

Aspects of Arsenic Contamination of Underground Waters

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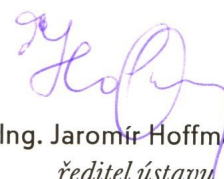
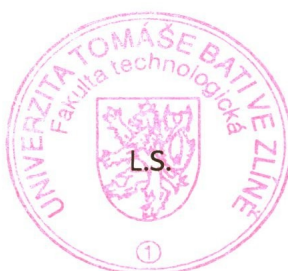
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ABSTRACT

Arsenic, the well-known poisonous element, has been found in groundwaters of many countries in the world. Its presence in water used for drinking, bathing, and irrigation poses health risks to as many as half a billion people who are exposed to it through use of tube wells or water-piped systems.

The purpose of my thesis is to summarize facts around the occurrence and toxicology of arsenic and list international and national arsenic drinking water standards as well. My paper also gives information on arsenic removal treatment options – the well-established ones, as well as, those which are feasible under economically challenged conditions. Potential future risks and challenges concerning presence of arsenic in groundwaters are also identified.

Keywords: arsenic, treatment, toxicology, groundwater, drinking water, poisoning, metalloid

ABSTRAKT

Prvek proslulý svou jedovatostí, arzen, byl nalezen v podzemních vodách mnoha zemí světa. Jeho přítomnost ve vodách používaných ke konzumaci, mytí a zavlažování představuje zdravotní rizika ohrožující až půl miliardy lidí, kteří s ním přicházejí do styku v rámci užívání trubních studní i vodovodů.

Účelem mé práce bylo shrnout dosavadní znalosti o výskytu a toxikologii arzenu, uvést národní a mezinárodní standardy obsahu arzenu v pitných vodách. Má práce dále podává informace o možnostech odstraňování arzenu – uvedeny jsou obecně používané metody i ty, které jsou snadno proveditelné v oblastech, jež vyžadují ekonomicky dostupná řešení. Práce uvádí možná budoucí rizika a problémy spojené s výskytem arzenu v podzemních vodách.

Klíčová slova: arzen, technologie odstraňování, toxikologie, podzemní voda, pitná voda, otrava, metaloid

“The dose makes the poison.” - Paracelsus (1493 – 1541)

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Finally, I offer a special thanks to the authors of the articles used as source of information for involvement in the arsenic poisoning issue since without their work, many more people would still be arsenic victims.



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INTRODUCTION

Arsenic (As) has been known since ancient times as a substance with a poison property. Some languages operate with several names for this substance, such as Hindi, which points to its wide use as a lethal but secretive weapon. The name itself was probably derived from Persian *az-arnikh* meaning “golden“ and inspired many to try and obtain gold from the arsenic ores (1). When the modern times struck, arsenic was a favorite poison but despite of this fact, it became part of coloring agents and was thus used in wallpapers, paints, and even items such as toys and wrapping paper (1). Many people have been poisoned by arsenic either by use of these items or murdered. Some of these victims are listed in Appendix I.

As arsenic poisonings started to occur, people become cautious and arsenic was eliminated from commercial goods. Nevertheless, a couple of decades ago, nobody would guess that this metalloid would cause the biggest poisoning threat around the world.

Since the 1970s, international organizations and various companies have been digging tube-wells in the third world countries in order to prevent water-borne diseases. Aquifers rich in arsenic were hit and the pumped water started to be used without proper tests being carried out. It took 20 years before local arsenicosis patients were identified through skin cancer, lung, and bladder problems (2, 3).

Arsenic poisonings through drinking water aren't privilege of a few developing countries though. Millions of people are being poisoned everyday in dozens of countries around the world (3). No limit on arsenic in water has been proved safe, which just emphasizes the necessity to treat drinking water with arsenic concentrations of several dozens or hundreds of micrograms/L. However, it is necessary to treat water sources even when arsenic concentrations don't reach these extremes since this lethal element is a slow but hard worker and even in small concentrations can cause serious health problems over years (2, 4, 5).

My thesis informs about occurrence, uses, and health effects of arsenic on humans, lists limits on arsenic concentration in drinking waters in certain countries, names areas where people are being poisoned by arsenic daily. My work also summarizes possible treatment options and conditions under which they are usable and identifies complications, as well as, impacts of the mass arsenic poisoning which is going on around the world.

1 OCCURANCE OF ARSENIC

1.1 Arsenic in nature

Arsenic is a yellow or gray, brittle, metal-like substance which is a natural part of Earth's soil and rocks (6). It is odorless and tasteless (7). Arsenic compounds are found mainly in copper or lead containing ores, predominantly in arsenopyrite (8). It is released into the environment naturally by erosion from mineral deposits, by volcanic eruption, or from forest fires. We can also find it in the water, air, soil, plants, as well as, in animals. Global natural emissions have been estimated to be 7,900 tons/year (9).

1.1.1 Arsenic in the air

Approximately half of arsenic released into the air (about 8,500 ton/year) comes from soil dust. The other half comes from industrial processes, mainly metal processing such as copper smelting (75%) (10). Mainly inorganic forms of As are present in the air. Concentrations can reach several hundred ng/m³ in some cities and exceed 1,000 ng/m³ nearby metal smelters and power plants. For example, in Prague, airborne arsenic concentrations reported in the past averaged at 450 ng/m³ in winter and 70 ng/m³ in summer (9).

1.1.2 Arsenic in soil

Industrial releases account for nearly 95% of all arsenic released into soils. Pesticide application, solid waste disposal, and sewage sludge are among other sources (10). Uncontaminated soil has As concentrations between 0.2 – 40 mg/kg. Soil nearby copper smelters may contain 100 – 2,500 mg/kg. Land after As based pesticides application may have As concentrations of 200 – 2,500 mg/kg (9).

1.2 Arsenic in water

Arsenic can be found in both above-ground and underground waters. Most of arsenic released in the water is the result of natural, weather-related processes. Other causes include industrial facilities, leaching from landfills, and releases from urban runoffs (10).

Arsenic can be present in both organic and inorganic forms in groundwater. Nevertheless, it has been confirmed its inorganic species such as arsenite (As (III)) and arsenate (As (V)) prevail (11). Inorganic forms, in particular, trivalent (As(III)) form, are the most toxic (besides gaseous arsine (12)), soluble, and mobile (13). The relative concentration of inorganic arsenic is strictly site specific and unpredictable.

Many places around the world sunk into having problems with higher concentrations of As in drinking water after deep tube wells were drilled and became used on regular basis. In cases of Bangladesh, Vietnam or China, As rich aquifers were hit by drilling. Concentrations of arsenic in these deep wells may increase with decreasing elevation as is the case in China (14). This could explain why mainly lower laying areas have had problems with arsenic in drinking water.

Underground water can get contaminated with arsenic by the following ways:

- hydrothermal volcanism (5)
- oxidation of arsenical sulphide minerals (15, 16)
- reduction of FeOOH and release of its sorbed load to groundwater (8)
- desorption of As from mineral sorption sites in response to increase of pH (15)
- evaporative concentration (17)

Arsenic manifestation in water demands specific conditions. Those are related to geochemical conditions and to the past and present hydrogeology of the affected area. Arsenic contamination can be found in both reducing and oxidizing groundwater conditions and both humid/temperate and arid climates (8).

1.3 Arsenic in food

Arsenic is known to accumulate in certain organisms and agricultural products. It enters the food chain by means of contaminated products and can further endanger human health. However, most As coming from agricultural products is in organic form - arsenobetaine and arsenocholine especially - that is much less harmful (18, 19).

Yet, spraying plants such as grapes with arsenic-containing pesticides may result in higher arsenic concentrations in wine (19).

Seafood may contain higher levels of arsenic (20), especially seaweed, bivalves, certain cold water and bottom-feeding fish, algae, clams, and oysters. While fish arsenic has low toxicity to humans and is rapidly excreted in urine (19), seaweed, on the other hand, contains the highest inorganic arsenic concentration of any seafood analyzed by Food and Drug Administration's (FDA) market basket survey (21). Seaweed called hijiki (*Hizikia fusiforme*), has been identified by the New Zealand authorities to have high levels of naturally occurring arsenic (22).

Agricultural products such as sugar or rice may contain certain amounts of As, especially if grown on land where arsenic-based pesticides were used (23).

Other commercially available food items which may contain As in high concentrations (ppm) include: sushi, sweet potatoes, carrots, green beans, peaches, and mixed cereals (21).

It should be mentioned that some aquatic plants are able to accumulate more than 1,000 mg/kg of As on a dry weight basis. A good example might be watercress (*Rorippa nasturtium-aquaticum*), which is being consumed by people in New Zealand (24).

The United States Environmental Protection Agency (EPA) has provided information that preparing foods in As-containing water increases As content by 10 - 30 % for most foods, and by 200 - 250 % in case of beans and grains (25).

1.4 Global production of arsenic

Almost all the world's As is obtained as a by-product of the copper (Cu), lead (Pb), cobalt (Co), and gold (Au) ores smelting. The peak of As trioxide global production was in 1970: 63,939 metric tons (1). Since then, the quantities produced have declined. Production of As III has dropped from estimated 42,100 tons per year in 1994 (26) to 37,500 tons in 2004. The world reserves are estimated to be 11 million tons of arsenic in arsenopyrite, copper ores, and gold-copper ores (27).

Table 1: Global production of arsenic trioxide (27)

<i>Country</i>	<i>Production of As (III) [tons]</i>
Belgium	1,000
Chile	8,000

<i>Country</i>	<i>Production of As (III) [tons]</i>
China	16,500
France	1,000
Kazakhstan	1,500
Mexico	2,500
Peru	3,500
Russia	1,500
Other countries	2,000
World total	37,500

1.5 Uses of arsenic

Arsenic has been used in many different fields. Besides being used as a poison since Ancient times, it was used as a coloring agent in sweets under the name of Scheele's Green in the 19th century, as a pigment called Paris Green, insecticide on fruit trees etc. (1, 6).

In today's world, use of arsenic is being limited, even banned, concerning commercial products in some countries such as the USA. However, inorganic arsenic compounds are still used to preserve wood. Chromated Copper Arsenate (CCA) timber was heavily used during the latter half of the 20th century as a structural and outdoor building material in cases of possible rotting or insect infestation (6). It is no longer used for residential applications, but remains used in industry (USA) (18). Among commercial products containing arsenic are: cattle and sheep dips, paints and pigments, antifouling paints, leaded gasoline and fire salts (19).

Arsenic enters the environment by means of certain industrial processes such as purifying industrial gases (namely sulfur), burning fossil fuels, burning CCA treated wood, electronics manufacturing of microwave devices (gallium arsenide, GaAs; indium arsenide, InAs), lasers, light-emitting diodes, photoelectric cells, semiconductor devices (arsine gas, AsH₃, as a dopant), hardening metal alloys, preserving animal hides, bronze plating, clarifying glass and ceramics (1, 9, 19).

Arsenic trioxide is used in Australia for treating termite infestations in houses (6).

The number of synthesized arsenic compounds is estimated to be 32,000 (20). Organic arsenic compounds are used as pesticides, mainly on cotton plants (18). Arsenic is a part of insecticides and herbicides, such as weed killers and defoliants, fungicides, and algicides.

In some countries, arsanilic acid and its derivatives 4-aminophenylarsonic and 3-nitro-4-hydroxyphenylarsonic acids are added to cattle and poultry feed at concentrations of 25 – 45 mg/kg as growth-stimulating agents (9).

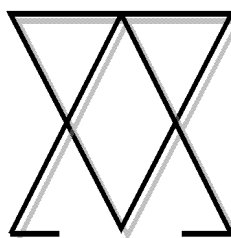
1.6 Arsenic and medicine

Arsenic has held a special place in medicine and until today, it's considered to be a panacea by some cultures. Arsenicals were mentioned as a remedy to treating ulcers and improving complexion by Hippocrates, Aristotle, Pliny and others. By the early 1900s, physicians were using less toxic organic preparations of arsenic to treat pellagra, malaria, and sleeping sickness (20). Until the 1940s, arsphenamine was used as *Salvarsan* – the first medication to treat syphilis (1, 20). Arsenic is still being used as a treatment for protozoal diseases, acute promyelocytic leukemia (6) and it's widely used in homeopathy as well (19). In some countries, arsenic serves as a treatment for trypanosomiasis and amebians in humans (20).

Arsenic is also present in Fowler's solution (Potassium arsenite), antiparasitic drugs (*Carbasone*), Donovan's solution, folk remedies such as "Asiatic pill," *kushtay*, yellow root; kelp-containing health foods, some naturopathic remedies, etc. (19, 20). The use of some products of traditional Chinese medicine produced in China has lately been compromised since the number of them was proved to contain as much as 36,000 ppm of As, which is 1,200 times more than FDA allows (28).

This metalloid has found its place in veterinary medicine as well, specifically as an antiparasitic agent (19).

Figure 1: The alchemical symbol for arsenic (6)



2 ARSENIC AND ITS TOXICITY

Arsenic belongs among the most explored elements of chemistry mainly due to its toxicity which is caused by the fact that As is very similar to its neighbor from the periodic table of the chemical elements – phosphorus (P). Arsenic can partly substitute P in biochemical reactions and thus be poisonous. Countless people have been poisoned either directly or indirectly by this lethal metalloid (6). In fact, arsenic remains the most common source of acute heavy metal and metalloid poisoning and is second only to lead in chronic ingestion (20).

1.1 Acute toxicity

Acute inhalation exposure to dust or fumes rich in arsenic may result in Gastro-intestinal (GI) effects.

Acute oral exposure to inorganic arsenic is manifested by GI problems such as nausea, vomiting. If Central Nervous System (CNS) is affected, patients suffer from headaches, weakness, and delirium. The cardiovascular system, liver, kidney, and blood may also be affected. The fatal dose of ingested arsenic trioxide is about 1 - 25 mg As/kg body weight (12).

A half an hour of exposure to 25 - 50 ppm of arsine may result in death in humans. Effects from acute arsine exposure include headaches, vomiting, abdominal pain, hemolytic anemia, hemoglobinuria, and jaundice, which may lead to kidney failure (29, 30).

2.1 Chronic toxicity

Humans can be exposed to arsenic through drinking contaminated water, ingestion of contaminated food, or through work in a metal foundry, mining, glass production, and the semiconductor industry (31).

The daily dietary intake is approximately 12 - 60 μg . Other sources estimate 10 - 15 $\mu\text{g}/\text{day}$ (4). Average is 30 $\mu\text{g}/\text{day}$. Major intake comes from fish, shellfish, grain, cereals, meat, and poultry (19). Chronic levels of 50 $\mu\text{g}/\text{l}$ can cause health problems after 10-15 years of exposure. After 15-30 years of exposure, victims often develop lung, kidney or bladder cancer (2). Concentrations of inorganic As of 600 $\mu\text{g}/\text{kg}$ body weight/day and above are lethal in humans (29, 30).

Provided the intake is bigger than 60 $\mu\text{g}/\text{day}$ and on a chronic basis, arsenic may cause the following: hyperkeratosis; hyperpigmentation; eczematous and follicular dermatitis; inability to coordinate voluntary muscular movements; edema in face, eyelids, and ankles; alopecia; muscle-aching; weakness; stomatitis; excessive salivation; anemia; leukopenia; thrombocytopenia; liver toxicity indicated by hepatomegaly, jaundice, and cirrhosis; ascited, peripheral neuropathy; paresthesias; proteinuria; hematuria; anuria; loss of hair, loss of nail, hearing loss; brain-wave abnormalities; impaired resistance to viral infections; CNS, peripheral nervous system and blood vessel damage (5, 12, 18, 32-35). Examples of the arsenicosis symptoms in pictures are in Appendix II.

Arsenical dermatosis was found to be the most common and earliest manifestation of chronic arsenic poisoning in a study carried out in the Bengal region (36).

Intake of As on a regular basis has been associated with cancer (12) such as bladder, liver, lung (29), lymphatic (37), and kidney cancer (38). Arsenic was one of the first chemicals recognized as a carcinogen, namely in 1879 when a group of miners in Saxony showed high rates of lung cancer caused partly due to inhalation of arsenic. In the 1930s, evidence existed that drinking water contaminated with As can cause skin cancer and was found in populations from Argentina, Taiwan, etc. (38). The International Agency for Research on Cancer has classified As in drinking water to be the established cause of skin, lung, and bladder cancer (39). The EPA has classified inorganic arsenic as a Group A, human carcinogen (29, 35).

Tobacco smoking has been found to interact with arsenic in the way of increasing lung cancer risk (32). Relative risk for smokers in Chile who were also drinking As-rich water was about 30 times that of non-smokers with low As concentrations in their drinking water (39).

The report by NAS from 1999 estimates that 50 $\mu\text{g}/\text{L}$ in water add 1% to a person's lifetime risk of dying from cancer. This is estimated to be the same risk as living with a cigarette smoker (4). Even concentration as low as 1 $\mu\text{g}/\text{L}$ gives person a 1/1000 lifetime chance of developing cancer (5).

Arsenic can injure pregnant woman or their unborn babies as it is able to pass through the placenta. Arsenic has teratogenic, mutagenic, and carcinogenic effects in a fetus (12, 18). Chronic arsenic exposure may also result in spontaneous abortion, stillbirth, and

malformations of the fetus (12, 40). Moreover, arsenic has been detected in low levels in breast milk (18).

Mutagenic effects include DNA damage, genetic alterations, and changes in chromosome structure. The trivalent form has manifested itself to be far more genotoxic than the pentavalent arsenic (12).

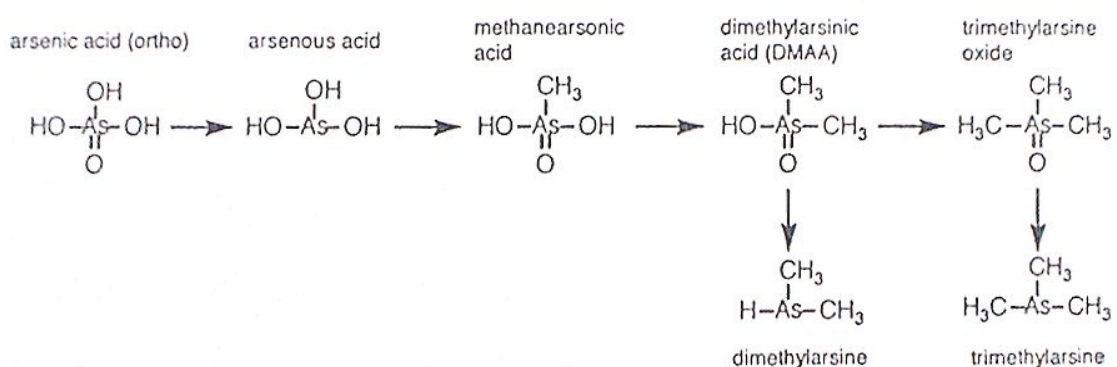
Moreover, some studies suggest that long-term exposure to arsenic in children may result in lower IQ scores, as children may be less efficient at converting inorganic arsenic to the less harmful organic forms than adults (18).

2.2 Metabolic pathways of arsenic

Water-soluble arsenic acids and their salts are rapidly absorbed after indigestion compared to poorly soluble arsenic forms, such as arsenic trioxide.

After consumption, As is stored in the liver, kidneys, spleen, heart, and lungs. Smaller amounts are also stored in the muscle and nerve tissues. Several weeks after ingestion, As is deposited in the hair and nails where it remains fixed to the keratin for years. Besides hair, it is deposited in the bones and teeth as well (41).

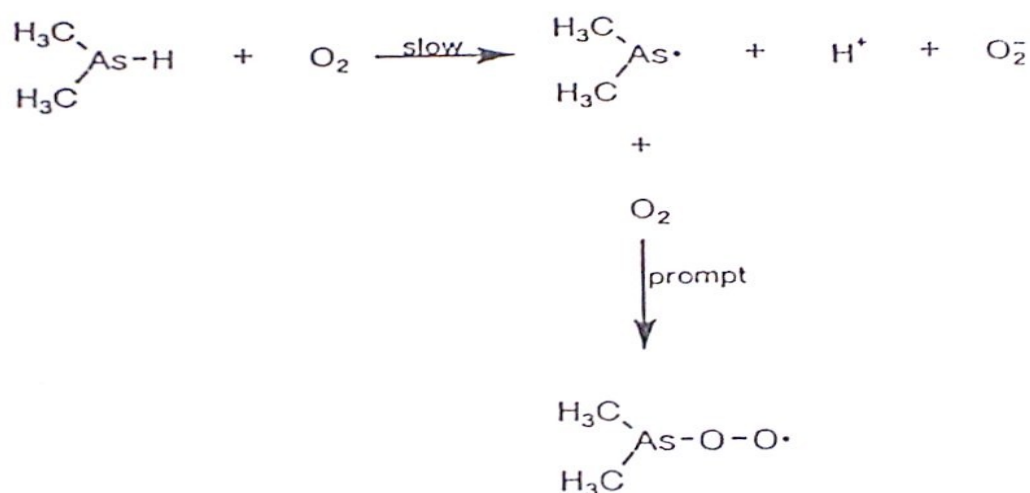
Figure 2: Proposed metabolic pathways of arsenic (41)



In mammals and microorganisms, inorganic arsenic is known to be reduced metabolically, then methylated to methanearsonic acid, and finally methylated to dimethylarsinic acid (DMAA). In some microorganisms, it can be methylated to trimethylated arsenic (41).

In mammals, the reduction and methylation takes place mainly in the blood and liver while the main metabolite is DMMA. By reaction of oxygen with dimethylarsine (a metabolite of DMMA), free radicals are produced as is obvious in Figure 3. It is believed, dimethylarsenic peroxy radical, rather than active oxygen in other cases, causes DNA damage (41).

Figure 3: Proposed reaction pathway of dimethylarsine and molecular oxygen (41)



Some scientists suppose that As disrupts the activity of hormones called glucocorticoids, regulating blood sugar and suppressing tumors. Arsenic binds them in cells and changes their structure. The theory says arsenic doesn't cause cancer but promotes the growth of tumors caused by other carcinogens. It is believed that As induced effects may appear at concentrations as low as 2 µg/L (4).

2.3 Symptoms of arsenic poisoning

- Garlic odor of breath and feces (after arsenic trioxide (6)), and metallic taste in mouth, As salts can cause oral irritation and burning in the mouth and throat when ingested (20);
- Acute poisoning: Adverse GI effects predominate with vomiting, abdominal pain and rice-water or bloody diarrhea. GI effects may also include inflammation, vesicle formation and eventual sloughing of the mucosa in the mouth, pharynx and esophagus, patients may experience acute distress, dehydration (often), and hypovolaemic shock (31);

- CNS effects are common: headache, dizziness, drowsiness and confusion;
- Symptoms may progress to include muscle weakness and spasms, hypothermia, lethargy, delirium, coma and convulsions;
- Cardiovascular effects: shock, cyanosis and cardiac arrhythmia (31);
- Liver damage may be manifested by elevated liver enzymes and jaundice;
- Injury to blood-forming tissues may cause anemia, leucopenia and thrombocytopenia;
- Arsenic gas exposure (31): An acute hemolytic anemia and striking chills, hemoglobinuria causes the urine to appear black and the patient becomes rapidly obtunded (33, 34).

Figure 4: 55% of the children in the group suffer from arsenical melanosis (93)



3 ARSENIC DRINKING WATER STANDARDS BY COUNTRY

The EPA has recently proposed an allowed limit for arsenic in drinking water to be 5 µg/L (4). Some sources suggest the Agency is planning to reduce the level to possibly as low as 2 ppb (42).

Table 2: Global safety guidelines concerning concentrations of As in drinking water as of 2006

<i>Country/ Organisation</i>	<i>Drinking Water Quality Guideline</i>	<i>Maximum permissible lvl. of As in drinking water</i>	<i>Source</i>
WHO	10 µg/L	50 ppb	(32)
Australia	7 µg/L	-	(16)
Bangladesh	50 µg/L	-	(25)
Brazil	50 ppb	-	(43)
Canada	25 µg/L	-	(44, 55)
Cambodia	50 µg/L	-	(45)
Chile	-	50 µg/L	(46)
China	50 µg/L	-	(14, 47)
Czech Republic	10 µg/L	-	(99)
EU	10 µg/L	10 µg/L	(2)
Hungary	50 µg/L	-	(48)
India	-	10 µg/L	(49)
Japan	10 µg/L	-	(50)
Myanmar	50 µg/L	-	(45)
New Zealand	10 µg/L	-	(5)
Taiwan	-	50 µg/L	(51)
Vietnam urban	10 µg/L	-	(45)
rural	50 µg/L		
USA	10 µg/L	-	(52)

4 CURRENT SITUATION – ARSENIC IS POISONING THE WORLD

4.1 AREAS AFFECTED

There are a lot of countries in the world which face environmental problems concerning arsenic including China (Inner Mongolia), USA, Canada, Argentina, India, Bangladesh, Taiwan, Chile, New Zealand, Mexico, Japan, Ghana, Hungary, Vietnam, Cambodia, Philippines, and Brazil (2-4). Arsenic occurrence associated with geothermal waters has been reported in several areas, including hot springs in Argentina, Czech Republic (100), Japan, New Zealand (5), Chile, Kamchatka, Iceland, France, Dominica, and the USA. (8) Arsenic contamination related to mining exists in Ghana, Thailand and the USA (8). Other areas such as Nepal, Pakistan, Thailand, Laos, and Sumatra have not been properly examined yet even though higher concentrations of As in local ground waters are probable (2). Illustrative maps of areas affected by high arsenic concentrations in drinking waters are shown in Appendices III and IV.

Arsenic may occur in many other countries where a certain area might be affected due to industrial or mining activities, such as Most or Chomutov areas in the Czech Republic. The local contaminated water is not used for drinking purposes and the population is provided with As-free water.

4.1.1 Argentina

Central Argentina with the Chaco-Pampean Plain, covering over a million km², is probably the largest region hit with higher As groundwater concentrations in the world. Five local provinces has had As concentrations elevated above acceptable standards. Arsenic concentrations in Córdoba ranged from 6 - 11,500 µg/L, La Pampa province As concentrations ranged between 4 - 5,280 µg/L, and Tucumán province reported 12 - 1,660 µg/L in drinking waters (8).

4.1.2 Bangladesh

Alluvial sediments in the region are believed to be the source of As in the groundwaters in this country. These sediments are rich in iron pyrites containing arsenic, which is released by reduction due to the presence of organic matter (53). Tube-wells were drilled in the 1970s to lower the risk of cholera and other water-born diseases in the region. Nowadays, millions

of tube wells exist (estimated 3 – 5 millions (54)) which pump water from the As-rich aquifers in the area. These contaminated wells have become, in many cases, the only source of water for local residents. In the late 1980s, the first cases of arsenicosis were reported. Today, approximately half of the country's population – alarming amount of 70 million people (54) are at risk and the situation is rightfully nicknamed “the biggest arsenic calamity in the world.” Some wells in use contain as much as 400 µg/L, the treatment is still scarce and the population through the whole country suffers from As related cancers and other symptoms of arsenicosis (27).

4.1.3 Cambodia

The Mekong floodplains had wells tested for arsenic with results exceeding WHO limits. The population at risk might be 70,000 –300,000 people (45).

4.1.4 Canada

Arsenic has been found in higher concentrations in hard rock areas of the Canadian Shield in Ontario (55). Elevated As concentrations in water supplies were also identified in Nova Scotia (particularly in Halifax and Guysborough Counties) in the 1970s (56). The Canadian government is considering lowering the allowed As limit from 25 µg/L to the current WHO limit of 10 µg/L (56). More research is required in order to identify areas with elevated As concentrations.

4.1.5 Chile

The northern region of Antofagasta in Chile shows higher concentrations of As in water, soil, and air. Arsenic can be found in volcanic rocks within the region. Rivers originating there carry the lethal metalloid and serve as a drinking water supply and water used for irrigation. Moreover, there are two copper refineries emitting thousands of tonnes/year of arsenic as a byproduct into the air. The level of As in water supplies peaked in the 1960s, being as high as 850 µg/L. Levels gradually decreased to meet the Chilean standard due to the new water treatment plant built in 1970. However, the Chilean standard for drinking water is set to 50 µg/L and some measurements still show levels of As of up to 75 µg/L (57). Higher numbers of lung and bladder cancer cases exist in the region compared to the

rest of the country (46). It is estimated that 7% of death among people over 30 can be attributed to As (4, 8).

4.1.6 China , Inner Mongolia

In 2003, higher As concentrations were reported from eight provinces and 37 counties in China. In 1980, cases of arsenicosis were reported in the Xinjiang Autonomy Region of China, where more than 100,000 people are at risk. In 1989, the Inner Mongolia was identified as another region with cases of arsenicosis. More than 600,000 people are exposed to As in their drinking water in the area. In 1994, vast parts of Shanxi province followed, with about 900,000 people at risk. These cases were caused by using contaminated water from pump wells (14).

The Chinese population also suffers from a special kind of arsenicosis due to burning coal. Certain local small-scale coal mines rich in As have been opened to the public where they were allowed to excavate coal. This coal has concentrations from 826 – 2,578 mg/kg; in which the highest concentration measured was 9,600 mg/kg. Local people use the coal for cooking, heating, drying corn and hot peppers, local staples, and in open stoves without chimneys. Arsenicosis of this type originates from breathing arsenic-rich air and consumption of contaminated corn and peppers. About 200,000 people are at risk (14). Others estimate that as many as 2 million people in the area are at risk (51).

In 1994, the Chinese government declared arsenicosis to be an endemic disease throughout the nation due to the amount of people and areas affected (14).

4.1.7 Ghana

Arsenic contamination is bound mainly to gold and silver mining since gold is being found in close association with arsenopyrite in sulphide-mineralized veins (58). The gold mining area of Obuasi shows higher levels of As in groundwater with maximum measured concentration of 64 µg/L. In Bolgatanga, minimum samples showed As levels above the guideline value, but one sample had As concentration of 140 µg/L. Other mining regions, especially the “Gold belt” in the SW, should be investigated since the population is showing signs similar to arsenic poisoning (58).

4.1.8 Hungary

Arsenic has been problem in the SE part of the country with population at risk of 400,000 people (59). The highest measured As concentration in a town waterworks was 220 µg/L, and in a village waterworks 330 µg/L (Bekes county). The project of lowering As concentration took place 1981 - 1995 and involved 80 settlements in seven counties. The limit was then 50 µg/L. Lower As concentrations were reached by building new piped systems in different aquifers, as well as, incorporating the old waterworks – mixing the waters (60). Arsenic exposure pertains to 1.2 million people using potable water in Hungary today, 20,000 people are at high risk (61).

4.1.9 India

In 1983, arsenic contamination in drinking water was identified in the Lower Ganges Plain in the state of West Bengal, neighbor to Bangladesh. The region's main source of water are tube wells being dug since the 1970s. Arsenic concentrations are as high as 814 µg/L in some areas. Testing has been taking place and thousands of water, hair, and urine samples were taken in the Bengal region. The Upper, Middle, and Lower Ganges Plains are home to 500 million people. Since As contamination is obvious in the Lower delta, namely West Bengal and Bangladesh, as well as, in the Upper Ganges region in Nepal, it is logical to suppose that As contamination might be widespread along the whole Ganges river plain. Arsenic-rich sediments from the Himalayas are the most probable source of As. The study from Bihar (62) has identified wells with concentrations as high as 1,025 µg/L and patients suffering from arsenicosis, as well as, many deaths due to cancers in the area (62, 63). Other reports estimate that 443 million people to be at risk in the Indian states of Uttar Pradesh, Bihar, Jharjhand, West Bengal, Assam, and Manipur in the Ganga-Meghna-Brahmaputra plain (64).

4.1.10 Laos

The area affected by elevated arsenic contamination of groundwater seems small. It is estimated that several hundred to several thousand people might be affected. Highest measured concentration was 120 µg/L (45).

4.1.11 Mexico

The region of La Gunera of north central Mexico has groundwater with As concentrations from 8 - 624 µg/L and with average of 100 µg/L. The problem was identified as long ago as 1958 (65). The estimated population exposed to drinking water containing more than 50 µg/L is about 400,000. The state of Sonora in the NW Mexico has also had cases of higher As concentrations in groundwaters ranging 2 - 305 µg/L, with the highest measured concentration being 7,400 µg/L (8). Several more areas in Mexico (Morelos, Chihuahua, Puebla, Nuevo León, Hidalgo) are known to have populations exposed to higher As concentrations (65).

4.1.12 Myanmar – Burma

The affected area is located in the river basin of the Irrawaddy river and about 3.4 million people are at risk (45). The area is yet to be properly tested.

4.1.13 Nepal

The area affected is a flat land in the southern part of Nepal, the Terai region, with half of the country's population (11,000,000 people) where hundreds of thousands tube-wells were drilled in order to supply drinking water in the 1970s and 1980s. About 500,000 people are at risk of As poisoning from the water. Estimates are that 1 in 20 people may show skin lesions indicating arsenicosis (25). A significant number of tested wells exceed allowed WHO limits, while the highest measured As concentration in the region's well was 1,200 µg/L, and the highest measured concentration in the country was 2,620 µg/L (66).

4.1.14 Taiwan

The SW coast of Taiwan has become dubbed “the Blackfoot disease endemic area” since many farmers suffer from this malady due to drinking water contaminated with arsenic. Range of As concentration in local drinking waters is 170 - 800 µg/L (51). The NE of the country has been affected as well. The highest measured concentration (1968) was 1,800 µg/L (8).

4.1.15 USA

The SW states such as Nevada, California, and Arizona in the United States have been known to have groundwaters with higher As concentrations. Other states have been recently identified with levels exceeding the allowed limit of 10 µg/L, namely Maine, Michigan, Minnesota, South Dakota, Oklahoma, and Wisconsin. Concentrations scarcely exceed the level of 50 µg/L and only locally reach concentrations as high as 2,600 µg/L (Tulare Basin of the San Joaquin Valley, CA) (8). Recently, the EPA has lowered As standard for drinking water to 10 µg/L (ppb). The water systems have to comply with the standard by January 23, 2006, which will result in further protection of about 13 million people who were drinking water with higher As concentrations (52).

4.1.16 Vietnam

Sampling of the Red River delta including the Hanoi urban area in September 1999 revealed that 50% of the tested family-based tube wells were exceeding the Vietnamese guideline of 50 µg/L, while the average concentration measured was 159 µg/L. The peak value measured was 3,000 µg/L. The worst affected area is south of Hanoi where the average value measured was 432 µg/L and 90% of these samples revealed concentrations above the Vietnamese guideline. The city of Hanoi water treatment accepts water containing up to 430 µg/L of arsenic, where the treatment is able to reduce the arsenic to roughly 90 µg/L. At the time of the study, the population did not show any symptoms of As poisoning, which was probably due to the fact that the groundwater was in use for 7 - 8 years while symptoms usually occur after 10 years of exposure (2). Approximately 11 million people are at potential risk (63).

4.2 Global outlook

Arsenic didn't belong among elements routinely tested in groundwater until recently (8). Nowadays, more areas are carrying out testing of possible sources of As in drinking water in order to determine risk factors for local populations. Due to global awareness and education, potentially arsenic-rich areas are being discovered all over the world.

The arsenic exposure through water usually began when waterworks started to be used. For example, in the 1940s within the affected villages of Hungary (60). In this case, the poisoning was ongoing for decades. Another example might be the Bengal region - WHO

experts have predicted (based on long-term exposure of the population) that about 10% of adult deaths in the region will be due to As poisoning in the coming decades (67).

In some areas, it might be a real challenge to comply with the WHO limit of 10 µg/L. For example, certain areas in Hungary might reach aquifers with waters low in As, but the water might not be of good quality from other points of view (high concentrations of ammonia(60)), while in other areas, the opposite might be the case – the water meets all other standards but arsenic concentration is elevated.

Arsenic limit will probably be lowered in the future and thus more areas will need to have the water tested and treated for As (4, 42). Certain countries, such as Czech Republic, already follow strict standard of 5 µg/L for nursing water and bottled water in order to ensure low intake of this toxic element by infants (101).

5 TREATMENT OF WATER CONTAMINATED WITH ARSENIC

5.1 Non Treatment Options

It is cost-effective and environmentally friendly to use non treatment options such as:

- Using alternative sources of water,
- Seasonal use of water contaminated with As while maintaining allowed annual concentration level,
- Blending high and low-arsenic water (11).

5.1.1 Alternative sources of water

This technique involves abandonment of water source contaminated with As and finding a new source which wouldn't impose any health and environmental risks. Because arsenic is many times present in underground water systems, it might be improbable to find such a source in certain locations, for example Bangladesh (Chapter 4.1.2.).

If the area affected by high concentration of As is small, As-free water can be purchased or connection to a nearby As-free water distribution system can be provided (11).

5.1.2 Seasonal use

This method involves seasonal use of water contaminated with As while maintaining allowed annual concentration level. Possible remedy may be to find another source of water while the old As-contaminated site may be used seasonally, or when the new one doesn't provide enough water. Monitoring of arsenic concentrations at the Point-of-Entry (POE) to the water distribution system should be conducted (11).

5.1.3 Blending

Multiple sources of water, both low and high in arsenic, are mixed in a common header to achieve the final concentration, which should be 10-20% under the allowed limit. The treated and untreated sources can be mixed, which brings financial relief (11).

1.2 Pretreatment

In order to determine the right choice of treatment, it is important to know the form and species of arsenic in water. It is known that arsenate (As(V)) is more effectively removed than arsenite (As(III)). Thus, if we are able to transform As(III) presented in the water into As(V) by an oxidant, removal will be more efficient (69, 70).

The data in the table below is based on results of the study, which can be accessed at (69). The tabular data is used here to illustrate which oxidants can be used to effectively transform As(III) to As(V) and consequently increase further treatment efficiency.

Table 3: Ability of oxidants to oxidize As(III) to As(V)

<i>Oxidant</i>	<i>General conditions</i>	<i>Fe, Mn present</i>	<i>Sulfide present</i>	<i>TOC present</i>	<i>Temperature drop (25°C to 5°C)</i>
<i>chlorine</i>	RO	RO	slower O	slower O	RO
<i>permanganate</i>	RO				RO
<i>ozone</i> ¹⁾	RO	RO	slower O	slow O	RO
<i>chlorine dioxide</i>	i	i	i	i	i
<i>monochloramine</i>	i	i	i	i	i
<i>filox media</i> ²⁾	RO				
<i>UV radiation</i>	i		RO		

RO – rapid oxidation

O – oxidation

i – ineffective for oxidation

¹⁾ pH = 6.3-8.3

²⁾ pH = 8.3

According to other sources (71), the preferred oxidant is KMnO₄ followed by filtration/precipitation step, or chlorine or hydrochlorine, where legally possible.

5.2 Types of treatments

The US EPA has identified seven Best Available Technologies (BAT) for As removal: activated alumina (AA), ion exchange, reverse osmosis (RO), modified coagulation/filtration, modified lime softening, electro dialysis reversal (EDR), and oxidation/filtration. (72)

Main considerations concerning selection of treatment are as follows:

- Water quality characteristics such as pH, iron (Fe) concentration, Fe : As ratio, form of As present,
- Ease of implementation in specific site,
- Residual management,
- Cost.

Besides these points, several more things have to be considered before deciding which treatment is the most suitable for a specific site, such as: existing treatment processes, target final As concentration, disposal of waste, waste discharge, land available, labor, acceptable percentage of water loss, maximum flow rate, average source flow rate, and specific requirements.

Concerning the water quality characteristics, iron can play a vital role in arsenic removal from water. Thus, Fe concentration and Fe:As ratio in water points out which As removal treatment to use (11):

- High iron level (>0.3 mg/L), high Fe:As ratio (20:1) → adsorption, As removal by iron, co/precipitation,
- High iron levels (>0.3 mg/L), low Fe:As ratio ($<20:1$) → coagulation/filtration, use of iron salts,
- Low iron levels (<0.3 mg/L) → adsorptive media, ion exchange (11).

5.2.1 Adsorption

Adsorption is a process that takes place when a liquid accumulates on the surface of a solid material - adsorbent. Removal of arsenic from water based on adsorption involves the contaminated water running through adsorptive granular material in a pressure vessel.

Negatively charged arsenic particles of As(V) are adsorbed on the surface of the positively charged adsorbents.

Adsorbent materials available: AA, titanium oxide based media, zirconium based media, Fe oxide, Fe hydroxide based media (11, 73), iron oxide-coated sand, MnO₂-coated sand, bauxite, hematite, feldspar, clay minerals (kaolinite, bentonite, Bijoypur clay), synthetic anion exchange resins, chitin and chitosan, bone char, and cellulose materials (sawdust, newspaper pulp) (74).

Advantages: Low-cost, simple operation of the system, both manual and automatic operation possible, and good performance in high silicate and high phosphate waters (Titanium oxide adsorbent (73)).

Disadvantages (AA): pH sensitive (shorter run lengths when pH higher), regeneration of the adsorbent is partial, and high As concentrations in brine stream after regeneration (75).

5.2.2 Arsenic removal by iron

The affinity of Fe media for As is strong under natural pH conditions. This allows the Fe based sorbents to decontaminate larger volumes compared to AA and the pH does not have to be adjusted. However, lower pH offers better results (11, 76). Presence of dissolved oxygen is also beneficial since it increases the rate of Fe corrosion and As removal (76).

Advantages: Natural pH conditions, removal efficiency 80 – 90% if the Fe : As ratio is at least 20:1 (1 mg of Fe removes 50 µg of As) (11, 76).

Disadvantages: Certain chemicals (such as phosphate and silicate) bind to Fe prior to As and may significantly decrease efficiency of As removal (54); solid waste water and backwash water is produced during the process (11).

5.2.3 Oxidation /Filtration

Oxidation/filtration is a process commonly used in Fe and manganese (Mn) removal from water. The process involves oxidation of their soluble forms to their insoluble forms and consequent removal by filtration process. If As is present in the water as well, both Fe and As can be oxidized. Arsenic will bind itself to iron depending on their initial concentrations. Special pressurized granular media can be used such as manganese oxide media including manganese greensand (glaucinite coated with Mn dioxide) and pyrolucite (ore composed of

solid Mn dioxide), which serve both as catalysts and media for precipitation of iron and manganese. Water is passed through column of manganese oxide, which adsorbs Fe, Mn, and As. Ferric chloride might be added prior to the treatment.

Sludge and waste water are created (11, 74).

5.2.4 Coagulation /Filtration

Pretreatment in form of oxidation is necessary in order to transform As(III) to As(V). Coagulants hydrolyze to form hydroxide particles which adsorb arsenic, and the solid material created is then filtered out in a pressure filter vessel (Appendix V).

Coagulants available: Aluminum (Al) salts, ferric salts. Ferric salts have shown better results than Al salts since Fe hydroxides create solution in the pH 5.5 - 8.5 and Fe has stronger affinity to As(V) (71), which is illustrated by Figure 5.

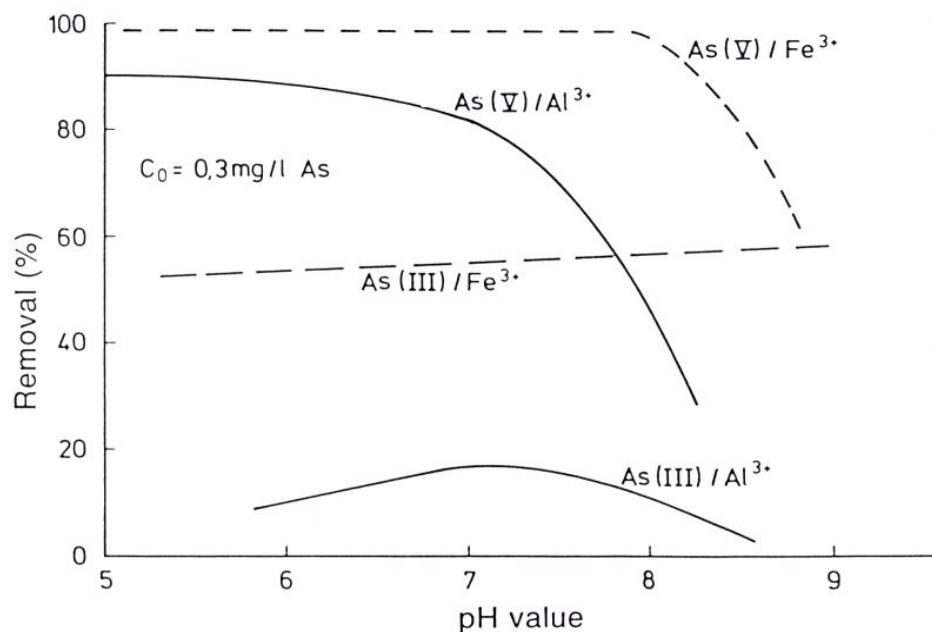
Filters used: Media filters, micro-filters (membranes).

Efficiency depends on: Type and dosage of coagulant, mixing intensity, pH.

Advantages: Up to 90% of dissolved As(V) can be removed from water.

Disadvantages: pH might need to be adjusted, sludge and backwash water is created (11, 74, 70)

Figure 5: Influence of pH on the removal of As(III) and As(V) from groundwater by Fe and Al ions. Initial As concentration: 0.3 ppm, dosage of metal ions: 0.09 mmol/L (71)



5.2.5 Ion Exchange

Ion Exchange is a physical-chemical process in which a solution and solid resin are present - they swap ions. As in the cases mentioned above, As(III) has to be oxidized to As(V) form first. Resin is usually an elastic 3-dimensional hydrocarbon network with large ionizable groups electrostatically bound to the resin. These groups are exchanged for ions with stronger affinity from the solution. A similar process is used for softening and nitrate removal from drinking water. Contaminated water is running through columns packed with the resin (strong base anion), which isn't sensitive towards pH from 6.5 - 9.0.

Efficiency depends on the presence of other anions, which compete with As in binding to the resin in the following order: $\text{SO}_4^{2-} > \text{HAsO}_4^{2-} > \text{NO}_3^-$, $\text{CO}_3^{2-} > \text{NO}_2^- > \text{Cl}^-$.

This process isn't suitable if contaminated water contains over 500 mg/L of TDS or/and over 50 mg/L of SO_4^{2-} or/and over 5 mg/L of NO_3^- .

Disadvantages: Chromatographic peaking – As(V) and nitrate levels in effluent stream can exceed levels in influent stream when sulfate ions displace As ions previously bound to the resin; resin fouling – ions bonding the active sites can't be removed by any regeneration method; backwash water, brine solution, rinse water, spent resin are usually produced (11, 74).

5.2.6 Lime softening

Lime softening is commonly used to reduce hardness, which is caused by the presence of calcium (Ca) and magnesium (Mg) ions in source waters. The lime provides hydroxide ions increasing pH, which results in Ca and Mg removal. This process has been used for removal of heavy metals, radionuclides, dissolved organics, and viruses through adsorption on calcium carbonate and magnesium hydroxide.

Disadvantages: Strong pH dependency: low removal is reached at pH less than 10, pH near 11 allows precipitation of magnesium hydroxide and efficiency of As removal is then up to 90% (77); production of large volume of sludge; recarbonation of water required (78).

5.2.7 Reverse osmosis (RO)

RO is a treatment for small water systems which may be installed on a faucet. Reverse osmosis can be used to treat various water quality problems: removal of organic carbon,

salts, dissolved minerals, microorganisms, color, metals, and As (11, 79). High pressure (5-20 MPa (80)) is used to force water through a semipermeable membrane while contaminants do not pass through the membrane. The membrane has usually two layers: a top layer of less than 1 μm thick and a porous sublayer of 50 - 150 μm thick (11) (Appendix V).

Advantages: Low sensitivity towards pH, easy manipulation, and cost effective as a small scale treatment (11, 79).

Disadvantages: Presence of Ca and Mg in water can cause scaling of the membrane; silicon (Si), metal hydroxides, colloid, bacteria can block the membrane; high sensitivity towards Cl (11); fairly slow process - producing 15 gallons of purified water/day; large quantities of wasted water since RO may require 3 - 10 gallons of untreated water to make one gallon of purified water (79).

5.2.8 Electrodialysis reversal (EDR)

EDR is comparable to RO. It is usually used to treat brackish waters or in wastewater recovery. EDR is a process reversing the polarity of electrodes on a controlled time cycle. The direction of ion movement in a membrane stack is reversed and thus automatic flushing of forming scales from the membrane surface is ensured (81).

Advantages: Fully automated, little operation required, no chemical additions.

Disadvantages: More expensive than RO, large amounts of water are wasted (75).

5.3 Treatment options by site

5.3.1 Point -of-Use (POU) Treatment

This treatment is installed on a single tap when water is used for drinking and cooking purposes only. It is usually plumbed in at the kitchen sink (75).

Advantages: Lower costs if treatment needed for up to 500 people

POU available for piped water systems:

- AA – preoxidation necessary, usable for 25 to 10,000 people (11) (Chapter 5.2.1.),
- RO (11) (Chapter 5.2.7.).

POU example for areas with no piped water systems:

- Iron-coated sand (a by-product of large-scale water treatment) in filters – no chemical additives needed - gravity powered system (82).

POU treatment has been the only solution for communities not connected to town piped water systems, which is quite common in Australia, New Zealand, Argentina, Hungary, and Serbia, as well as, in many rural areas of developing countries such as Bangladesh and India. (82).

5.3.2 Point -of-Entry (POE) Treatment

POE treatment is for the entire building. POE treatment includes Ion Exchange, adsorptive media, reverse osmosis, etc. (Chapter 5.2.1 – 5.2.8.)

5.4 Rescue and other treatment options

When the affected areas are financially challenged, it is necessary to find an inexpensive instant solution until a long-term solution, such as a piped water system, can be implemented. This poses a challenge to those trying to solve the situation locally, as it is necessary to ensure that the contaminated sources are properly marked (in case of wells, red paint signals not to use the water source, green color signals the arsenic concentration is acceptable) and not used any longer. People have to be educated about the problem as to why the clear clean water is a poison to them. An alternative source of water or instant solution has to be found as soon as possible in order to prevent further poisoning (39). Several instant treatment options have been discovered and are in trial (Table 4).

Many people, institutions, and organizations have been involved in order to find a solution. The urgency of the problem is well illustrated by the fact that the United States Academy of Engineering and the Grainger Foundation offered the Grainger Challenge Prizes of \$1,000,000, \$200,000, and \$100,000 for first, second, and third place for the design and creation of a workable, sustainable, economical, POU water treatment system for arsenic-contaminated groundwaters in developing countries (84).

5.4.1 Rain -water collectors

Where As contamination has been proven, a simple and less expensive solution of rain water collectors may be used. In such cases, tanks or roof collectors can be arranged. Regular maintenance is necessary, especially in tropical areas where mosquito larvae might contaminate the water (32, 83, 86).

5.4.2 Variations on adsorption while using inexpensive materials

Since the biggest problem in most developing countries is affordability, UNESCO and other agencies have been supporting simple solutions by implementing simple technologies and cheaper materials. A good working example might be the so called “Four Pitcher System“, where water is poured in the first pitcher, charcoal and brick chips in the second pitcher, while sand in the third one, and As-free water is in the fourth pitcher. Arsenic is oxidized while it flows from the first pitcher to the second and is adsorbed to iron. The ground-water has to be rich in iron for the system to be effective.

Another example might be the “Two Bucket System“. The contaminated water is poured into the top bucket to which potassium permanganate and aluminium sulfate is added. The tube well water is then filtered through the sand in the bottom bucket (86) (Appendix V).

Table 4: Point-of-Use methods that have been applied for arsenic removal from groundwater or shallow aquifers (70)

Removal Method Name	Summary of Known Operating Principles (2005)
Double Bucket or BUET	Coagulation/co-precipitation/adsorption (Bucket 1) followed by sand filtration (Bucket 2)
DPHE or Danida	Oxidation/coagulation/co-precipitation (stirred tank) followed by sand filtration (second smaller tank)
AIIPH in India	Mixing/oxidation (Tank 1) followed by flocculation (Tank 2) followed by sedimentation (Tank 3) followed by filtration (Tank 4)
Alcan	Activated alumina adsorption in a two bucket series
BUET Activated Alumina	Oxidation/coagulation/co-precipitation/adsorption/filtration followed by activated alumina adsorption

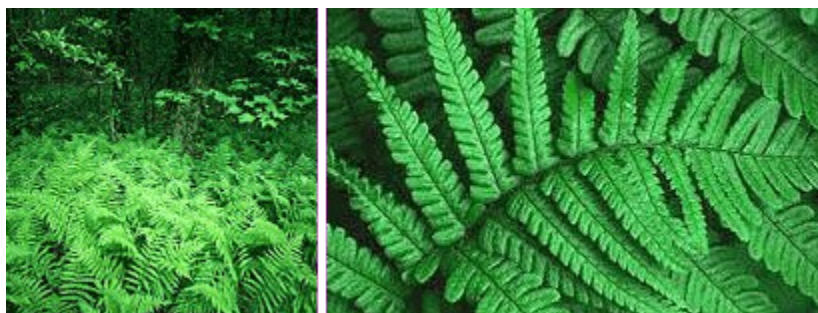
Removal Method Name	Summary of Known Operating Principles (2005)
Sono-3-Kolshi	Sand/iron/brick filter (Bucket 1) followed by sand/charcoal/brick filter (Bucket 2) followed by clean water collection (Bucket 3)
Sono 45-25	Iron filings oxidation (Bucket 1) followed by sand filtration (Bucket 2)
Read-F	Copolymer/cerium oxide adsorption followed by sand filtration
Safi	Kaolin adsorption simultaneous with ferric oxide oxidation
Tetrahedron	Chlorination/pre-filtration (Column 1) followed by ion exchange (Column 2)

5.4.3 Phytoremediation

This technology uses plants to stabilize As in situ or extract it from the soil in order to be stored in an area where it doesn't pose an environmental risk. This technology has proved to be effective for mitigation of As leaching from a disused wood-waste pile. Ferns especially (such as Brake fern - *Pteris vittata* (6)), may be used to extract As from contaminated soil. Arsenic enriched plants should be disposed at sealed landfills (24).

An example of such a remedy on the market can be edenfern™, which is able to extract arsenic from soil having As concentrations from 1 - 2,500 mg/kg (ppm). The accumulation of As takes place in the plant's fronds into which the arsenic is soaked up by the plant. The fern is then harvested while topsoil is preserved. It can typically take 2 - 4 months to reduce arsenic in soil by 10 mg/kg in case the soil has 50 mg/kg total arsenic (87, 88).

Figure 6: edenfern™ (88)



6 IMPACT ON THE ENVIRONMENT AND COMMUNITIES

6.1 Social problems

When assessing the impact of arsenic poisoning, we have to take socio-economic consequences into account as well. Since most of the cases of arsenicosis have been recorded in developing countries, the level of education, nutrition and health treatment might be limited. In many cases, people with arsenicosis have been ostracized from village communities since their skin condition left the impression of leprosy or a hereditary disease. As a result, arsenic has produced not only physical but also psychological pain as daughters and sons became orphans, and women and men lost their life partners, families, or jobs (42).

6.2 Limited solutions

Even though solutions (Chapter 5) are available, certain communities are left with As rich water as their only source of drinking water. Reasons may vary: people can't afford the treatment, none As-free water sources have been found in the area, the water testing was improper, etc. People in such communities have no other chance than to return to the contaminated source and keep using it. (3)

Figure 7: A newly installed shallow dug-well which replaced a tube well with As concentration of 220 $\mu\text{g/L}$. As concentration in this dug-well was 6 $\mu\text{g/L}$ but concentrations in similar ones may be in range from 2 - 50 $\mu\text{g/L}$. (39)



6.3 Diet and crops challenge

Some of the small scale solutions available to the locals address only drinking issues, leaving contaminated water for bathing and irrigation use. If such water is used for irrigation, people are poisoned by the agricultural products. If the products, such as rice, are exported, people in farther areas are being poisoned unknowingly by buying the contaminated products. Alternatively, if the products originating from arsenic-rich land are proved to have elevated concentrations of As, they may be refused by the market. Presence of arsenic in groundwater may then induce crisis economical in cases of dependency on the agriculture which is quite typical for developing countries (23). The top 10 rice-producing countries in the world are: China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Japan, Philippines, Brazil (98). Eight out of these 10 countries are listed in Chapter 4.1 among countries with areas having As-rich groundwaters.

Nutrition may play a crucial role in susceptibility to arsenic-caused skin lesions. Low intake of calcium, animal protein, folate and fiber may increase susceptibility. A study from West Bengal suggests undernourishment may double effects of arsenic poisoning (39, 89).

6.4 Problems concerning arsenic guidelines

Setting of the As guidelines is also an issue. In many cases, the standard is set to 50 $\mu\text{g/L}$, which is easier to meet than 10 $\mu\text{g/L}$, but might still pose risk of health problems, including cancers. In some areas, meeting the limit of 50 $\mu\text{g/L}$ is a challenge so far, such as the Bengal region. It is advisable to leave the standard at that level and lower it as much as possible in a span of next decades (39).

6.5 Complexity of the problem

While accessing problematic areas, all possible sources of contamination have to be considered. A good example might be contamination of wells and a lake nearby an old abandoned gold mine in the Shubenacadie River lakes area in Nova Scotia, Canada, where wildlife and humans were affected (56). Thus, it is necessary to look into possible contamination caused by no longer As producing plants, mines, etc. in order to prevent further damage done by this dangerous metalloid.

CONCLUSION

Arsenic contamination is a problem affecting approximately 500 million people worldwide. This poisonous metalloid occurring in groundwaters used as drinking waters is a known carcinogen, mutagen and teratogen in humans. While symptoms of chronic exposure may become obvious in approximately 10 – 15 years, the overall effect on the human body depends on the dose, health, and nutritional conditions of individuals. Children, for example, in general, are physically less equipped to convert inorganic arsenic into less harmful organic forms and thus represent the most endangered part of the population. Arsenic imposes high risk in pregnant women since this lethal element penetrates through the placenta and threatens both the fetus and the mother.

Since WHO lowered its limit for As concentration in drinking water to 10 µg/L, various technologies have to be implemented in order to meet the set standard in dozens of countries worldwide if health risks want to be eliminated. However, a lot of national standards have remained at the level of 50 µg/L, which has been proved to be a hazardous amount if taken on consistent basis. This policy seems logical, since various areas have not been able to meet the old standard yet.

The US EPA has identified seven BAT technologies for As treatment in drinking waters: Activated Alumina, Ion Exchange, Reverse osmosis, modified coagulation/filtration, modified lime softening, Electrodialysis reversal, and oxidation/filtration. Not all of them can be readily implemented in the affected areas due to economical and various other reasons.

Numerous other aspects of As poisoning have not been issued yet. More tests have to be carried out in order to identify all affected areas and populations as well as impact on the food chain. Sociological aspects have to be addressed in order to ensure normal lives to arsenic victims. Education seems to be the key in the fight against arsenic poisoning since the higher the awareness of the problem, the larger chance of saving victims worldwide.

The winner of the Grainger Challenge first prize of \$1,000,000 for the design and creation of a workable, sustainable, economical, POU water treatment system for As-contaminated groundwaters in developing countries will be known in February 2007. Hopefully, the world will also see the arsenic victims as winners in the battle with this lethal element as more awareness will be raised, proper testings carried out and useful technologies implemented.

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LIST OF ACRONYMS

AA	Activated Alumina
AIIIPH	All India Institute of Hygiene and Public Health
Al	Aluminium
As	Arsenic
AsH ₃	Arsine gas
ATSDR	Agency for Toxic Substances and Disease Registry, USA
Au	Gold
BAT	Best Available Technology
BUET	Bangladesh University of Engineering and Technology
Ca	Calcium
CCA	Chromated copper arsenate
Cl	Chlorine
CNS	Central Nervous System
Co	Cobalt
CO ₃ ⁻²	Carbonate anion
Cu	Copper
Dept.	Department
DMMA	Dimethylarsinic acid
DNA	Deoxyribonucleic acid
DPHE	Department of Public Health Engineering, Bangladesh
EDR	Electrodialysis reversal
EPA	Environmental Protection Agency, USA
EU	European Union
FDA	Food and Drug Administration, USA
Fe	Ferrum, Iron
FeOOH	Hydrous ferric oxide
GaAs	Gallium arsenide
GI	gastrointestinal
HAsO ₄ ⁻²	Hydrogen arsenate anion
i	ineffective for oxidation
InAs	Indium arsenide
km ²	square kilometer
KMnO ₄	Potassium permanganate

µg/L	microgram per liter
Mg	Magnesium
mg/kg	milligram per kilogram
mmol/L	millimol per liter
Mn	Manganese
MnO ₂	Manganese dioxide
NAS	National Academy of Sciences, USA
NIOSH	National Institute for Occupational Safety and Health, USA
NE	north-east, north-eastern
ng/m ³	nanogram per cubic meter
No.	number
NO ⁻²	Nitrite anion
NO ⁻³	Nitrate anion
NW	north-west, north-western
O	oxidation
P	Phosphorus
Pb	Lead
POE	Point-of-Entry
POU	Point-of-Use
pp	pages
ppb	parts per billion
ppm	parts per million
RO	rapid oxidation
TDS	Total Dissolved Solids
Si	Silicon
SE	south-east, south-eastern
SO ₄ ⁻²	Sulfate anion
SW	south-west, south-western
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
USA	United States of America
UV	ultra-violet
Vol.	Volume
WHO	World Health Organization

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Appendix I Famous cases of arsenic poisoning

Appendix II Common symptoms of arsenic poisoning

Appendix III Maps - arsenic contamination in groundwaters

Appendix IV Maps - arsenic contamination in groundwaters 2

Appendix V Examples of arsenic removal systems

APPENDIX I: FAMOUS CASES OF ARSENIC POISONING

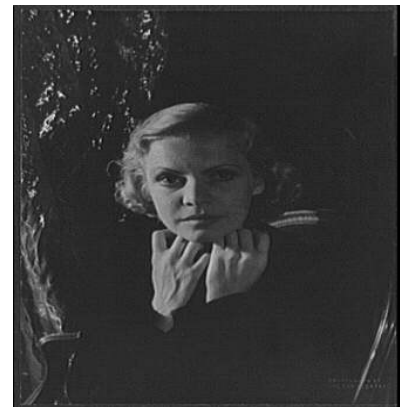
Napoleon on his Imperial throne by Jean Auguste Dominique Ingres (1780–1867), painted 1806 - a theory says that Napoleon Bonaparte (1769 – 1821) suffered and died from As poisoning during his imprisonment on the island of Saint Helena. Forensic samples of his hair did show high levels, 13 times the normal amount, of the element. (90)



Composite of three images of Monet's Paintings

Emerald Green, a pigment frequently used by Impressionist painters is based on As. Cezanne developed severe diabetes (symptom of chronic As poisoning), Monet's blindness and Van Gogh's neurological disorders could have been partially due to their use of Emerald Green.(90)

Clare Boothe Luce (1903 – 1987), Carl Van Vechten's photograph - the American ambassador to Italy in the years just following World War II. Although she did not die from her poisoning, she suffered an increasing variety of physical and psychological symptoms until arsenic poisoning was diagnosed, and its source traced to the old, arsenic-laden flaking paint on the ceiling of her bedroom. (90)



APPENDIX II: COMMON SYMPTOMS OF ARSENIC POISONING

The Blackfoot disease
typical for farmers
exposed to As in
Taiwan (91)



Keratosis on feet and hands
of people exposed to As in
the Bengal region (92, 93)

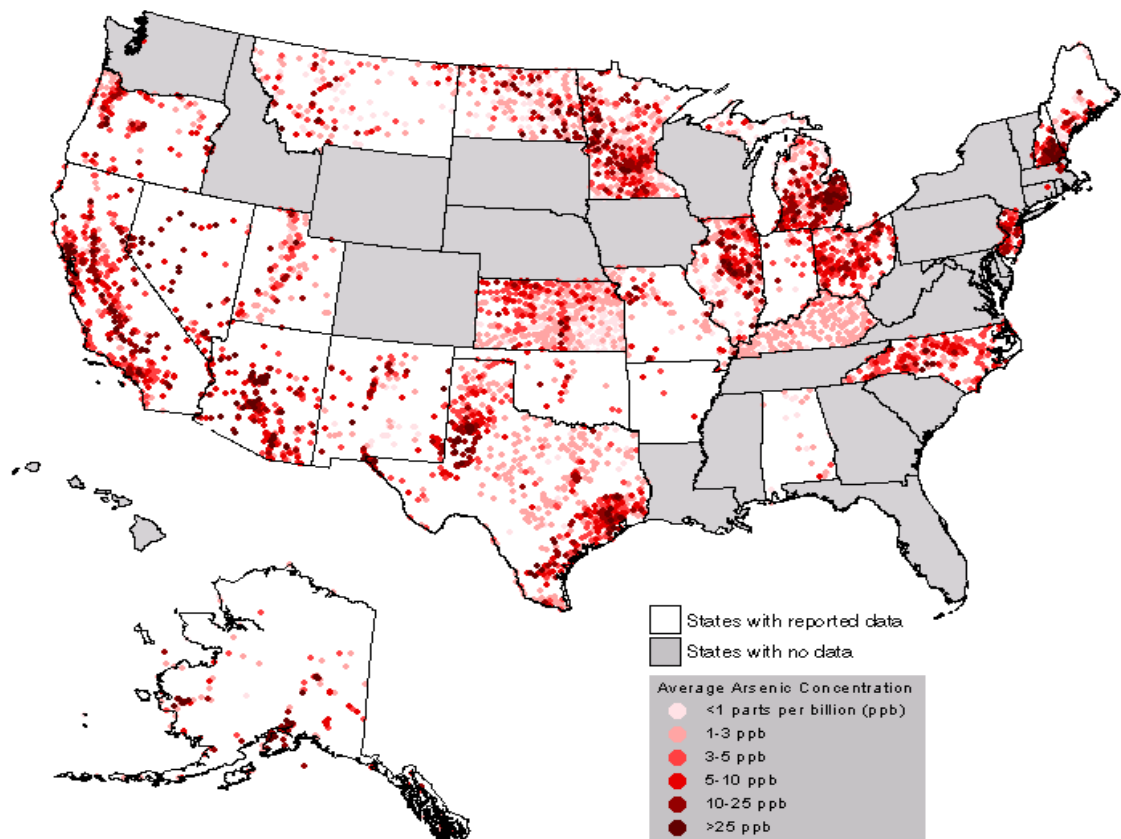


APPENDIX III: ARSENIC GROUNDWATERS CONTAMINATION

Global arsenic occurrence map (94)

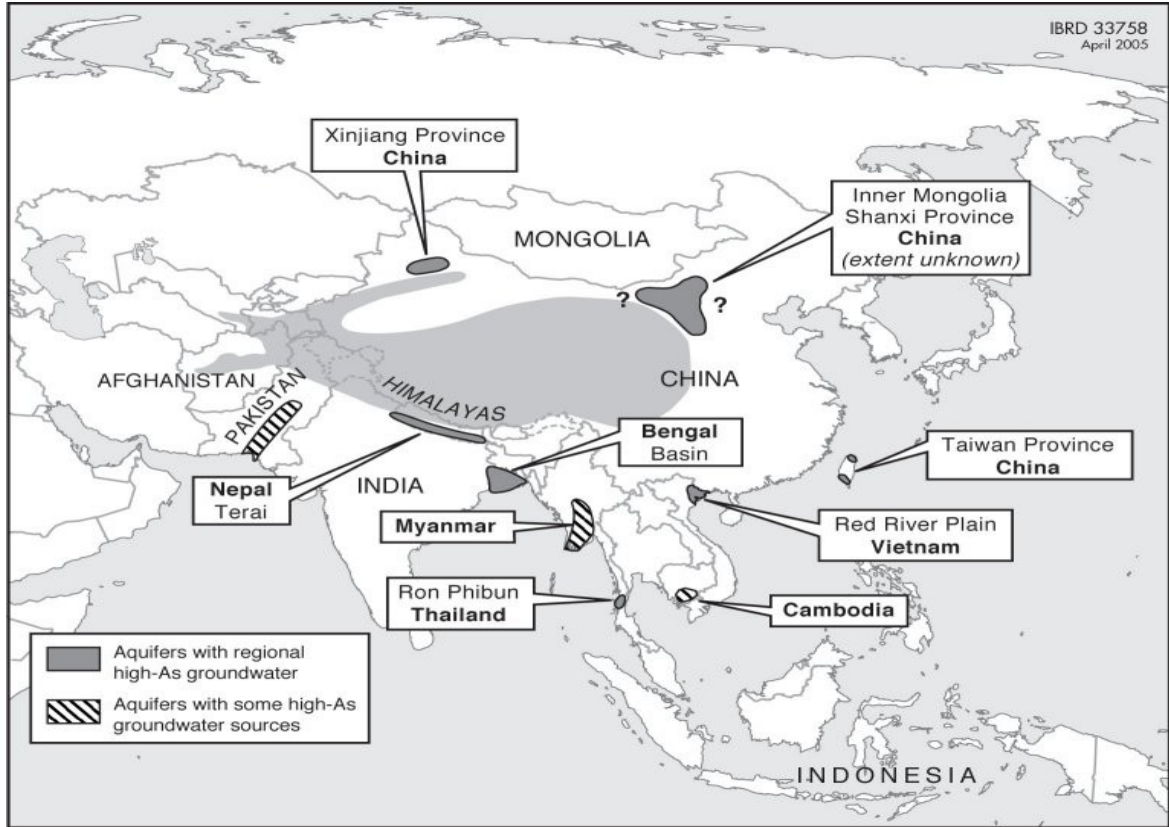


US national arsenic occurrence map (95)

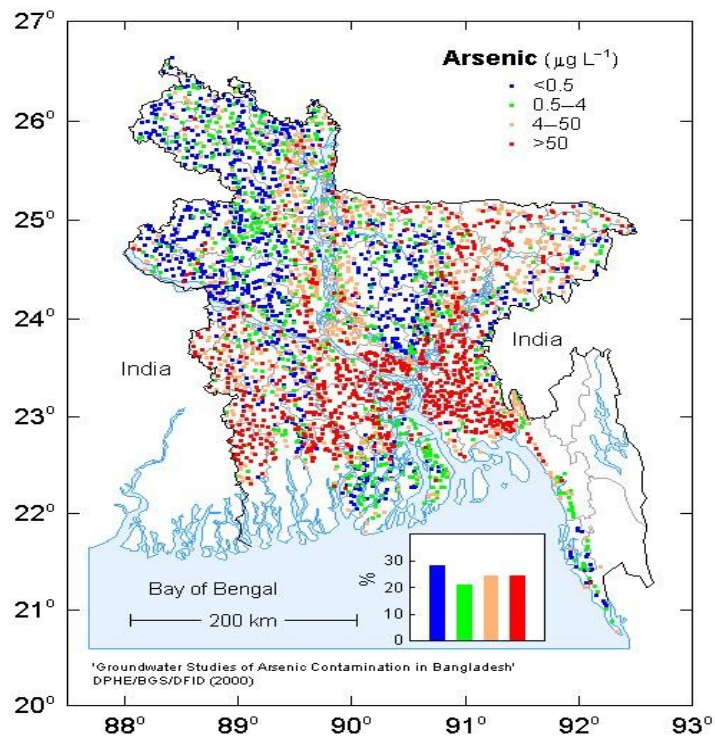


APPENDIX IV: ARSENIC GROUNDWATERS CONTAMINATION 2

Map of arsenic occurrence in Asia (94)

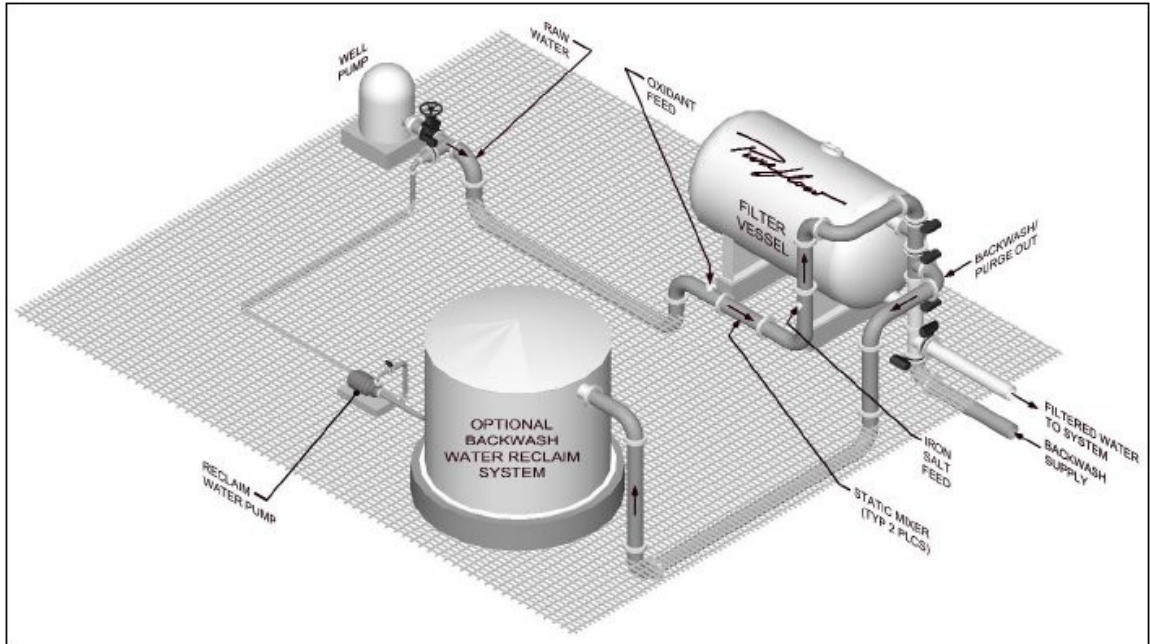


Bangladesh national arsenic occurrence map (96)



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Reverse osmosis connected to a kitchen sink (97)



EVIDENČNÍ LIST BAKALÁŘSKÉ PRÁCE/BC. THESIS FILE

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SOUHRN/SUMMARY

ČESKY/CZECH: Tato práce informuje o výskytu, použití a zdravotních důsledcích arzenu na lidský organismus, uvádí povolené koncentrační limity arzenu v pitných vodách jednotlivých zemí světa, jmenuje oblasti, kde lidé trpí otravami arzenem v důsledku konzumace místní vody. Tato práce se dále zabývá technologiemi odstraňování arzenu z vod, podmínkami, v nichž jsou různé technologie aplikovatelné a identifikuje dopady masových otrav arzenem.

ANGLICKY/ENGLISH: The thesis informs about occurrence, uses, and health effects of arsenic on humans, lists limits on arsenic concentration in drinking waters in certain countries, names areas where people are being poisoned by arsenic daily through drinking of local water. This paper also summarizes possible treatment options and conditions under which they are feasible and identifies impacts of the mass arsenic poisonings.

