

# GROUNDWATER ARSENIC POISONING AND A SOLUTION TO THE ARSENIC DISASTER IN BANGLADESH.

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## ABSTRACT

The oxidation of arsenopyrite or ferrous hydroxides rich in arsenic present in the Bengal Delta sediments may be responsible for the release of arsenic oxides in solution to the ground water. The subsequent migration of this arsenic contaminated groundwater through these deltaic sediments may be one of the principal causes of arsenic poisoning in Bangladesh.

Arsenopyrite and ferrous hydroxides would be stable in the reducing environment below the groundwater table. If the groundwater table were lowered by increased irrigation during the dry season and the sediments exposed to the oxygen of the atmosphere these arsenic rich minerals would oxidize releasing arsenic.

Increased irrigation did become necessary during India's 23 years of unilateral diversion of Ganges water at Farakka Barrage in the West Bengal state of India. This cut the normal flow of the Ganges River during the dry season. If the oxidation of arsenic bearing minerals is the cause of arsenic release to the groundwater due to a lowered water table then the solution to the arsenic problem is to restore the natural river flow of the Ganges River. This would restore the groundwater level to a level that existed in Bangladesh prior to the construction and commission of Farakka Barrage in 1975.

Other man made environmental disasters created by the Farakka, Tista and other barrages/dams constructed in the common rivers of Bangladesh and India would also be solved if these barrages were removed and a normal flow restored. The river beds could then be dredged and groundwater produced at a safe yield rate.

Adequate supplies of fresh water are available from river water and annual rain fall, collected in surface reservoirs during the wet season, to supply the domestic and industrial needs of the nation. To prevent contamination by bacteria, industrial chemicals, heavy metals and inorganic contaminants, the water should be filtered, treated. A continuous program of testing for contaminants must be established to assure water safety. The density of population and the amount of water required could only be safely delivered through a closed system of water mains and pipes. The initial cost would be high but in the long run it would be the cheapest and safest method of delivery.

A comprehensive plan not only for water supplies but associated waste disposal should be worked out for all of Bangladesh. Individual units within the plan could then be developed on the basis of need and tied into the overall plan as it develops. Other environmental problems such as waste disposal, flooding, water diversion projects, river control, wildlife protection, desertification, land subsidence, earthquake damage control and other environmental problems could be integrated and approached in the same way.

## **INTRODUCTION**

Bangladesh is located in one of the major disaster and environmentally endangered areas of the world (Map-1). Prior to 1975 the country had never faced an environmental crisis of the present magnitude. More than 75 million people are being poisoned by groundwater arsenic contamination. The source of the arsenic in the groundwater that caused the poisoning has not been determined beyond a reasonable doubt by any known investigation conducted in Bangladesh so far. The source of arsenic contamination and when or how long it has been present should be determined in order to remedy the problem and prevent future occurrences. The authors have searched and analyzed historical, medical, geological, hydrogeological and geochemical data available to them in order to answer the questions concerning the source and time of arsenic contamination. Until this information is known a final solution, a secure future and a healthy environment for the people is not assured..

### **WHEN DID THE GROUNDWATER ARSENIC POISONING IN BANGLADESH BEGIN?**

During 1983 and 1987 Dr. K.C. Shaha, Professor of Dermatology(retired)of School of Tropical Medicine, Calcutta conducted surveys in the seven districts of west Bengal of India. In 1983 Dr.Shaha identified patients poisoned by arsenic who had been drinking tubewell water with concentration of arsenic ranged from (0.06-1.25) PPM and a mean concentration of 0.32 PPM. According to Dr. Shaha's survey the time required for the symptoms of arsenic poisoning to appear varies from six months to two years and is dependent on age(Example-Photographs Plate 1).

In 1996 the Asian Arsenic Network(AAN) conducted skin examinations on 167 people from the West Bengal of India who had drunk tubewell water for a period of from 4 months to 45 years. The largest group (63) drank the tubewell water for 6-10 years. One hundred sixty three people out of one hundred sixty seven (97.6 %) ranging in age from 3-80 years, were found to have skin lesions related to arsenic poisoning. Based on Dr. Shaha's survey, the AAN estimated the beginning of arsenic contamination in West Bengal began around 1980-1981. No such survey is known to have been conducted in Bangladesh, however, in West Bengal we have seen evidence of poisoning after six months of drinking of arsenic contaminated water. Infants and the young are more susceptible than adults. High concentration may cause poisoning over a shorter period of time. A recent UK/DFID report states: "There is clearly a very serious problem of arsenic in groundwater in much of southern and eastern Bangladesh. In terms of the population exposed Bangladesh has the most serious groundwater arsenic poisoning problem in the world. The arsenic contamination occurs in groundwater from the alluvial and deltaic sediments that make up much of the area. Descriptions of the problem are complicated by large variability at both local and regional scales. The arsenic is of geological origin and is probably only apparent now because it is only in the last 20-30 years that groundwater has been extensively used for drinking water in the rural areas. However, the arsenic has probably been present in the groundwater for thousands of years. It is difficult to say for sure whether it will get better or worse with time but the likelihood is that any changes are likely to be rather slow."

Beark of the New York Times, "Until 1970's most villagers drank water from hand-dug wells or natural ponds, that they often shared with bathing cows and water buffaloes. Cholera and diarrhea diseases flourished in this water and each year hundreds of thousands of death originated in the earthen pitchers that villagers carried to their porches." Prior to 1970's people died of cholera and diarrhea but no one noticed the symptoms of arsenic poisoning. There is little doubt that the origin of groundwater arsenic poisoning in Bangladesh is geological but the UK/DFID statement on the age of the arsenic poisoning in groundwater in Bangladesh contradicts the historical medical evidences. In 1999, Miah, M. A., University of Arkansas, U.S.A. reported that prior to the 1970's hundreds of thousands of people in 2800 villages of Ganges Delta drink water from 280,000 hand-dug wells (Plate 2). The wells were about one to two meters in diameter and about eight meters deep. We know of no difference in the inorganic and organic quality of water from tubewells and hand-dug wells. Both extract water from subsurface geological formations i.e., groundwater and from about the same depth. Tube wells are made of steel or plastic and hand-dug wells are constructed with concrete rings or are simply a big hole in the ground. Before tubewells were drilled as many as 25-40 people collected their drinking water from one single hand-dug well. If conditions were the same after the tubewell were drilled as when the hand dug wells were used then the hand-dug well water would have been poisoned by arsenic in the same geologically contaminated areas where poisoning occurs today. If groundwater arsenic contamination had been present for thousands of years, as suggested by the UK report, then both shallow hand-dug wells and tubewells would extract arsenic contaminated water and would have impacted water users with arsenic poisoning before 1975. If the UK/DFID statement were true, then prior to 1965 the people who had been drinking hand-dug well water for hundreds of years would have certainly been poisoned by arsenic. Prior to 1975 there is no evidence that arsenic poisoning had affected people in Bangladesh, therefore, it appears that the groundwater arsenic poisoning in Bangladesh is a recent environmental episode and began after 1975. If the lag time for the appearance of arsenic poisoning is six months and infants and children are more susceptible than adults, then the people who had been drinking tubewell water during the period 1965 to 1975 would have been impacted by arsenic poisoning. During the 1965 to 1975 period about 4.5 million wells were installed and millions of children and infants drank water from these wells. Therefore, the UK/DFID statement on the age of groundwater arsenic poisoning in Bangladesh is not based on scientific facts but rather it is based on speculation. The UK/DFID report states that " the top of shallow aquifer, at depths of less than 10m, also appears to be less contaminated than deeper down as indicated by the observation that shallow hand dug wells are usually uncontaminated even in areas of high arsenic contamination. These wells, however, face the highest risk of microbiological contamination". Lack of permeability, lithological change and other petrophysical properties, or atmospheric oxygen in large hand dug wells, may have prevented or protected tube wells and hand dug wells from contamination from adjacent areas but it would be illogical to find hand dug wells are uncontaminated and tubewells are contaminated in a similar geological, hydrological and geochemical conditions. If the UK/DFID data were true then using hand-dug well water would be the best solution for arsenic disaster in Bangladesh.

## HOW DID ARSENIC ENTER THE GROUNDWATER IN BANGLADESH?

Presently, two theories about the arsenic poisoning in Bangladesh are known. In 1996, Dipankar Das et al., conducted a geochemical survey in the six districts of west Bengal bordering the western part of Bangladesh. These districts are Mulda, Murshidabad, Bardhaman, Nadia, North 24-Pargana and South-24 Pargana. They did a subsurface investigation, some laboratory analysis, and observed the presence of arsenopyrite minerals in the sediments. They stated that the source of arsenic in groundwater and in the soil is from pyrite minerals containing arsenic. However they did not discuss how arsenic is released in groundwater from arsenopyrite. They cited the oxidation of pyrite process presented in the literature from the U.S. However, in their conclusions they state that: "The way that arsenic enters the groundwater in these six districts is not well understood. Our bore-hole analyses show arsenic-rich  $\text{FeS}_2$  in sediment layers. Since iron pyrite ( $\text{FeS}_2$ ) is not soluble in water, the question therefore arises as to how arsenic from pyrites enters the water. Although pyrite is not soluble in water, it decomposes when exposed to air or in aerated water. A probable explanation may be that the changes of geochemical environment due to high withdrawal of groundwater might have resulted in the decomposition of pyrites to ferrous sulfate, Ferric sulfate and sulfuric acid and thus arsenic in pyrites become available. Our mineralogical study by XRD(X-ray diffraction) shows the presence of  $\text{FeSO}_4$  in sample DD-70." The group that studied arsenic in the groundwater of the western USA reported: "mobilization of arsenic in sedimentary aquifers may be, in part, a result of changes in the geochemical environment due to agricultural irrigation. In the deeper subsurface, elevated arsenic concentrations are associated with compaction caused by groundwater withdrawal" (Welch et al., 1988)." If the time of arsenic contamination is after 1975 in Bangladesh, a probable explanation is that the changes in geochemical environment due to the high withdrawal of ground water resulted in the decomposition of pyrites to oxides of iron, arsenic, sulfuric acid. These oxides are soluble in water containing sulfuric acid. In the reducing conditions below the water table and in the presence of organic matter non poisonous oxides of arsenic are reduced to poisonous oxide forms. The UK/DFID report mentioned that the oxidation of arsenic pyrite is not be a major cause of groundwater arsenic poisoning in Bangladesh rather they postulated an 'arsenic adsorption and oxyhydroxide reduction' hypothesis as the main cause of groundwater arsenic poisoning in Bangladesh. The UK/DFID states that: "a number of anthropogenic explanations have been given for the occurrence of arsenic in groundwater. While it is possible that some may explain isolated cases of arsenic contamination, none of the anthropogenic explanations can account for the regional extent of groundwater contamination in Bangladesh and West Bengal. There is little doubt that the source of arsenic is of geological. The arsenic content of alluvial sediments in Bangladesh is usually in the range 2-10 mg/kg; only slightly greater than typical sediments (2-6 mg/kg). However, it appears that an unusually large proportion of the arsenic is present in a soluble form. The high groundwater arsenic concentrations are associated with the gray sands rather than the brown sands. There is a good correlation between extractable iron and arsenic in the sediments and a relatively large proportion (often half or more) of the arsenic can be dissolved by acid ammonium oxalate, an extract that selectively dissolves hydrous ferric

oxide and other poorly ordered oxides. It therefore appears likely that a high proportion of the arsenic in the sediments is present as adsorbed arsenic. This would not be true of arsenic present in primary minerals such as arsenic-rich pyrite. The greatest arsenic concentrations are mainly found in the fine-grained sediments especially the gray clays. A large number of other elements are also enriched in the clays including iron, phosphorus and sulfur. In Nawabganj, the clays near the surface are not enriched with arsenic to any greater extent than the clays below 150 m, in other words, there is no evidence for the weathering and deposition of a discrete set of arsenic-rich sediments at some particular time in the past. It is not yet clear how important these relatively arsenic-rich sediments are for providing arsenic to the adjacent, more permeable sandy aquifer horizons. There is unlikely to be a simple relationship between the arsenic content of the sediment and that of the water passing through it." The original sources of arsenic probably existed as both sulfide and oxide minerals. Oxidation of pyrite in the source areas and during sediment transport would have released soluble arsenic and sulfate. The sulfate would have been lost to the sea but the arsenic, as As(V), would subsequently have been sorbed by the secondary iron oxides formed. These oxides are present as colloidal-sized particles and tend to accumulate in the lower parts of the delta. Physical separation of the sediments during their transport and reworking in the delta region has resulted in a separation of the arsenic-rich minerals. The finer-grained sediments tend to be concentrated in the lower energy parts of the delta. This is likely to be responsible for the greater contamination in the south and east of Bangladesh. The map of arsenic-contaminated groundwater shows that highly contaminated areas are found in the catchments of the Ganges, Brahmaputra and Meghna rivers. This finding strongly suggests that there were multiple source areas for the arsenic.

The types of sediment deposited in the delta region have been strongly influenced by global changes in sea level during the Pleistocene glaciations. For example, sea level was more than 100 m lower at the peak of the last Ice Age, around 18,000 years ago. At that time the major rivers cut deeply incised valleys into the soft sediments of the delta. All of the highly contaminated groundwater occur in sediments deposited since that time, while those sediments predating the low sea level stand contain little or no arsenic-contaminated groundwater." The climate of Bangladesh is conducive to the formation of laterite type soils from which most of the elements have been leached out leaving behind only the most insoluble oxides such as aluminum hydroxide (gibbsite) and ferric oxides and hydroxides. The minerals present in saturated zone below the water table could be similar to minerals found in some marshes. Drainage of some tidal marshes or the exposure of acid-forming underclays results in acid sulfate soils (cat clays) that contain pyrite, jarosite, mackinawite, and alunite (Dost, 1973; Iverson and Hallberg, 1976) Some of the minerals groups present include { Beudantite group (Sr, Be, Ca, Al, Pb)  $\text{FeO}_3(\text{AsO}_4, \text{SO}_4)(\text{OH})_6$  Jarosite  $[\text{K Fe}_3(\text{SO}_4, \text{AsO}_4)_2(\text{OH})_6]$  Alunite Group:  $\text{AB}_3(\text{XO}_4)(\text{OH})_6$ . If arsenic were present in trace amounts in the ground water it could be concentrated in minerals such as Beudantite and released when the water table is lowered exposing this layer of accumulation to oxidation

An extensive sampling and analysis of the iron hydroxide zones at the interface of water table and zone of aeration may reveal the presence of these arsenic bearing minerals. If

these arsenic bearing iron hydroxides, Beudantite group, Jarosite and Alunite Group:  $AB_3(XO_4)(OH)_6$  are present, the lowering of the groundwater table could cause arsenic to be released by further oxidation in the dewatered zone and leaching would create a surge of arsenic oxides into the water table below. The reducing groundwater environments form poisonous arsenic compounds that would migrate with the ground water flow through the sediments.

The correlation between extractable iron and arsenic does not necessarily imply the adsorption hypothesis as proposed by UK/DFID as well as Ross Nickson of University of London. Their theory needs to be established based on mineralogical research.. The high surface area of fine grained particles allows oxidation to occurs very rapidly. If the lowering of the water table began 23 years ago with the diversion of water by the Farakka barrage there is sufficient time to release and leach, absorbed arsenic if present in pyrites or iron hydroxides to the water table.

The UK/DFID report also states that “ The ‘pyrite oxidation’ hypothesis proposed by scientists from West Bengal is therefore unlikely to be a major process, and the ‘oxyhydroxide reduction’ hypothesis (Nickson, R. et. al, 1998 in Nature; v395:338) is probably the main cause of arsenic mobilization in groundwater. It is difficult to account for the low sulfate concentrations if arsenic had been released by oxidation of pyrite. Moreover, mineralogical examination suggests that the small amount of pyrite present in the sediments have been precipitated since burial.”

Recently another group of scientists headed by Prosun Bhattacharya of Sweden Royal Institute of Technology agreed with the UK/DFID report and rejected the oxidation hypothesis and supported the oxyhydroxide reduction hypothesis for groundwater arsenic poisoning in Bangladesh.

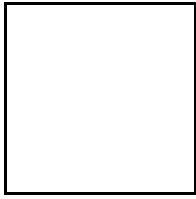
The mineral pyrite occurs in several different morphological forms and the grain sizes ranging from invisible to several inches in size. The “framboidal” form is considered highly reactive and characterized by a small grain size and large surface area. Frequent lithofacies change, vertical and horizontal distribution of thickness are common in a delta. Water table elevations in the Bengal delta fluctuate in response to seasonal conditions forming a zone of cyclic wetting and drying. This provides optimal conditions for the oxidation and subsequent leaching of pyrite and associated weathering products. Bangladesh has been experiencing cyclic wetting and drying for the last 23 years which allows enough time for oxidation of pyrite minerals. The sulfate concentration level in water depends on many factors:

1. Pyrite grain size.
2. Length of time (23 years) of cyclic wetting, drying, and leaching.
3. Pyrite abundance, reaction rate, migration time from generating area to the sample collection location,.
4. Residence time, dilution factor due to precipitation, water table fluctuations and addition or loses from other sources.
5. Sediment types
6. Depth of sampling

Depending on the geological condition, there may be high or low concentrations at different sampling times.

## **OFFSITE SOURCES OF ARSENIC CONTAMINATION IN BANGLADESH**

Bangladesh is located down gradient from West Bengal. During wet season the country receives huge amounts of surface water and pollution carried by rain water from the Indian Subcontinent. The groundwater flow directions of major aquifers in the six districts of West Bengal are to the south and south easterly direction towards Bangladesh. Being located down gradient, Bangladesh is receiving huge quantities of arsenic contaminated water from West Bengal. The migration of arsenic contaminated water from West Bengal to the Ganges delta of Bangladesh may have increased the concentration of arsenic in both soil and groundwater (Map 2). A contributing factor to the groundwater arsenic poisoning in Bangladesh may have been India's 23 years of unilateral diversion of water from the Ganges river. In 1995, Miah, M.A. in the article "Farakka the Death Trap" states that "India's continued diversion of 1,133 cum/sec out of 1728 cubic meter per second for about two decades during the dry season, has made serious impacts on the Ganges basin ecosystems. He further states: "water level in ponds have dropped about 60 percent both in quantity and duration. During dry seasons agriculture has had to rely on underground water for irrigation". In 1996, Miah M.A. in the article The Water Crisis in Bangladesh: A challenge to Integrated Water Management in Urban Areas states that "Farakka is not only the name of the barrage on the Ganges, it has been a symbol of environmental havoc in the national life of Bangladesh. India has built barrages on 17 more rivers in the east and northeast border with Bangladesh. The Barak barrage to the northeast corner near 25 degree parallel is one of them. The construction of this barrage is built at Teepaimuch which is located between Assam and Manipur provinces. The barrage will be built at a height of 161 meters. The Farakka case study gives us enough information on what we can expect from the rest of the barrages. The Barak barrage will affect the east and northeast part of Bangladesh which fall under the Meghna basin" (Map 3). In addition to the Farakka barrage, the 17 dam/barrages that India has constructed may have significant influence on the arsenic and other environmental disasters in Bangladesh. There is a strong correlation between the post Farakka disasters and the Farakka barrage (Fig. 1). The hydrograph shows the annual Pre Farakka discharge (1968-1975), the discharge under natural condition and the annual Post-Farakka discharge (1974-1996), the discharge because of India's unilateral diversion violating the natural as well as international river laws has caused many disasters both down stream and up stream. The construction and commission of Farakka barrage, India's 23 years of unilateral diversion of water, the construction of other dams/barrages in common rivers of Bangladesh and India the following disasters in Bangladesh are believed to have been caused by or aggravated by these projects.



Prior to 1975 the magnitude of the problems listed below were not known.

1. Groundwater Arsenic poisoning in Bangladesh
2. Severe Floods(1988 and 1998)
3. Depletion of Surface water Resources
4. Depletion of Groundwater Resources
5. Desertification
6. Extinction of aquatic species.
7. Impact on fish industry
8. Drop of organic matter content in the soil.
9. Destruction of Agriculture and Horticulture
10. Inland saline water intrusion
11. Loss of navigable waterways
12. Riverbank erosion
13. Climate change
14. Loss of professions
15. Outbreak of environmental diseases
16. Land subsidence (from water table lowering)
17. Social unsuitability due to symptoms of arsenic poisoning

People must now use buses and vans during the dry season instead of the long tradition of using boats, Photo 1 & 2. Because the river has no water during the dry season the people cultivate the river bed instead of long time practice of using the river for fishing.

Depleted Ganges threat to Sundarban wetlands.

WASHINGTON, Nov 30: More than 50 per cent of the world's major rivers are seriously depleted and polluted, poisoning surrounding ecosystems and threatening the health of tens of millions of people, says the World Commission on Water (WCW). A similar problem affects the Ganges, which serves 500 million people. It has become so depleted that during the dry season, the Sundarban wetlands in Bangladesh-one of the world's most unique ecosystems comes under serious threat. In Eurasia, the sickest rivers labeled "very unhealthy" by the commission-include in Central Asia, the Gages, which flows from the Himalayas to the Bay of Bengal.

## **SOLUTIONS TO MITIGATE THE GROUNDWATER ARSENIC POISONING IN BANGLADESH?**

The best solution appears to be the restoration of the thousands of years old natural environment by restoring the river flow and groundwater level that existed prior to the 1975

commission of Farakka, Tista and other barrages that India constructed on on common rivers of Bangladesh and India.

## **CONCLUSION**

The groundwater arsenic poisoning in Bangladesh is a recent environmental episode. It appears to be directly related to the Farakka, Tista and other dams/barrages that India constructed in the Bangladesh and India's common rivers. The arsenic contamination in Bangladesh began after 1975. The lowering of the water table and exposure and oxidation of arsenic minerals present in the Bengal sediments is the cause of arsenic poisoning of the groundwater.

The natural groundwater flow that existed prior to 1975 should be restored by removing all dams/barrages that India constructed in the common rivers of Bangladesh and India. The removal of dams/barrage and the dredging of rivers to decrease the number of disasters in both Bangladesh and in the upstream region of India..

The flushing of arsenic contaminants may take a long time but the removal of dams/barrages affecting Bangladesh will provide plenty of water during the dry season for drinking, irrigation and industry. The river water should be filtered, treated, continually tested and delivered through a closed system to provide a safe water supply for the nation.

**ACKNOWLEDGEMENTS.** The authors are thankful to several news media, environmentally concerned people for their very important questions related to arsenic problem in Bangladesh. Sincere thanks to Prof. M. A .Miah for providing us valuable information.

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