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Arsenic Contamination of Drinking Water and Health Hazards

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Arsenic contamination of drinking water and Health Hazards

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Introduction:

Arsenic is a gray, brittle, metal-like substance that is a natural part of the earth's soil and rocks. Arsenic compounds are present in many kinds of rocks, especially in ores that contain copper or lead.

High concentration of arsenic in ground water is now a worldwide problem and has been reported in USA, China, Chile, Bangladesh, Taiwan, Mexico, Argentina, Poland, Canada, Hungary, Japan and India. Among 21 countries in different parts of the world affected by groundwater arsenic contamination, the largest population at risk is in Bangladesh followed by West Bengal in India. Millions of people in Bangladesh are at risk of chronic arsenic toxicity from drinking contaminated groundwater.

Uses:
Arsenic is still used as wood preservative, drug for the treatment of acute promyelocytic leukemia, semiconductor products, low melting glass production, non-ferrous alloys and industrial chemical. It was once used as Fowler's solution and pesticide. Fowler's solution is 1% arsenic trioxide which was used for the treatment of psoriasis, asthma, syphilis and leukemia from 1786 until the late 1960s. Pesticides. Arsenic was one of the primary ingredients in pesticides like rat and ant poison before synthetic organic pesticides were available.

Concentrations:
Arsenic is present in air, soil and water. However, its concentration in different media varies. Very low concentration is present in air and high concentration in soil. The concentration of arsenic in water is in between air and soil.

AIR

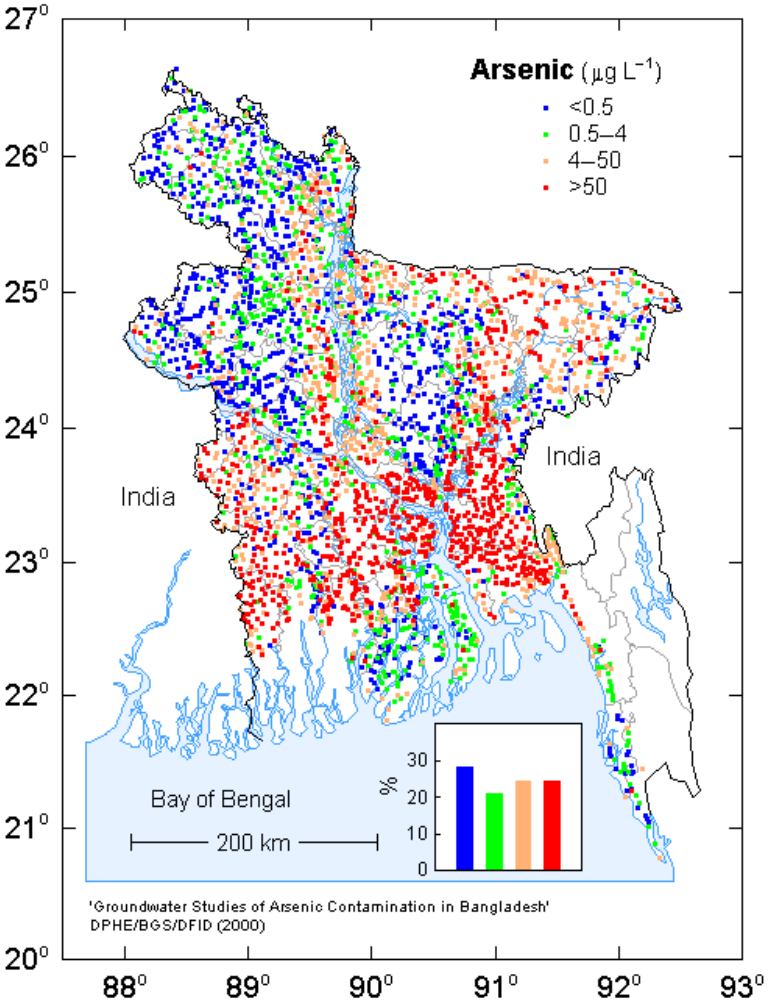
The concentration of arsenic in air is in the range of nanogram level. But high concentration of arsenic is present in air near coal-fired power generation, smelting of ores, burning vegetation, volcanism, natural low-temperature biomethylation and microbial reduction. It exists primarily adsorbed to particles <2 μm in diameter.

SOIL

The average arsenic contents in the soils of Bashail and Shahrasti Upazillas are 517.0 ± 539.6 μg/kg and 883.5 ± 621.7 μg/kg respectively (Khan et al., 2007). Huq et al (2003) also estimated the amount of arsenic in different districts of Bangladesh and showed that it is less than 10 mg/kg. The concentration of arsenic as high as 80 mg/kg of soil is found in an area receiving arsenic-contaminated irrigation.

WATER

The shallow tubewell of 61 districts out of 64 are contaminated with high concentration of arsenic. Arsenic contamination is maximum in the southern and northeastern Bangladesh at a depth of 10 to 100 meters. The mean concentration of arsenic in arsenic affected area is 587.7 μg/l. Highest concentration is 1588.3 μg/l (Sinha et al., 2003).



FOODSTUFFS

The mean (± SD) concentration of arsenic in raw rice is 878.5 ± 379.3 µg/kg. Among the foodstuffs, the lowest concentration of arsenic (61.3 ± 63.7 µg/kg) is found in the leaves of *Convolvus arvensis* (local name *kalmi* leaf). The highest concentration of arsenic is found in arum leaf and root (1181.1 ± 658.9 µg/kg and 1153.9 ± 479.7 µg/kg)(Khan et al., 2007). Rice and vegetables are contaminated with a high concentration of arsenic and their concentrations are not related to an increased concentration of arsenic in soil.

Table: Amount of arsenic in different foodstuffs

Foodstuffs	*Botanical name*	*Number of samples*	*Amount of arsenic (µg/kg)*
Amaranth	*Amaranthus esculentus*	43	619.3 ± 453.6
Amaranth leaf	*Amaranthus esculentus*	35	588.7 ± 451.8
Arum lati		38	1,140.6 ± 403.0
Arum leaf	*Colocasia esculenta*	50	1,181.1 ± 658.9
Arum root	*Colocasia esculenta*	22	1,153.9 ± 479.7
Arum stem	*Colocasia esculenta*	46	967.5 ± 445.8
Banana	*Musa sapientum*	12	452.7 ± 345.3
Egg plant	*Solanum xanthocarpum*	49	894.7 ± 488.3
Chili		35	699.1 ± 296.3
Dhundal		11	638.7 ± 206.6
Guava	*Psidium guajava*	82	772.2 ± 427.0
Halancha leaf		24	674.4 ± 398.7
Indian spinach	*Basella alba*	74	771.6 ± 368.1
Jute leaf	*Corchorus olitortus*	10	632.4 ± 448.7
Kalmi leaf	*Convolvus arvensis*	4	61.3 ± 63.7
Lady's finger	*Hibiscus esculentus*	52	729.2 ± 463.0
Lemon	*Citrus limon*	31	619.0 ± 309.3
Onion		2	504.9 ± 185.8
Papaya (green)	*Carica papaya*	47	683.2 ± 413.3
Potato	*Solanum tuberosum*	2	448.5 ± 314.7
Potato leaf	*Solanum tuberosum*	7	671.4 ± 316.1
Pumpkin	*Cucurbita moschata*	2	264.9 ± 43.6
Pumpkin leaf	*Cucurbita moschata*	28	748.0 ± 486.0
Raw rice	*Oryza sativa*	75	878.5 ± 379.5
Ridge gourd		11	716.7 ± 439.3
Snake gourd	*Trichosanthes anguina*	22	686.3 ± 403.6

(Khan et al., 2007)

Foodstuffs grown in arsenic contaminated soil not only consumed by the people of arsenic exposed areas but also by the people of arsenic non-exposed areas in Bangladesh, even some of the vegetables are exported to other countries. A study shows that arsenic content of the vegetables from the United Kingdom was approximately 2 to 3 fold lower than those observed for the vegetables imported from Bangladesh (Al Rmalli et al., 2005). That is,

people drinking arsenic safe drinking water have the chance to expose of arsenic contaminated foodstuffs.

Speciation: The mean concentrations of inorganic arsenic, monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) in raw rice

Table: Speciation of arsenic in rice and vegetables from two arsenic-exposed areas in Bangladesh

Foodstuffs	*Local name*	*Number of samples*	*Speciation of arsenic in foodstuffs (μg/kg)*			
			Inorganic	*MMA*	*DMA*	*Total*
Raw rice	Chaal	75	296.3	222.5	363.4	882.2
Non-leafy vegetables						
Amaranth stem	Data	39	166.0	144.4	309.0	619.4
Arum stem	Kachur data	40	229.7	323.1	410.1	962.9
Dhundal	Dhundal	9	214.7	241.7	182.2	638.6
Egg plant	Begoon	42	252.6	191.6	449.1	893.3
Lady's finger	Dherosh	42	211.6	155.9	318.0	685.5
Papaya (green)	Kacha pepe	45	177.9	220.5	282.5	680.9
Pumpkin	Kumra	2	0	331.4	433.5	764.9
Ridge gourd	Jhingha	11	141.2	89.3	486.0	716.5
Snake gourd	Chichinga	22	270.3	121.6	294.7	686.6
Roots and tubers						
Arum lati	Kachur lata	34	377.6	232.3	533.5	1143.4
Arum root	Maan kachu	16	274.4	149.8	706.7	1130.9
Leafy vegetables						
Amaranth leaf	Data shak	34	39.1	134.3	284.8	458.2
Arum leaf	Kachu shak	45	369.3	230.6	534.4	1134.3
Halancha leaf	Halancha leaf	22	196.0	130.2	348.1	674.3
Indian spinach	Pui shak	73	227.7	157.5	386.0	771.2
Jute leaf	Paat shak	10	212.1	98.4	321.8	632.3
Kalmi leaf	Kalmi leaf	3	62.3	0	49.2	111.5
Potato leaf	Alu shak	5	249.8	128.7	326.5	705.0
Pumpkin leaf	Kumra shak	26	225.3	193.4	365.9	784.6
Potato	Alu	2	0	270.7	177.8	448.5

(Misbahuddin et al., 2007)

were 296.3, 222.5 and 363.4 μg/kg respectively. High concentrations of inorganic arsenic (range 270-377 μg/kg) were found in arum lati, arum leaf, arum root and snake gourd. Low concentrations of inorganic arsenic (range 0-62 μg/kg) were present in potato, pumpkin, amaranth leaf and kalmi leaf. Vegetables contained 27.9% inorganic arsenic, 21.5% MMA and 50.6% DMA. The average daily intake of arsenic by an adult was 1017.9 μg of which 54.3% was from the raw rice and vegetables (Misbahuddin et al., 2007). The remaining 45.7% of arsenic intake was from drinking water. Considering the total intake of inorganic arsenic, raw rice and vegetables contributed only 27.4%. Foodstuffs contributed a higher concentration of total arsenic intake than drinking water in arsenic-exposed areas in Bangladesh.

Contribution of drinking water in total intake of arsenic: The amount of average daily intake of arsenic is estimated from the data of daily intake of food (Jahan and Hossain, 1998) and the average amount of arsenic in water and foodstuffs. On average the daily intake of total arsenic is 1017.9 μg of which 62.7% are as inorganic arsenic, 13.7% as MMA and 23.6% as DMA. Of the total intake of arsenic, 35.0% from drinking water, 10.6% from water for cooking rice, 37.0% from rice, and 17.4% from vegetables, fruits, fish and meat. That is, half of total intake of arsenic is from foodstuffs. While considering the intake of inorganic arsenic raw rice and vegetables contribute only 27.4%. Of the total intake of arsenic per day, MMA and DMA are supplied totally from the rice and vegetables. So, vegetables contain 27.9% inorganic arsenic, 21.5% MMA and 50.6% DMA.

The average daily dietary intake of total arsenic by Canadians is estimated to be 38.1 μg (Dabeka et al., 1993); United States, 62 μg; United Kingdom, 89 μg; New Zealand, 55 μg and Belgians, 45 μg (Yamauch and Fowler, 1994). The predominant species is the arsenobetaine which is known to be non-toxic.

Properties of water

Presence of high concentration of arsenic in water does not alter the color, taste and odor of water.

Pharmacokinetics

ABSORPTION

Both trivalent and pentavalent arsenic are rapidly and extensively absorbed from the gastrointestinal tract. Presence of food within the stomach modifies the bioavailability.

Arsenic is absorbed from the respiratory tract. Extent of absorption is more in coal-fired power plant, smelting of ores and during cigarette smoking. The absorption of arsenic through skin is less than 2% from water and soil over a 24-hour period. Arsenic readily crosses the placenta.

DISTRIBUTION

Inorganic arsenic is rapidly cleared from blood. It is widely distributed in the body. Inorganic arsenic is the predominant form in tissues, followed by DMA. MMA level is uniformly low and detected only in liver and kidney.

BIOTRANSFORMATION

Both trivalent and pentavalent arsenic are extensively metabolized to DMA. Women show more metabolism than men.

EXCRETION

Urine is the primary route of excretion. DMA is the predominant form of arsenic that is excreted in urine. Only up to 8% of the total dose of arsenic is excreted in feces irrespective of route of administration. Biliary excretion is very low. The amount of arsenic that appears in the feces is the unabsorbed arsenic from the gastrointestinal tract.

Higher intakes of cysteine, methionine, calcium, protein, and vitamin B-12 are associated with lower percentages of inorganic arsenic and higher ratios of MMA to inorganic arsenic in urine. Higher intakes of niacin and choline are associated with higher DMA-to-MMA ratios, after adjustment for age, sex, smoking, total urinary arsenic, and total energy intake (Heck et al., 2007).

Health hazards

Melanosis

Leukomelanosis

The disease is usually first diagnosed on the basis of skin manifestations such as melanosis (hyperpigmentation), leucomela-nosis (hypopigmentation) and hyperkeratosis. Melanosis is mostly present (95%) as either diffuse (~90%) or spotted (~50%) (rain-drop patterns). It is usually develop after 6 months of exposure of high dose of arsenic. Leucomelanosis (35%) is splotchy, irregular discoloration on trunk and forearms; often together with melanosis. It is usually develop after 12 months of exposure of high dose of arsenic. Hyperkeratosis is present in 2/3rd of the cases. It is bilateral hardening and actinic nodules (0.4-1 cm in diameter) on soles and palms especially lateral borders of palms, on roots or lateral surfaces of fingers. Keratosis develops after 5 years of exposure of arsenic. It is less common in children.

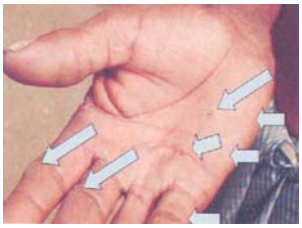
In addition, there may be hepatomegaly, often with noncirrhotic portal fibrosis and portal hypertension. Neuropathy, peripheral vascular disease, burning sensations in the eyes; similar to Guillain-Barré syndrome, with loss of touch, hyperpathia, tremor, deep tendon reflexes in lower limbs and dizziness are also found in some cases. Non-pitting edema of the legs may be present.

Squamous cell carcinomas, often with several foci, arising *de novo* or originating from hyperkeratosis, often in the feet and hands, sometimes on trunk, lesions 0.8-3.5 cm in diameter. Gangrene and vascular disease are common co-symptoms. Amputation of limb is common remedy. Bowen's syndrome, often on trunk in scaly, crusted plaques 1-10 mm diameter may develop after 10 years of exposure to arsenic.

Lung, bladder, urinary tract cancers often found in older subjects. However, it remains under-diagnosed in Bangladesh.

Drinking tube-well water with more than 50 μg/l of arsenic during pregnancy significantly increased the risks of fetal loss and infant death. There was a significant dose response of arsenic exposure to risk of infant death. Women of reproductive age should urgently be prioritized for mitigation activities where drinking water is contaminated by arsenic (Rahman et al., 2007).

> Exposure to arsenic from drinking water was associated with reduced intellectual function before and after adjusting for water manganese, for blood lead levels, and for socio-demographic features known to contribute to intellectual function. With covariate adjustment, water arsenic remained significantly negatively associated with both Performance and Processing Speed raw scores; associations were less strong than in our previously studied 10-year-olds (Wasserman et al., 2007).



Keratosis

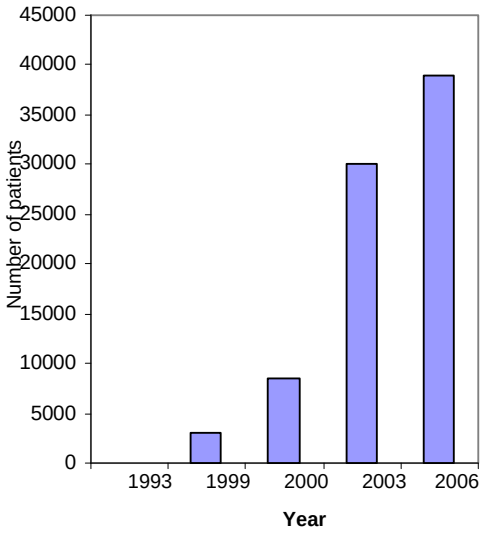


Figure: Number of patients of arsenicosis in Bangladesh (Government sources)

First reported case in Bangladesh was in 1993. Exact number of patients in not known. Data from Government authority are at least 5 times less than the actual figure. For example, in Muradnagar the number of arsenicosis patients was more than 500 whereas the Government report shows only 104 cases.

According to the official reports, the number of patients raised to 2,953 in 1999, about 8,500 in 2000, about 30,000 in 2003 and about 39,000 in 2006. That is there is sharp increase in the number of patients in the recent years.

Median lethal dose

The median lethal dose of arsenic depends on the animal, arsenic species and route of administration. Trivalent arsenic is more acute toxic than the others. That is low dose is required.

Table: Acute median lethal dose of arsenic species

Chemical	Species	Route	LD_{50}
Trivalent arsenic (arsenic trioxide)	Rat	oral	20 mg/kg
Trivalent arsenic (sodium arsenate)	Rat	Intraperitoneal	10 mg/kg
Pentavalent arsenic (sodium arsenite)	Rat	Intraperitoneal	34 mg/kg
MMA	Rat	oral	1100 mg/kg
DMA	Rat	oral	1315 mg/kg
Arsenobetaine	Mouse	oral	>10,000 mg/kg

Analytical methods

Total arsenic is usually estimated in most of the laboratories. In some limited laboratories, speciation of arsenic (trivalent arsenic, pentavalent arsenic, trivalent MMA, pentavalent MMA, trivalent DMA, pentavalent DMA, arsenicholine, arsenibutaine, etc) are measures. In addition, kit method (semi-quantitative method) and Gutzitz test (qualitative method) are also used at the field level.

Total arsenic is estimated by UV-Vis spectrophotometer, atomic absorption spectrophotometer with either hydride generator or graphite furnace, ICP-MS, HPLC-Atomic fluorescent spectrometry and HPLC-MS/MS. Estimation of total arsenic using hydride generator is more sensitive than using graphite furnace.

Speciation of arsenic can be done using atomic absorption spectrophotometer with hydride generator or graphite furnace, ICP-MS, HPLC-Atomic fluorescent spectrometry and HPLC-MS/MS. The last three methods are more sensitive. However, these instruments are quite expensive.

Safe water options

Safe water option will be at house hold level and large scale production.

A community-based drinking-water model may be introduced. Options include: pond-sand filters, rainwater harvesting, dugwell, deep-protected tubewell, and shallow tubewell with treatment devices. Shallow tubewell water can be made arsenic free using Safi filter and Three-Pitcher method.

Large scale production of arsenic removal technologies includes oxidation, precipitation/coagulation/membrane separation and adsorption.

RAIN WATER HARVESTING

Rainwater is used in many parts of the world to meet the demand for fresh water. Gibraltar has one of the largest rainwater collection systems in existence. Rainwater harvesting is popular in Kenya, South Africa, Botswana, Tanzania, Sri Lanka, Thailand, some parts of Alaska and Hawaii City of Austin, Texas. It is even collected in some areas of Bangladesh where shallow groundwater is problematic due to salinity.

Advantages: The maximum amount of average annual rainfall occurs in the northeastern districts (55 cm) of Sylhet and Moulivibazar, the minimum amount falls in the western/southwestern districts (15 cm) of Meherpur, Kushtia, Chuadanga, Chapai Nawabganj, Noagaon, and Rajshahi. Rainfall is mainly restricted during the months of April to September. Consequently, rainwater harvesting will be relatively easier during certain months of the year in the certain parts of Bangladesh. Groundwater contamination by arsenic is more severe in the western/southwestern districts, where rainwater harvesting would be more appropriate to solve the polluted drinking water problems.

Rainwater is naturally soft (unlike well water), contains almost no dissolved minerals or salts, is free of chemical treatment, and is a relatively reliable source of water for households. Rainwater collected and used on site can supplement or replace other sources of household water. Rainwater can be used as drinking water if proper treatment is done before using.

An average rainfall of 72 inches and using 1,100-gallon storage tanks, enough water could be collected in 12 hours to serve a family of six for 45 days.

Disadvantages: No water will be available during the dry season. Saving rainwater in vessels for later use will be practically impossible, for it will require a huge number of such containers. Another possibility would be to dig ponds to gather rainwater for use during dry months. However, a series of problems will arise from such measure. There are not enough lands available in various parts of all villages in Bangladesh. Ponds will be subject to surface run-off that will carry different pollutants from non-point sources. Possible non-point sources of contamination include fertilizer, pesticides, chicken and cow manure, dissolved minerals, sediments, sewage, decaying plants, algae, bacteria, aerosol fallout, and detergents. The amount of surface run-off can be reduced by building elevated banks around ponds. Water will be lost to evaporation if the ponds are not completely covered. Ponds will be connected to groundwater flow and will be subject to contamination by dissolved chemicals.

DUGWELLS

Dhaka Community Hospital (DCH) team has implemented 66 sanitary, arsenic-free, dugwells between 2000 and 2004 in Pabna district of Bangladesh where there was a great need of safe water because, in some villages, 90% of tubewells were highly contaminated with arsenic. The capital cost for running water is US$ 5-6 per person. In total, 1,549 families now have access to safe arsenic-free dugwell water. Some of them have a water-pipe up to their kitchen. All of these were implemented with active participation of community members. They also pay for water-use and are themselves responsible for the maintenance and water quality. The bacteria levels are low but not always zero, and studies are in progress to reduce bacteria by chlorination (Joya et al., 2006).

POND SAND FILTER

Filtration is the process whereby water is purified by passing it through a porous material or media. In slow sand filtration a bed of fine sand is used through which the water slowly percolates. The suspended matter present in the untreated water is largely retained in the upper 0.5-2 cm of the filter bed. This allows the filter to be cleaned by scraping away the top layer of sand. The filter cleaning operation need not take more than one day, but one to two more days are required after cleaning for the filter bed again to become fully effective.

Advantages: One pond sand filter can supply the daily requirement of water for drinking and cooking for 40-60 families. The construction cost is low (Tk. 25,000-40,000), depending on the size.

Disadvantages: Most of the ponds dry-up during the summer season. Ponds are usually used for washing livestock. It is difficult to get a pond free from fertilizers and pesticide. In recent years a large number of ponds are used for culture fisheries and therefore chemical fertilizers and pesticides are used. Agricultural and domestic runoff, and also from sewerage discharges into the pond are also important. Operation and maintenance of pond sand filter are also important. A community interest is need.

To solve these problems, Bangladesh will have to develop an integrated water resources development plan.

DEEP TUBEWELL

There are two main aquifers in Bangladesh - shallow and deep. Usually there is a thick layer of silt and clay between the two aquifers. Water can not easily pass through this layer. It has been observed that the deeper aquifer is much less contaminated than the shallow one. A hydro-geological study conducted by the British Geological Survey in 1999 tested 280 tubewells of >200 meter of depth and found unsafe levels of arsenic in only two of them – less than 1%. DPHE has also tested many deep tubewells, and found only limited arsenic contamination. BRAC has also tested some deep tubewells that were contaminated with arsenic beyond acceptable limit. These sporadic statistics indicate the uncertain safety of the deep aquifer and careful observation is needed before making a general recommendation for this option as a safe source for arsenic free water in the future. So, deep tubewells cannot be drilled in all areas. This is because in some parts of the country, rocky layers make drilling impossible. Due to these constraints, deep tubewells that are not yet scientifically proven to be safe were not included as a safe source of arsenic free water in the BRAC/UNICEF community-based arsenic mitigation project.

LARGE SCALE PRODUCTION

Some low-cost adsorbents are superior including treated slags, carbons developed from agricultural waste (char carbons and coconut husk carbons), biosorbents (immobilized biomass, orange juice residue), goethite and some commercial adsorbents, which include resins, gels, silica, treated silica tested for arsenic removal come out to be superior. Immobilized biomass adsorbents offered outstanding performances. Strong acids and bases seem to be the best desorbing agents to produce arsenic concentrates (Mohan and Pittman, 2007).

Treatment of arsenicosis

There is no specific treatment. After diagnosis, the first step is to stop drinking arsenic-contaminated water and allow the patient to use arsenic-safe water. Some investigators suggest the use of retinol, beta-carotene, ascorbic acid, alpha-tocopherol, selenium, spirulina, and zinc in the treatment of arsenicosis. They are either used alone or in combination. All these substances are considered as antioxidants. However, our foodstuffs contain hundreds of antioxidants. Naturally question has arisen how much contribution of these supplement(s) while taking a lot of antioxidants in foodstuffs.

Treatment with these antioxidants require 4-12 month. Prolong duration of treatment influences the compliance and treatment cost.

Chelating agents, like dimercaprol (BAL), 2,3-dimercaptopropane-sulphonate sodium (DMPS) and meso-2,3-dimercaptosuccinic acid (DMSA), are effective in the treatment of acute arsenic poisoning, but their usefulness is yet to be established in treating arsenicosis.

Supplementation of zinc also reduces the accumulated arsenic from different tissues of rat, following chronic exposure to arsenic. But simultaneous administration of zinc and arsenic may cause more accumulation of arsenic. Therefore, while prescribing zinc one should ensure the complete stoppage of arsenic.

The large dose of spirulina (10 g/day) in powder or tablet form may affect the compliance of the patient. In addition, it has offensive smell and taste.

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