsenate to arsenite, followed by methylation of arsenite (As III) anion to produce methylarsenic compounds such as monomethylarsonic and dimethylarsines and ultimately may lead to the production of arsine gas [18]. This conversion of inorganic arsenic species to organic methylated arsenic compounds affects the tissue distribution and arsenic retention in living systems which determines the toxicity of arsenic [20].

Due to similarities in chemical behavior of As and P, As is believed to be taken up via the phosphate uptake system in biological systems. Reduction of arsenate to arsenite increases As uptake due to competition between arsenate and the phosphate anion. Arsenic species with oxidation state of 3 (As III) are more toxic than the species with oxidation number 5 (As V). The toxicity of arsenite (As III) may be due to its ability to form bonds with the sulphydryl, thiols and hydroxyl groups in the enzyme thereby interfering with enzyme activity [21]. The reduction of arsenite to arsenenate followed by expulsion of the arsenite from the cell is one of the detoxification mechanisms of living cells [22].

It was formerly believed that the inorganic species are more toxic than the organic species until some studies reported that organic As species with oxidation number 3 are more toxic than inorganic species [20]. Monomethyl arsenic...
Acid (MMA III) species has been detected in urine of humans exposed to As in drinking water raising questions about the metabolism of As in living systems [23-24].

Though methylation has been associated with As detoxification, MMA III has been associated with carcinogenicity in the transplacental exposure model in the mouse [25-26]. A recent study has suggested that when MMA values are higher than dimethyl arsenic acid (DMA), it indicates incomplete methylation which could also affect the toxicity of As [27]. Their results showed that subjects with skin lesions have higher levels of urinary inorganic As and MMA which they attributed to a lower As methylation capacity. Previous studies have shown that complete methylation has been associated with lower risk of As induced diseases [28].

It has been reported that the metabolism of arsenic catalyzed by As methyltransferase is a sequential process of reduction followed by oxidative methylation back to pentavalency [29]. Studies have presented evidences supporting changes in DNA methylation as a cause of As carcinogenesis [30-32]. Arsenic toxicity may cause carcinogenicity by increasing oxidative DNA damage, chromosomal aberration and interfering with cellular signaling pathways [33]. Toxicity of As may also be caused by oxidative stress triggered by As exposure [28].

**Exposure Routes of Arsenic in the Environment**

**Arsenic contaminated groundwater**

Groundwater sources are believed to be safer and cleaner than surface waters which are exposed to aerial deposition and discharges, but this is not so in many parts of the world. Groundwater sources are used as drinking water for millions of people worldwide especially in developing countries where wells and boreholes are the main sources of drinking water. This makes contamination of groundwater a serious public health concern.

Arsenic contaminated groundwater has been reported in more than 30 countries worldwide including countries in Asia, Europe, Africa, North America and South America [10]. Arsenic contaminated groundwater has been most frequently detected in South and South-east Asia in the past decades with about 110 million of people living in countries like Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam facing health risks of As exposure [14].

Bangladesh has the most severe level of As contamination in groundwater with about 84% of groundwater sampled having As concentration above 10 µgL⁻¹, putting 75 million people at risk while 1.2 million people are exposed to As poisoning due to release of As from minerals like arsenopyrite, iron sulfate and iron oxide underground [5]. Ten years later, due to mitigation efforts, 52% of sampled wells in Bangladesh now have As concentrations below 10 µgL⁻¹ [34].

Arsenic contamination of groundwater occurs due to natural and anthropogenic sources. Natural sources such as arsenic rich sulfide minerals are responsible for the contamination in Bangladesh. Two mechanisms proposed for mobilization of As into groundwater in Bangladesh are arsenopyrite oxidation and hydroxide reduction processes [9]. The natural sources of As in ground water are dependent on the local geology, hydrology and geochemical characteristics of the aquifers [35]. Arsenic can also be mobilized naturally through evaporative concentration, leaching from sulfides by carbonate, and microbial mobilization [36].

The As contamination in Nepal and Australia is also due to natural sources. Arsenic concentrations ranging from below detection to 131 µgL⁻¹ has been reported in the groundwater of Nepal due to microbiologically mediated reductive dissolution of iron III oxyhydroxides in the aquifer [7]. It has been found that microbes such as dissimilatory iron-reducing bacteria (Shewanella oneidensis MR-1 and Shewanella sp. strain MR-4) can increase the mobilization of As into groundwater [37]. An extremely high As concentration (7000 µgL⁻¹) was reported for groundwater in Perth, Western Australia due to exposure of pyritic sediments and redox conditions [6]. This value is 700 times higher than acceptable limit of 10 µgL⁻¹.

About 10% of the groundwater analyzed in the United States had As concentrations exceeding the maximum contaminant limit (MCL) of 10 µgL⁻¹ showing low As exposure in the region [2]. High As concentrations in groundwater from natural origin in the United States are due to volcanic activities while human activities such as mining and smelting of ores containing As can also lead to contamination [38].

Mining has been reported to contaminate groundwater in India, China and Europe. Gold mining may contaminate groundwater because gold and As coexist in the earth crust. A study in India reported that about 79% of tube wells sampled near a gold mine had As concentrations above the regulatory limit (10 µgL⁻¹) and a maximum concentration of 303 µgL⁻¹ [11]. Similarly, As concentrations up to 325 µgL⁻¹ was reported in the groundwater of an abandoned tungsten mine in China [39]. In Europe, leaching of dumps at abandoned mine sites was thought to be responsible for the
Table 2. Arsenic concentrations in contaminated soil, water and food crops

<table>
<thead>
<tr>
<th>Country</th>
<th>Soil (mgkg$^{-1}$)</th>
<th>Groundwater (µgL$^{-1}$)</th>
<th>Rice (mgkg$^{-1}$)</th>
<th>Vegetables (mgkg$^{-1}$)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>5.64-29.5</td>
<td>290-710</td>
<td>0.02-3.40</td>
<td>0.09-2.03</td>
<td>Das et al., 2002</td>
</tr>
<tr>
<td>India</td>
<td>5.7-9.7</td>
<td>320-640</td>
<td>0.33-0.45</td>
<td>NA</td>
<td>Bhattacharya et al., 2010</td>
</tr>
<tr>
<td>China</td>
<td>129</td>
<td>329</td>
<td>1.09</td>
<td>2.38</td>
<td>Liu et al., 2010</td>
</tr>
<tr>
<td>Nepal</td>
<td>6.1-16.7</td>
<td>ND-1014</td>
<td>0.18</td>
<td>0.33</td>
<td>Dahal et al., 2008</td>
</tr>
<tr>
<td>Taiwan</td>
<td>7.92-12.7</td>
<td>13.8-881</td>
<td>NA</td>
<td>0.01-0.15</td>
<td>Kar et al., 2013</td>
</tr>
<tr>
<td>Limits</td>
<td>20</td>
<td>100</td>
<td>1</td>
<td>1</td>
<td>Bhattacharya et al., 2010</td>
</tr>
</tbody>
</table>

a-European Union limit for agricultural soil ND-not detected; NA-not available. b-FAO limit for irrigation water. c-WHO limit for Arsenic in food crops.

 occurrence of As contamination of groundwater at a site that belongs to both Portugal and Spain [12].

In Bolivia, 90% of wells sampled had As concentrations greater than the regulatory limit of 10 µgL$^{-1}$ showing severe exposure of the general public to As [40]. Arsenic concentrations up to 2000 µgL$^{-1}$ have been reported in Latin America including countries like Argentina, Chile, Bolivia, Peru and Mexico exposing about 4.5 million people to As contamination in drinking water [16]. Maximum As concentration (1100 µgL$^{-1}$) reported in Cambodia is lower than that of Latin America [8]. Groundwater As concentrations reported in Finland (<0.05 to 64 µgL$^{-1}$) and Ghana (1-141 µgL$^{-1}$) are about twenty times or more lower than that of Cambodia and Latin America showing the As contamination is very low [41-42].

Another source of As mobilization into the groundwater is the addition of phosphate fertilizer to arsenic contaminated soils. It has been reported that application of P increased the
desorption of As in contaminated sheep dip soil and artificial arsenic contaminated soils (spiked soil) \[43\]. Phosphate is able to displace As from exchange sites in the soil due to similarities with the arsenate anion. This concept is used in phytoremediation of As contaminated soils by arsenic hyperaccumulating plants which absorbs the As displaced by phosphate \[44\]-\[46\]. In the absence of these plants, As mobilized by phosphate additions releases As into groundwater.

**Arsenic contaminated soils**

The soil is both a source and sink for contaminants like As (Fig. 1). As contaminated groundwater can pollute the soil and increase soil and plant As concentrations when used for irrigation of farmlands. This contaminates the food chain thereby posing great health risk to the general public. This was demonstrated in a study in China where As contaminated groundwater was used to irrigate soil and crops (sunflower and maize) for 3 yrs \[47\]. The estimated annual As loading per m\(^2\) varied between 120 and 186 mg with topsoil having greater concentration \[47\].

In a similar study, irrigation with As contaminated groundwater led to an accumulation of As in the soil and crop grown (wheat) \[48\]. Annual As loading in the soil was estimated to be 37.5 and 140 mg for two sites. It has been reported that irrigation with As contaminated water (79 to 436 μgL\(^{-1}\)) led to elevated As concentrations of rice field soils \[49\]. About 71% of the As that was applied in irrigation water accumulated in the top soil (0 to 75 mm). But As concentrations in the soil layer decreased significantly by the end of the planting season probably due to leaching after flooding and rainfall.

In West Bengal, India, the crops and vegetables cultivated in the As contaminated soil accumulated a significant amount of As which polluted the food chain \[14\]. Similarly, As contamination of top soils of private gardens after 150 years of industrial activity probably contaminated vegetables in Southern France \[50\].

Rice is an efficient accumulator of As because it translocates As more than other food crops \[51\]-\[52\]. It also happens to be a staple in Asia where there is severe As contamination indicating serious health risk in the region \[53\]. A past study has reported that rice may be the largest contributor of As in China via the contaminated food chain \[54\]. For the total population in China, daily As intake was estimated to be around 42 μgday\(^{-1}\) with rice contributing most (60%) of the total As intake \[54\].

Another study has reported extensive As contamination of soil, water, rice, vegetables, and fish at an abandoned tungsten mine in China (Table 2) \[39\]. Though, the As contaminated groundwater used for irrigation in all the countries on Table 2 were above FAO limit, the As concentrations in soil and food crops were higher than standard limits only in Bangladesh and China. A diet of rice in Bangladesh greatly exposes the population to As because of the level of As contamination in the country \[55\]. This was not the case in Australia where concentrations of As in both Australian grown and imported rice were below the 1 mgkg\(^{-1}\) limit set by Food Standards of Australia \[56\].

However, total concentration of As in food may not be a good indicator of health risk as bioaccessibility. It has been reported that the bioaccessibility of inorganic As in rice is very high, typically 70% or more suggesting high health risks in contaminated areas \[57\]. Washing and cooking of rice may reduce the arsenic concentrations. Studies have reported that cooking of rice before eating and discarding of water after cooking can reduce As concentrations in rice \[58\]-\[59\].

Other human activities such as mining also contribute to As contamination in soils due to discharges from waste dumps in abandoned mining and processing sites \[12\]. Elevated As concentrations have been reported in surface soils of Canada nearby a smelting complex \[60\]. The use of arsenical pesticides (Table 1) has resulted into extensive As contamination in the environment. For example, arsenic trioxide was used in cattle dip vats to eradicate cattle fever tick which resulted in As contaminated soils many decades after its use \[61\]. The use of MSMA as herbicide for weed control in golf courses has also led to elevated concentrations of As in the soil \[3\], \[62\].

Arsenic concentrations of 19, 131, 291 and 294 mgkg\(^{-1}\) As was reported for golf course, CCA contaminated soil, cattle dip vat soil, and mining soil respectively \[3\]. These values are far above USEPA’s regional screening level of 0.39 mgkg\(^{-1}\) As for residential soils indicating they pose a health risk to the general public \[63\]. These As contaminated soils also contaminate groundwater below through leaching (Fig. 1). Elevated As concentrations has been reported in the groundwater of golf courses contaminated with the herbicide MSMA and groundwater of cattle dip vat soils \[61\]-\[62\]. The use of chromate copper arsenate (CCA) as wood preservative has also led to elevated concentrations of As in the soil. Arsenic concentrations up to 76 mgkg\(^{-1}\) has been reported in soil under CCA sprayed structures (wood deck) \[64\]. Children are particularly exposed to As while playing outdoors on playground structures sprayed with the wood preservative; CCA.
Arsenic contaminated dust

Exposure to contaminated dust from contaminated soil can exacerbate risk of As poisoning and associated health risks. Adults and children are exposed to As in dust through dermal contact, inhalation or incidental ingestion [65]. Risk of incidental ingestion of dust is higher with children who play on the floor indoors and with soil outdoors [66]. A human risk assessment study in Pakistan has shown that dust ingestion is the main route for As accumulation in biological tissues like hair and nail, followed by inhalation and dermal contact [67].

They reported that total As of indoor dust was two to three times higher than soil dust. As bioaccessibility ranged from 75.4% to 83.2% in indoor dust and ranged from 13.8% to 20.2% in soil dust [67]. This suggests higher health risk to children playing on the floor indoors. Geogenic dust from arid environments is also a significant source of As in the air [68]. Exposure to geogenic dust from Nevada, USA, rich in As, has been found to reduce the ability of the immune system to produce antibodies against a T cell dependent antigen and suppress natural killer cell activity in mice [68].

Natural sources such as volcano eruptions and forest fire also introduce As into the atmosphere. Anthropogenic emissions from coal power plants, industries, pesticide applications and refuse burning contribute much more As into the atmosphere [69]. Combustion of coal releases arsenic from coal waste products into the environment [53, 70].

It has been estimated that about 31,000 tons of As are released annually into the atmosphere worldwide with Europe contributing 575 tons annually [71]. A recent study provided evidence for long range transport of arsenic as particulate matter from industrial sources like copper smelters in Spain [72]. They reported As concentrations that ranged from 8.1 to 16.4 ng m⁻³ in PM₂.₅ and 9.3 to 15.2 ng m⁻³ in PM₁₀. These values are higher than the standard of 6 ng m⁻³ set by the European commission for As in the air [73]. The 24 hr average for As concentration in the atmosphere of Canada, given as less than 0.3 μg m⁻³, is higher than the air quality standards indicating that the air is polluted to levels that can adversely affect human health [74].

Mining is a source of As contamination in the atmosphere because of dust produced during processing of arsenical ores. It has been estimated that about 670 kg As was emitted to the atmosphere from a mine in Australia during 2012-2013 [75]. Long term exposure of As bearing mine waste can lead to higher As in the air due to Aeolian transport of wind-blown particles [15]. Communities in the vicinity of these mines are exposed to As and face possible health effects due to inhalation of dust generated from these mines by Aeolian processes [15].

Health risks of airborne exposure to As in mines and smelters are even higher for the workers at these sites. It has been reported that miners and smelter workers face increased lung cancer risks due to high levels of As in airborne dust [76]. This was confirmed in a study that reported high concentrations of As in urine of workers in a copper production plant in China especially workers of the electrolytic process [77].

**Biomarkers of Arsenic Exposure**

Biomarkers of As exposure commonly used are concentrations of As in human tissues such as hair, nail, urine, skin and blood serum. Table 3 shows concentrations of some biomarkers for selected countries such as Bangladesh, India, China, UK, Pakistan, Cambodia and Nigeria. A lot of work has been done on biomarkers of As exposure in Bangladesh and India because of the history of severe As contamination in these countries. The table shows that Bangladesh is the most impacted with As contamination and exposure.

A previous study analyzed hair, nail and urine samples of people living in the As affected areas of Bangladesh and India [78]. Their results showed that 93% had As concentrations above the normal/toxic range in Bangladesh while 77% had concentrations above the normal/toxic level in India. In China, 70% of urine As, 76% of nail As and 62% of nail As were above normal limits [79]. Hair, nail and urine As from other countries like Cambodia, Pakistan, and Nigeria were also above normal levels (Table 3). Samples from the United Kingdom were however below toxic levels showing exposure to As was low in the region.

### Table 3. Biomarkers of As Exposure

<table>
<thead>
<tr>
<th>Country</th>
<th>Hair (µg kg⁻¹)</th>
<th>Nails (µg kg⁻¹)</th>
<th>Urine (µg L⁻¹)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>280-28,060</td>
<td>260-79,460</td>
<td>24-3086</td>
<td>Chowdhury et al., 2000</td>
</tr>
<tr>
<td>India</td>
<td>137-10,900</td>
<td>764-10,700</td>
<td>234-4,030</td>
<td>Ahamed et al., 2006</td>
</tr>
<tr>
<td>Pakistan</td>
<td>380-2,360</td>
<td>880-2,500</td>
<td>NA</td>
<td>Subhani et al., 2015</td>
</tr>
<tr>
<td>Cambodia</td>
<td>100-7,950</td>
<td>200-6,500</td>
<td>NA</td>
<td>Gault et al., 2008</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1,600-11,600</td>
<td>1000-7,400</td>
<td>NA</td>
<td>Ndiiowere, 1985</td>
</tr>
<tr>
<td>UK</td>
<td>116-141</td>
<td>154-723</td>
<td>NA</td>
<td>Brima et al., 2006</td>
</tr>
<tr>
<td>China</td>
<td>2,920</td>
<td>NA</td>
<td>164</td>
<td>Liu et al., 2010</td>
</tr>
<tr>
<td>Normal</td>
<td>80-250</td>
<td>430-1030</td>
<td>3.33-26.7</td>
<td>Mukherjee et al., 2006</td>
</tr>
</tbody>
</table>
Several studies have reported correlations between these biomarkers and As in drinking water or food. For example, the arsenic content of the groundwater from Cambodia used for drinking water purposes was positively correlated with both nail and hair As concentrations. Another study later confirmed this and reported that the significant correlation between the scalp hair As content and both As concentrations in groundwater and individual average daily doses of As showed that As accumulation in Cambodia residents was mainly through a groundwater drinking route. Similarly, the urine, hair and nail concentrations of As was significantly correlated with drinking water As concentrations in a region in India which shows that drinking water is a major exposure route.

A study investigated the effect of occupational exposure of outdoor workers like traffic policemen and police drivers to As in the air. Results show that total urinary As concentrations of these outdoor workers were significantly correlated to As concentrations in the air. This indicates that workers were occupationally exposed to urban air pollutants like As. Personal exposure to As in the air and urine As concentrations was significantly higher in traffic policemen than police drivers.

**Impact of As exposure on Public Health**

Arsenic contamination affects pregnant women and the unborn, children and adults exposed through drinking water, diet or by inhalation of polluted air. Arsenic exposure has been associated with stillbirths, preterm births, enhanced placental T-cells and changed cord in pregnant women. Arsenic exposure has also been linked with low birth weight, neonatal mortality, infant mortality and early onset menopause. Long term exposure to As may also cause skin lesions, hyperkeratosis, and ultimately cause cancer. Studies have shown an association between high As exposure and cardiovascular diseases. These may be caused by adverse effects of As on endothelial cells of the vasculature.

The World Health Organization (WHO) has listed some of the immediate symptoms of acute As poisoning as vomiting, abdominal pain and diarrhea followed by numbness, muscle cramp and even mortality in severe cases. Some other symptoms of As are conjunctival congestion, non-pitting foot swelling, hepatomegaly, splenomegaly, ascites, Bowen’s disease and gangrene. It was observed that symptoms of chronic As toxicity developed after 6 months to 2 years or more of exposure in India and Bangladesh. The time of onset depends on the concentration of As in the drinking water, volume of intake, and the health and nutritional status of individuals.

Table 4 shows health effects of As exposure in different parts of the world. Long-term exposure to As in Bangladesh produced severe arsenicosis which was revealed in skin problems, diabetes mellitus, vascular disease, neuropathy, and also multiple cancers. Stages of As poisoning in Bangladesh are melanosis, keratosis and hyperkeratosis. In Argentina where a large percentage of water samples had As concentrations above acceptable limits, the percentage of skin cancer in patients with arsenicosis reached 88% while there was a higher incidence rate of colorectal, lung, breast, prostate and skin cancer in both sexes. Furthermore, liver and skin cancer mortality risk ratios were higher in regions with medium/high concentrations than in those with low concentrations.

There are conflicting reports on arsenicosis in Cambodia. A past study reported that there were cases of arsenicosis in Cambodia since 2006 while another study in Cambodia reported that elevated As concentrations in groundwater may lead to arsenicosis in the near future. The signs of arsenicosis in Cambodia were given as hypomelanosis followed by hyperkeratosis, then hyperpigmentation and mee’s lines. In India, studies have reported that chronic As exposure can cause respiratory disease, gastrointestinal disorder, liver malfunction, nervous system disorder, haematological diseases like anaemia, leucopaenia and thrombocytopenia, diabetes and cardiovascular diseases. Similarly, in Latin America, chronic As exposure has led to cancer of the...
bladder, lung, kidney, liver, and skin; reproductive health problems, cardiovascular diseases, respiratory diseases and impaired cognitive development in children [16]. In China, urinary As concentrations were significantly associated with hearing disorders showing that As may also have a deleterious effect on the auditory system [93-94].

**Conclusion**

Extensive contamination of groundwater with As has been reported in more than 30 countries. The most severe ones have been detected in South and Southwest Asia many decades ago. Use of arsenic contaminated groundwater as irrigation water for farmlands has led to contamination of soil and food crops. Other anthropogenic sources of As are wood preservation, agricultural and mining activities. Elevated As concentrations in the soil have led to groundwater contamination and higher As concentrations in the air. Humans are exposed to As through contamination of the food chain, drinking water and inhalation of As in the air. Exposure to As has a deleterious effect on virtually every organ in the body; gastrointestinal, cardiovascular, auditory, and respiratory systems. Arsenic contamination devastates communities and so it must be managed and controlled to preserve environmental health.

**Conflicting interests**

The authors have declared that no conflict of interests exist.

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**Abbreviations**

As: Arsenic; MSMA: monosodium methane arsonate; DSMMA: disodium methane arsenate; MCL: maximum contaminant limit; MMA: Monomethyl arsenic acid; DMA: dimethyl arsenic acid.

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