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Arsenic, the poison and poisoned groundwater of Bangladesh: A review

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ARSENIC: THE FIERY POISON

Evidence of poison related knowledge in Egypt can be traced to the writings of an ancient Egyptian alchemist named Agathodiamon (100 BC approx.), who spoke of a (unidentified) mineral that when mixed with natron produced a "fiery poison". He described this poison as "disappearing in water" giving a clear solution. This "fiery poison" may exist as the roots for some of the later poisons those were invisible when mixed with water, and indicates that such an elusive poison may have been available to some civilizations such as Egypt as early as 100 BC. As to the "fiery poison" which this alchemist had concocted, it appears that he must surely have created arsenic trioxide, due to the relation between the unidentified mineral and his other writings (Emsley, 2005).

Among the many new chemicals reviewed for their chemical-warfare potential during the 1920s and 1930s were bis (trichloromethyl) oxalate, a congener of phosgene and the tetrachlorodinitroethanes. Other chemicals examined included disulfur decaflouride and various arsenical vesicants. Arsenical vesicants damaged the skin and poisoned through skin penetration (Ministry for Foreign Affairs, Helsinki, 1982).

Arsenic is a chemical element having the symbol "As" with atomic number 33. It was first written about by Albertus Magnus (Germany) in 1250. He is believed to have been the first to isolate the element in 1250 (Emsley, 2001). Arsenic is very similar chemically to its predecessor, phosphorus. Like phosphorous it forms colorless, odorless, crystalline oxides As_2O_3 and As_2O_5 which are hygroscopic and readily soluble in water to form acidic solutions.

During the 18th, 19th and 20th centuries a number of arsenic compounds have been used as medicines, including arsphenamine (by Paul Ehrlich) and arsenic trioxide (by Thomas Fowler). Arsphenamine as well as Neosalvarsan were indicated for syphilis and trypanosomiasis, but have been suppressed by modern antibiotics. Arsenic trioxide has been used in a variety of ways over the past 200 years, but most commonly in the treatment of cancer. The US Food and Drug Administration (FDA) in 2000 approved this compound for the treatment of patients with acute promyelocytic leukemia (Antman, 2001).

ARSENIC EXPOSURE AND ITS HEALTH CONSEQUENCES

Chronic arsenic exposure is associated with many human health conditions, including skin lesions and cancers of the liver, lung, bladder, and skin (Ahsan *et al.*, 2000; Mazumder *et al.*, 1998; Haque *et al.*, 2003; Smith *et al.*, 1998), as well as other non cancer health effects, such as adverse reproductive outcomes, neurologic disorders and impaired cognitive development in children (Ahmad *et al.*, 2001; Calderon *et al.*, 2001; Mukherjee *et al.*, 2003; Wasserman *et al.*, 2004).

Arsenic is known to cause arsenicosis due to its appearance in drinking water; the most common

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species being arsenate ($HAsO_4^{2-}$, pentavalent arsenic) and arsenite (H_3AsO_3, trivalent arsenic). The ability of arsenic to undergo redox conversion between As (III) and As (V) makes it availability in the environment possible (Croal *et al.*, 2004).

A puzzling observation about arsenic has been the drastic difference in metabolism, dispersion and carcinogenicity between human and rats. In particular, rats show a longer retention time in the blood for arsenic, whereas arsenic is rapidly cleared from human blood (half life 1 h). These biological differences have not been understood and can limit the use of animal models for understanding human health effects. Lu *et al.* (2007) made an important new discovery that may explain these differences. In characterizing arsenic species in rats that were treated with inorganic arsenate, monomethylarsonic acid and dimethylarsinic acid, they found that arsenic significantly accumulated in the red blood cells of rats in the form of hemoglobin complexed with dymethylarsinous acid, regardless of the species of arsenic the rat was exposed to. This suggests a rapid methylation of arsenic species followed by strong binding of dymethylarsinous acid to rat hemoglobin. Epidemiological evidence from Chile shows a dose dependent connection between chronic arsenic exposure and various forms of cancer, particularly when other risk factors, like cigarette smoking, are present. These effects have been demonstrated to persist below 50 parts per billion (ppm) (Ferreccio and Sancha, 2006).

A study on cancer rates in Taiwan suggested that significant increases in cancer mortality appear only at levels above 150 ppm (Lamm *et al.*, 2006). Epidemiological studies have identified arsenic compounds as carcinogenic to human. They increase the mutagenicity and clastogenicity in combination with other DNA damaging agents and there are indications of inhibition of DNA repair processes. Two steps of nucleotide excision repair (NER) are affected by arsenite. Most severely, the incision frequency is reduced at concentration as low as 2.5μM arsenic (III); at higher, cytotoxic concentrations, the ligation of repair patches is also impaired. Both the global genome repair pathway and the transcription-coupled repair pathway are affected by arsenite (Hartwig *et al.*, 1997). Analyzing multiple epidemiological studies on inorganic arsenic exposure suggests a small but measurable risk increase for bladder cancer at 10 parts per billion (ppb) (Chu and Crawford-Brown, 2006). Exposure to arsenic in the childhood may contribute to cancers that develop in adulthood (Ries *et al.*, 1999). Several individual risk factors are associated with the development of nonmelanoma skin cancers, arsenic, though in low percentage, is one of them (Yoon and Roenigk, 2004). Inorganic arsenic compounds causes cancer, inorganic oxides of arsenic may develop cancer.

Moreover, epidemiological studies have revealed that chronic arsenic exposure in many countries caused the increased risk of mortality associated with cardiovascular disease (Alam *et al.*, 2008). Cardiovascular effects in humans drinking arsenic-contaminated water include blackfoot disease (resulting from gangrene caused by obstruction of peripheral blood vessels), atherosclerosis, cerebrovascular diseases, and ischemic heart diseases (Tseng, 1977; Rahman *et al.*, 1999). These diseases have been clinically associated with abnormal platelet activity and thrombosis and, as a consequence, new drugs have been developed to therapeutically control platelet action and thrombosis (Hollopeter *et al.*, 2001).

The northern United States, including parts of Michigan, Wisconsin, Minnesota and the Dakotas are known to have significant concentrations of arsenic in ground water. An increased level of skin cancer has been associated with arsenic exposure in Wisconsin, even at levels below the 10 ppb drinking water standard (Knobeloch *et al.*, 2006). Arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Bangladesh and neighboring countries. It is estimated that approximately 57 million people are drinking groundwater with arsenic concentration elevated above the World Health Organization's standard of 10 ppb (Meharg, 2005). Around 1.1 billion people (about one sixth of global population) lack access to improved drinking water sources (WHO, 2000). In Bangladesh as well as many other parts of the world, contamination of groundwater with arsenic is a major health problem.

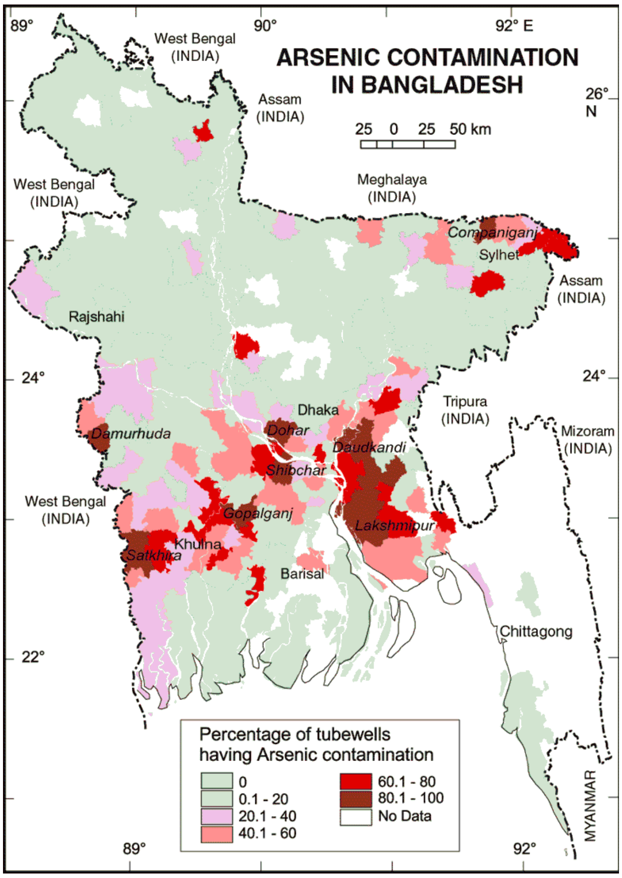

Figure 1: Arsenic contaminated areas of Bangladesh (source: Banglapedia).

ARSENIC CONTAMINATION AND BANGLADESH

More than 100 million people worldwide have been estimated to be chronically exposed to arsenic from drinking water containing high arsenic levels (Alaerts *et al.*, 2001; Chowdhury *et al.*, 2000; Dhaka Community Hospital Trust, 2005). Although more than 20 countries have been affected by arsenic contamination of drinking water, the situation is perhaps the most devastating in Bangladesh because of the number of affected people. Among the country's 7-11 million hand pumped tube wells, approximately half have been estimated to supply groundwater with an arsenic concentration more than 50μg/L; the maximum allowable limit of arsenic in drinking water in Bangladesh (BAMWSP, 2006; Josephson, 2002; Uddin and Huda, 2011). Among the country's total population of 130 million, 35 million people are believed to be exposed to a concentration more than 10μg/L, and thus are at higher risk of developing cancer and other arsenic related, life threatening conditions (British Geological Survey, 2001; Dhaka Community Hospital Trust, 2005; Hoque *et al.*, 2000; Milton and Rahman, 1999).

The most comprehensive and systematic survey was conducted by DPHE in 1998-99 in collaboration with

Table 1: Results of the analysis of rocks and sediments of Bangladesh for arsenic (Islam and Uddin, 2002).

Rocks/sediments of the formation	Number of sample analyzed	Arsenic content (ppm)	Remarks
Marine sediments from the Bay of Bengal	58	1 - 24	Analyzed in Germany
Alluvium	10	Less than 1.5 - 3.5	Oxidized zone at ~1.5 m contains ~530 ppm. Mud layer at 105 ft, 19 ppm at Debidwar
Peat	1	5.0	High at Samta (262 mg/kg)
Madhupur Clay	2	2-4	
Dihing	1	2.4	
Dupi Tila	3	1.2-1.75	
Girujan Clay	2	1.5-2.1	
Tipam Sandstone	2	1.0	
Surma Group	-	-	Not analyzed
Barail Sandstone	-	-	Not analyzed
Sylhet Limestone	1	1.5	
Tura Sandstone	-	-	Not analyzed
Rajmahal Trap	1	8.0	
Gondwana Coal Ash	1	8.0	
Pre-Cambrian Rock	6	3.0-5.0	

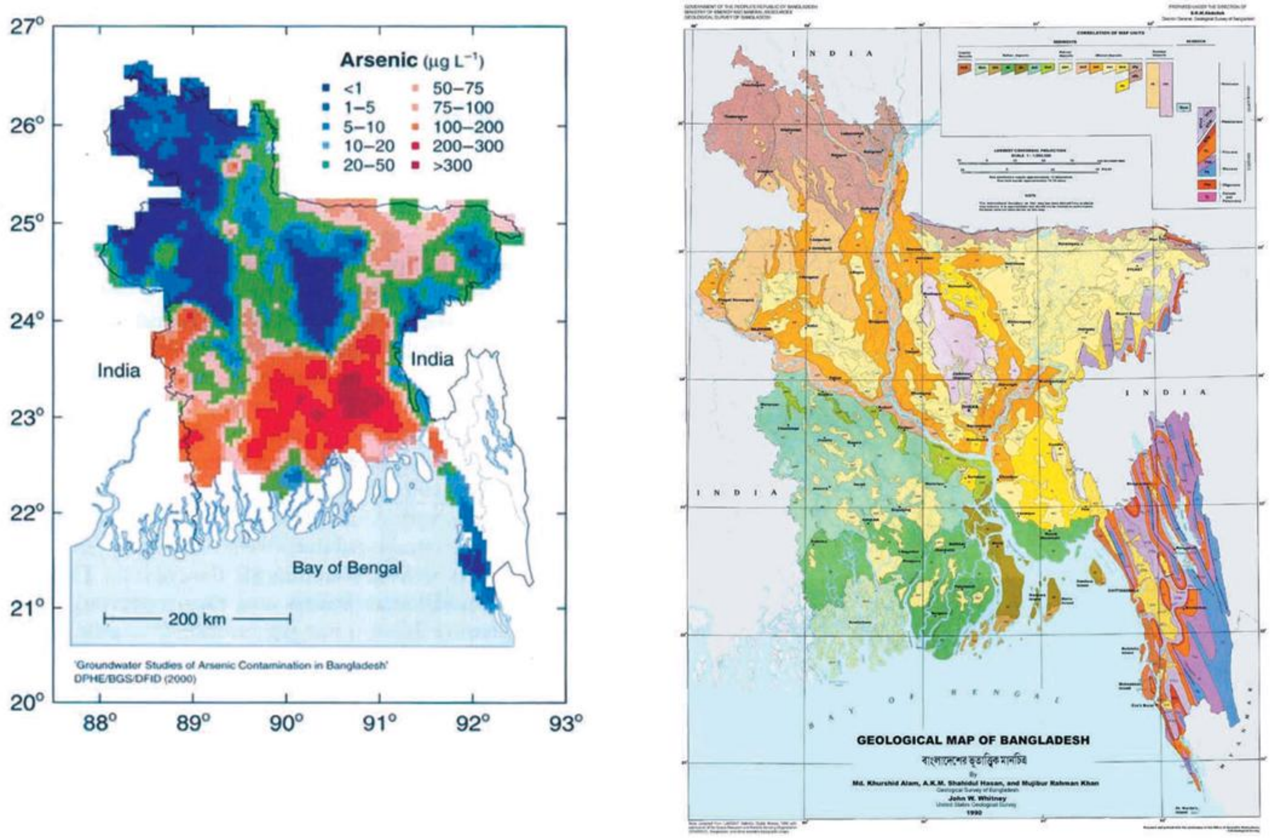

Figure 2: The relationship between Arsenic distribution (left, BGS-DPHE, 2001) and Geology of Bangladesh (right, Alam *et al.*, 1990).

the British Geological Survey and Mott MacDonald Limited. According to different surveys conducted the worst affected districts are Chandpur (90%), Munshiganj (83%), Gopalganj (79%), Madaripur (69%), Noakhali (69%), Satkhira (67%), Comilla (65%), Faridpur (65%), Shariatpur (65%), Meherpur (60%) and Bagerhat (60%). The least affected districts are Thakurgaon, Panchagarh, Nilphamari, Natore, Lalmonirhat, Patuakhali, and Barguna, where none of the samples exceeded the Bangladesh limit (Figure 1) (Banglapedia).

The latest information shows that in 61 out of 64 districts, tube wells in various percentages are producing water with arsenic higher than the national standard of 0.05 milligram per liter. In many upazilas (sub-districts) more than 90% of the tube wells are producing water that are not safe for drinking or cooking purposes. The problem of arsenic contamination of the groundwater was come to known from 1993 but unfortunately it did not get the proper attention till very recently. By this time more than 30 million people are facing the problem and probably 70-80 million people are threatened with the problem. This shows the enormous magnitude of the problem faced by the country. Some other countries like India (West Bengal part of the Bengle delta), China, Vietnam and Laos are also facing similar problem. In Bangladesh groundwater of the upper and the main aquifers are seriously affected by arsenic contamination in most part of the country. Distribution of arsenic contaminated water in the country is related to the geology (Figure 2). Geological Survey of Bangladesh has analyzed the sediment samples from each geological formation (Islam and Uddin, 2002). The result is shown in Table 1.

In Bangladesh post glacial sedimentation is important because of arsenic concentration in it. Arsenic contamination is not uniform in all areas of Bangladesh (Figure 1). It is observed the broad surface geological divisions have a good correlation with the arsenic distribution in the country. Arsenic bearing aquifers has no uniformity with depth and thickness. The contamination of aquifers is generally found within 7 to 159m depths (Uddin and Abdullah, 2003).

CONCLUSION

It is clear from different studies that the people of Bangladesh are at the highest risk of arsenic poisoning and arsenic related negative health outcomes. But the huge campaign by the government in past few years and the cooperation of various national and international non-government organizations (NGOs) make the situation under control. The people in Bangladesh are well aware of arsenic with the help of electronic media, mass media, print media etc. But these short of awareness programs need to be continued.

CONFLICT OF INTEREST

Nadia Saffoon works as a Product Executive at the Marketing Strategy Department in Ziska Pharmaceuticals Limited. She and other authors declare no conflict of interest regarding the manuscript.

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