

Study on Arsenic Poisoning by Worldwide Drinking Water, its Effects and Prevention

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Abstract: The present studies were conducted to evaluate the arsenic poisoning worldwide in drinking water. Arsenic not only contaminates the surface and groundwater but also enters into food chains like vegetables and food staff. Human beings are directly exposed to arsenic poisoning due to consumption of water resources containing arsenic. Sea foods and fish are two main sources of arsenic in human diet. Consumption of arsenic poisoned water can cause severe health problems like cancer, hyperkeratosis, gangrene and peripheral vascular diseases. The arsenic is excreted from the body through skin, hair, urine, breath etc. Arsenic poisoning can be diagnosed by the measurement of total amount of arsenic in urine. Symptoms of arsenic poisoning include red or swollen skin, changes in the skin color, abdominal pain, vomiting and nausea, diarrhea, cramping of muscles, finger and toe tingling etc. Arsenic poisoning may be relieved through steroid ingestion at its early stage or use of selenium. It is very difficult to remove all the arsenic from water bodies so the main remedy is to stop drinking water having arsenic content. Arsenic poisoning also affects the plant 's yield, its reproductive capacity, fertility and fruit production. Arsenic accumulation in plants will damage the cellular membranes and may lead to the leaking of electrolyte.

Keywords: Arsenic poisoning, drinking water, effects, prevention.

Introduction

Arsenic is an element in periodic table having atomic number 33. It possesses steel gray color and is crystalline in nature with three allotropic forms namely gray, yellow and black. It occurs in 3 and 4 oxidation states. Arsenic has the ability to form covalent bonds with metals and nonmetals (D.C, 2001) to produce a variety of compounds, either inorganic or organic. Inorganic arsenic is cosmopolitan in nature, either as As^{3+} or As^{5+} . Most rocks contain 1-5 ppm of arsenic. As^{3+} may exist as trioxide, Na arsenite, and arsenic chloride. Organic arsenic is less abundant than inorganic arsenic and is created during a biomethylation method by several organisms as well as humans and shellfish. However, arsenic occurs naturally in rocks and soil and the bulk of arsenic is discharged during industrial smelting (Gilbert, 2011). Arsenic with sulphide ore is present in the sedimentary rock. The spreading of arsenic in the environment is due to anthropogenic activities like smelting etc. This arsenic can be mobilized when dissolved in water (Cullen and Reimer, 1989).

The higher concentration of arsenic in drinking water may lead to serious health problems. Over a long period, consumption of contaminated well water will result in chronic arsenic poisoning. The mean concentration of arsenic poisoning was observed to be 0.58 ppm during the years of 1968 and 1969 in drinking water of Antofagasta city, Chile. This concentration was lowered to 0.08 ppm (about 7.2 times less as compared to that observed in 1968 and 1969) in 1971 due to the building of filtration plant in 1970. In 1968-1969, the effects of arsenic poisoning

were observed in 145 men and 168 females from every 100,000 people. Such incidences decreased to 9.1 males and 10 females in the year 1971 due to establishment of filtration plants (Zaldivar, 1974). There are some factors like geochemical and hydrological, which control the solubility of arsenic in ground water (Rodríguez-Lado et al., 2013). More than 150 million people are affected in the world by the consumption of arsenic through drinking water. To minimize this issue, treatment of arsenic contaminated water is highly important (Singh et al., 2015). The metabolism plays an important role in toxicity of arsenic. This metabolism process will oxidize the arsenic and will change it to pentavalent state through oxidative methylation. This pentavalent state of arsenic is more dangerous (Hughes 2002). Arsenic toxicity is well known all over the world due to its unique properties. The main mechanism of diseases caused by arsenic poisoning is not known yet. However, inorganic arsenic is the main source of cancer including lung cancer, bladder cancer and skin cancer etc. (Hong et al., 2014).

The arsenic causes apoptosis (Miller et al., 2002). A compound namely "dimethyl arsenic acid" is a source of arsenic poisoning, it causes the breakdown of DNA strands and induces cancer in humans (Wanibuchi et al., 2004). Some biomarkers are used for the detection of arsenic poisoning in human like measurement of total amount of arsenic in urine (Hughes, 2006). The sensitivity and apoptosis control of arsenic trioxide has not yet been determined. This information has let the arsenic to be more dangerous than any other heavy metals like mercury, lead etc. (Davison et al., 2002). Arsenic poisoning may be relieved through steroid

ingestion but at an early stage. A disease like leukocytosis can be relieved without the administration of the process chemotherapy (Zhang et al., 2001).

Types of Arsenic Poisoning

Acute Arsenic Poisoning

Acute poisoning means “the exposure for a short time interval”. The exposure may be single or multiple. Within fourteen days, the adverse symptoms will occur after consumption. Arsenobetaine is a compound causing acute toxicity, when applied on male mice through oral ingestion of dose 10g per kg. The study demonstrated that oral ingestion showed no significant symptoms of toxicity (Kaise et al., 1985). However, industrial and environmental exposure may lead towards acute arsenic poisoning. It may occur due to ingestion of arsenic accidentally or occasionally. Ingestion of arsenic is fatal and ingestion through intravenous way is dangerous (Tournel et al., 2011).

Chronic Arsenic Poisoning

The chronic arsenic poisoning is the exposure of a body to arsenic for a long time. The exposure of people occurs not only through drinking water but also through food *etc.* It may also be caused through burning of coal as this burning produces gases with higher arsenic contents which are either dissolved in water bodies or they are stuck on the food we eat which leads to chronic arsenic poisoning (Liu et al., 2002). According to World Health Organization (WHO), about two hundred million people are chronically exposed worldwide to arsenic *via* drinking water (Naujokas Marisa et al., 2013).

The main cause of chronic arsenic poisoning is methylated arsenic found in trivalent oxidation state. This methylated arsenic is found in the urine of humans, which is cytotoxic and disturbs the enzymatic activities within the body of humans (Thomas et al., 2001). The liver is also affected by the consumption of drinking water due to chronic arsenic poisoning in West Bengal, India (Mazumder, 2005).

Sources of Arsenic Poisoning

Drinking water

Arsenic occurs naturally in ground water. Industrial effluents are the major source of arsenic poisoning; when these effluents are dissolved in drinking water bodies, may cause cancer in humans because arsenic is a carcinogen (Schoolmeester and White, 1980). The worldwide health issue nowadays related to arsenic poisoning is due to consumption of high concentration of arsenic through drinking water (Yoshida et al., 2004). Groundwater contains soluble arsenic in a concentration higher than recommended by World Health Organization (WHO). The recommended concentration of arsenic is 10 mg per liter. Arsenic contamination in drinking water has mainly two

sources “natural” and “anthropogenic”. Both these sources led towards the contamination of water resources adding arsenic to it (Nordstrom, 2002).

Food

Arsenic poisoning may also be spread through food items. Organic arsenic compounds are mainly found in food. The organic arsenic compounds which are normally found in food depend upon the type of food, that may include monomethyl arsenic acid, arsenobetaine, arsenosugars *etc* which exist mostly in marine animals like fish, crabs *etc.* The major form of arsenic in marine animals is arsenobetaine which is considered as a nontoxic compound for human consumption. The main source of arsenocholine is shrimp, which is chemically similar to arsenobetaine, and is considered as nontoxic for human consumption (Borak and Hosgood, 2007). Sea foods and fish are two main sources of arsenic in the diet of humans, who consume a large amount of arsenic through sea foods. The organoarsenical arsenobetaine (AB) is a dominating arsenical in finfish. A rather less amount of AB and relatively higher amount of arsenosugars and inorganic arsenic (iAs), are found in blue mussels, algae and other filter feeders. The arsenolipids are majorly found in fatty fish. Sea foods also contain minor amounts of sulfur-containing arsenicals, methyl arsenate, dimethylarsenate, trimethylarsoniopropionate and trimethylarsine oxide. The carcinogenic arsenical iAs is toxic and is bio transformed in humans and excreted in urine as the carcinogens methylarsonate and dimethylarsinate produce reactive intermediates in the process. Processing of seafood may also result in transformation of arsenicals (Molin et al., 2015). There are many other sources of arsenic poisoning like, soil, air, pesticides, copper smelting *etc.*

Effects of Arsenic Poisoning on Human Health

Arsenic is a metalloid which is present in drinking water. It affects either through anthropogenic or geogenic activities (Baig et al., 2009). Arsenic not only contaminates the surface and groundwater but also enters into food chains like vegetables and food stuff (Su and Yang, 2009). Tseng et al. (1977) in Taiwan, first reported the contamination of drinking water in 1961 related to chronic arsenical poisoning consumption (Tseng, 1977). Consumption of arsenic poisoned water can cause severe health problems like cancer, hyperkeratosis, gangrene and peripheral vascular diseases. Chronic illness called arsenicosis is due to drinking of arsenic contaminated water for a long period and is known as arsenic poisoning. Chronic arsenical poisoning is also called arsenicalism. Slow poisoning disease condition caused by arsenic is called arsenicism (Kapaj et al., 2006). The lethal dose of arsenic for humans is 125 milligrams. Arsenic is 4 times poisonous as compared to mercury. The excretion of arsenic through body is carried out through skin, hairs, urine, breath *etc.* The intake of arsenic affects almost all the organs of human

body and toxicity effect clinically appears after 6 months to 2 years. Figure 1 demonstrates the toxic effects of arsenic poisoning on human (A) skin and (B) hands.

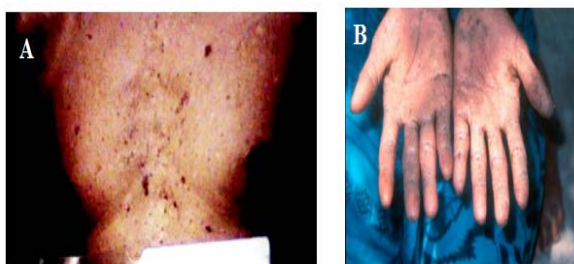


Fig. 1. Toxic effects of arsenic poisoning on human (A) skin and (B) hands

Effects of Arsenic Poisoning on Plants

Arsenic is toxic to plants and is generally a non-essential element. In plant parts, the roots are mainly exposed to arsenic. Fruit production, fertility, yield, and reproductive capacity of plants is disturbed by accumulation of arsenic contents in shoots. Genotype dependent proportion of arsenic plays a key role in death of plants in such a manner that it accommodates in shoots and other tissues of plants. The arsenic content will interfere with the metabolic processes in plants and may lead to the death of plants. Arsenic accumulation in plants will damage the cellular membranes and may lead to the leaking of electrolyte (Garg, 2011; Singh et al., 2006). Figure 2 demonstrates the toxic effects of arsenic poisoning on plants.

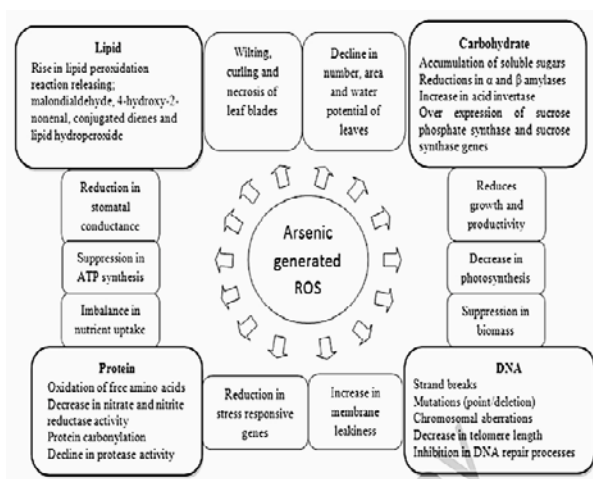


Fig. 2 Effects of arsenic poisoning on plants (flowsheet diagram) (Mazumder, 2008).

Symptoms of Arsenic poisoning

- Red or swollen skin
- Changes in the skin, such alteration in pigmentation
- Abdominal pain

- Vomiting and nausea
- Diarrhea
- Abnormal condition in hearth rhythm
- Cramping of muscles
- Finger and toe tingling (Luo, 2017).

Arsenic poisoning symptoms are not much prominent. While some of the symptoms could be seen in humans especially like gastrointestinal pain and anemia caused by arsenic consumption through drinking water (Hall, 2002). The major arsenic symptom is cancer. Arsenic consumption leads to the risk of cancer including the lungs, skin and kidney cancers etc. (Gebel, 2001; Ratnaik, 2003).

Arsenic Poisoning Worldwide

The arsenic poisoning is mainly found in underdeveloped countries like Pakistan, Bangladesh, and India. Moreover, the developed countries like America, France, Italy, Japan and China etc. also face the problems of arsenic poisoning.

Toxicity in Underdeveloped Countries

Pakistan is one of the underdeveloped countries and also faces problem of arsenic poisoning. For example, this toxicity can be seen in Tharparkar region Sindh, Pakistan (Fig. 3) where toxicity level of arsenic is on the peak (Brahman et al., 2013; 2016). Table 1 displays the statistical data of arsenic poisoning from Tharparkar Sindh, Pakistan.

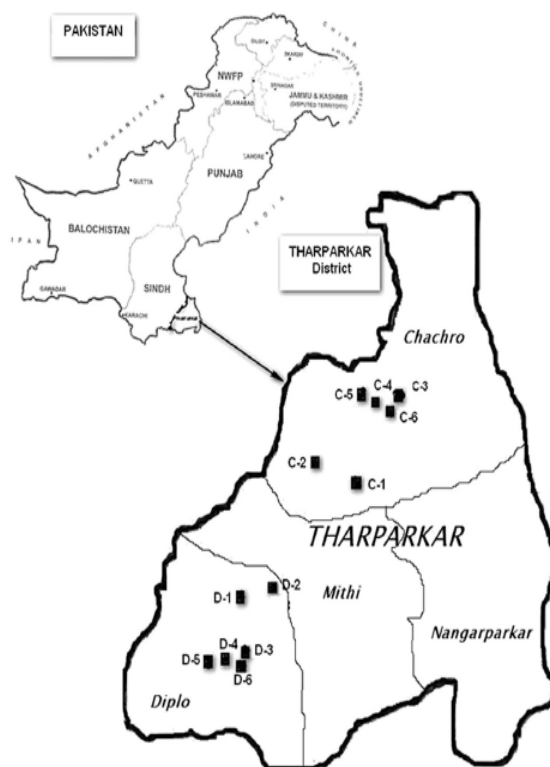


Fig. 3 Map of Tharparkar Pakistan (Brahman et al., 2013).

Table 1 Statistical data of arsenic poisoning from Tharparkar Sindh, Pakistan (Brahman et al., 2016).

Species	Concentration added (µg/L)	Mean ± SD (µg/L)	% recovery	
As ³⁺	0.00	1.18 ± 0.12	--	
	2.5	363 ± 0.15	98.4	
	5.0	612 ± 0.24	99.0	
	10.0	11.1 ± 0.17	99.3	
			--	
iAs	0.00	4.4 ± 0.28	98.9	
	2.5	683 ± 0.15	99.0	
	5.0	9.31 ± 0.19	99.0	
	10.0	1426 ± 0.35	99.0	
Certified samples	Certified values	MDM	%recovery	T-value
Water (SRM 164e)	60.45 ± 0.72	59.9±0.89 (1.39)	99.1	0.309
Human hair in mg/kg (BCR 397)	0.31 ± 0.02	0.305±0.014 (4.59)	98.4	0.515

People mainly drink the arsenic contaminated water in Tharparkar (Sindh), Pakistan (Brahman et al., 2016). Four main species of arsenic in water are dimethyl arsenic acid, arsenate and arsenite etc. which are easily dissolved in water. Arsenic consumption through drinking water will create non-cancer effect such as keratosis, hyper and hypo-pigmentation etc. (Brahman et al., 2013). Just like Pakistan, Bangladesh also suffers from arsenic poisoning. The ratio of arsenic poisoning in Bangladesh is much more than Pakistan. Because of high rate of poverty, the people lack safe water to drink. The main diseases due to consumption of high amount of arsenic in Bangladesh are alteration in pigmentation, skin lesions etc. (Milton et al., 2001).

Toxicity in Developed Countries

Developed countries like America (Fig. 4) also face arsenic poisoning. The areas in America, which are not in the reach of municipal water system, consume high concentration of arsenic in their drinking water. About 43 million people in America face such problems (Schlanger, 2017).

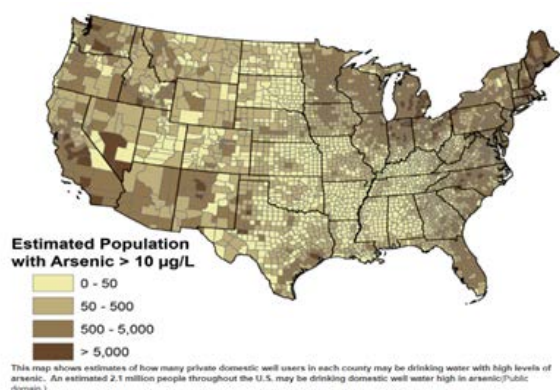


Fig. 4 Map of arsenic poisoning in USA.

There are areas in USA where arsenic concentration is high like Washington, California, Nevada, New Mexico etc (Ayotte, 2017). Table 2 compares the arsenic occurrence in ground water from the selected areas worldwide.

Table 2. Comparison of arsenic occurrence in ground water from the selected areas worldwide (Bhattacharya et al., 2007).

Region/Country	Affected area	Arsenic conc.(ug/L)	Contamination mechanism
Bangladesh (52 districts)	118,012 km ²	<2 - 900	Reduction of Fe-oxyhydroxides/Sulfide oxidation in alluvial sediments
Mexico, USA	4263 km ² Large areas	300-1100 100-500	Oxidation of sulfide from mine waste. Desorption of arsenic from Fe-oxyhydroxides/sulfide oxidation.
China, Xinjiang inner	4800 km ²	<50-1860	Reducing environment alluvial sediments.

Prevention of Arsenic Poisoning

In Humans

Arsenic poisoning mostly affects humans. A disease known as arsenicosis causes much damage to human health due to long term exposure to arsenic present in the environment. Arsenic accumulation can be prevented by using selenium, which reduces arsenic activities in human body (Wuyi et al., 2001). It is very difficult to remove all the arsenic from water bodies but prevention is better than cure. Therefore, we should prevent arsenic contaminated drinking water. If a person is suffering from arsenicosis, the main remedy is to stop drinking water having arsenic content. It will reduce further consumption of arsenic content (Saha et al., 1999).

Control of arsenic is more complex. Some actions can be taken for prevention e.g. the hand pump can be painted as green or red for differentiation between high arsenic and low arsenic contents respectively. The main solution is to treat water by the process of co-precipitation and ion exchange methods. Arsenic is excreted from the body through urine, so no special treatment is required at initial stage. But prevention is the important issue and for this purpose education plays an important role in order to prevent drinking of arsenic contaminated water (Smith, 2000). Prevention can be done by using various kinds of chelating agents like sodium ethylenediaminetetra acetate, 2, 3 dimercaptopropanol (BAL) etc. BAL can protect against arsenic induced embryo toxicity (Domingo, 1995). Garlic is an important species for the prevention of arsenic poisoning. Investigations reveal that the use of an aqueous sample of garlic has the ability to convert the hepatic tissue to normal tissue (Flora et al., 2009). Many underdeveloped countries worldwide have poverty level at peak point where drinking water is not suitable and always contains arsenic content.

Prevention of arsenic poisoning in these countries has only a single solution which is to reduce the poverty level in these countries and giving education to the people, who will become capable of preventing themselves from drinking arsenic contaminated water (Li et al., 2006).

To prevent cytolethality and induced cellular caspase 3 activation in cells, caused by arsenic consumption, one can use a method of membrane permeable radical trapping reagent (Sakurai et al., 2005). To prevent from arsenic poisoning, one should avoid growing root vegetables and leafy green plants like *brassica* family may contain highest amount of arsenic content so avoid using it as food. Some plants like tomato have the ability to prevent themselves from arsenic exposure; for this purpose some modifications are made, like gene coding (Goupil et al., 2009)

In Plants

There are a variety of mechanisms used by plants in order to respond to arsenic toxicity like hyper accumulation, phytochelation and antioxidant defence system. Mychorrizhe fungi also plays an important role in uprooting arsenic toxicity in crop plants (Garg, 2011). A mutant gene was identified to encode the translocon protein which imports preproteins from the cytoplasm into the chloroplast. The gene is translocated at the outer envelope membrane of chloroplast 132 (Wang et al., 2018). Microbiome also protects plants from arsenic toxicity in communities or villages where contaminated water is used for plant irrigation (Coryell et al., 2018). Fourteen natural products have the ability to prevent plants from arsenic poisoning (Bhattacharya, 2017)

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Conclusion

Arsenic not only contaminates the surface and groundwater but also enters into food chains like vegetables and food stuff. The lethal dose of arsenic for humans is 125 milligrams. The intake of arsenic affects almost all the organs of human body and toxicity effects will clinically appear after 6 months to 2 years. Consumption of arsenic poisoned water can cause severe health problems like cancer, hyperkeratosis, gangrene and peripheral vascular diseases. Symptoms of arsenic poisoning include red or swollen skin, changes in the skin color, abdominal pain, vomiting and nausea, diarrhea, cramping of muscles, finger and toe tingling etc. Arsenic poisoning

is common in Tharparkar, Sindh, Pakistan and other underdeveloped as well as developed countries. Arsenic poisoning may be reduced through steroid ingestion at its early stage or use of selenium. It is very difficult to remove all the arsenic from water bodies so the main remedy is to stop drinking water from having arsenic content. Prevention can be done by using various kinds of chelating agents like sodium ethylenediaminetetra acetate, 2, 3 dimercaptopropanol (BAL) etc. Arsenic poisoning also affects the plant's yield, its reproductive capacity, fertility and fruit production. Arsenic accumulation in plants will damage the cellular membranes and may lead to the leaking of electrolyte.

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