GROUNDWATER ARSENIC CONTAMINATION IN BANGLADESH: CAUSES, EFFECTS AND REMEDIATION[1]

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ABSTRACT

The serious arsenic contamination of groundwater in Bangladesh has come out recently as the biggest natural calamity in the world. The people in 59 out of 64 districts comprising 126,134 km^2 of Bangladesh are suffering due to the arsenic contamination in drinking water. Seventy five million people are at risk and 24 million are potentially exposed to arsenic contamination. Most of the recognized stages of arsenic poisoning have been identified in Bangladesh and the risk of arsenic poisoning in the population is increasing everyday. The severity of arsenic contamination is demanding extensive research in this field. Many studies have been carried out in Bangladesh, in West Bengal, India and other countries as well, but the situation is still out of sound control. The present study is an overview of groundwater arsenic contamination in Bangladesh. This study highlights the causes and mechanisms of arsenic contamination in groundwater. The effects of arsenic contamination on human health have been revealed. It also presents several measures to remedy the arsenic contamination in groundwater.

INTRODUCTION

Groundwater arsenic contamination in Bangladesh is reported to be the biggest arsenic calamity in the world in terms of the affected population[1]. The Government of Bangladesh has addressed it as a national disaster. Arsenic contamination of groundwater in Bangladesh was first detected in 1993[2]. Further investigations were carried out in the following years. The institutions that contributed in the investigations are the School of Environmental Studies (SOES) from Jadavpur University in Calcutta, Bangladesh Atomic Energy Commission

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(BAEC), Dhaka Community Hospital (DCH), Department of Public Health Engineering (DPHE), and National Institute of Preventive and Social Medicine (NIPSOM). DPHE collected and analyzed 31,651 well water samples with the assistance of WHO, UNICEF and DFID[3]. The laboratory reports have confirmed that the groundwater in Bangladesh is severely contaminated by arsenic. The millions of shallow and deep wells that had been sunk in various parts of the country are dispensing their own special brand of poison. In consequence, a large number of populations in Bangladesh are suffering from the toxic effects of arsenic contaminated water.

Recent studies in Bangladesh indicate that the groundwater is severely contaminated with arsenic above the maximum permissible limit of drinking water. In 1996, altogether 400 measurements were conducted in Bangladesh[4]. Arsenic concentrations in about half of the measurements were above the maximum permissible level of 0.05 mg/l in Bangladesh. In 1998, British Geological Survey (BGS) collected 2022 water samples from 41 arsenic-affected districts[4]. Laboratory tests revealed that 35% of these water samples were found to have arsenic concentrations above 0.05 mg/l. The survey results are shown in Table 1.

Table 1: Percentage of Groundwater Surveyed in 1998 by British Geological Survey with Arsenic Levels above 0.05 mg/l[4]

District	Percentage of Groundwater Surveyed	District	Percentage of Groundwater Surveyed
Bagerhat	66	Madaripur	93
Barisal	63	Magura	19
Brahmanbaria	38	Manikganj	15
Chandpur	96	Meherpur	60
Chittagong	20	Moulvibazar	12
Chuadanga	44	Munshiganj	83
Comilla	65	Narail	43
Cox's Bazar	3	Narayanganj	24
Dhaka	37	Nawabganj	4
Faridpur	66	Noakhali	75
Feni	39	Pabna	17
Gopalganj	94	Pirojpur	24
Jessore	51	Rajbari	24
Jhalakati	14	Rajshahi	6
Jhenaidah	26	Satkhira	73
Khulna	32	Shariatpur	80
Kushtia	28	Syllhet	19
Lakshmipur	68		

NIPSOM and SOES conducted a study in Rajarampur village of Nawabganj district in 1996. The report shows that 29% of the 294 tube-wells tested had arsenic concentrations greater than 0.05 mg/l[5]. Between September 1996 and June 1997, DCH also conducted a field survey in Samta village of Jessore district in collaboration with SOES[6]. In total, 265 tube-wells were examined and it was found that about 91% of the tube-wells had arsenic concentrations higher than 0.05 mg/l. Further studies by SOES and DCH in the Ganges delta exhibited that 59% of the 7800 groundwater samples had arsenic concentrations greater than 0.05 mg/l[7]. So far from August 1995 to February 2000, SOES and DCH had jointly analyzed 22003 tube-well water samples collected from 64 districts in Bangladesh[8]. Five years sampling results indicate that out of 64 districts in Bangladesh, arsenic in groundwater is above 0.01 mg/l in 54 districts and above 0.05 mg/l in 47 districts. The experts from Bangladesh Council for Scientific and Industrial Research (BCSIR) have been found the highest level of arsenic contamination, 14 mg/l of shallow tube-well water in Pabna[9]. The recent statistics on arsenic contamination indicate that 59 out of 64 districts of Bangladesh have been affected by arsenic contamination[3]. Approximately, arsenic has contaminated the ground water in 85% of the total area of Bangladesh and about 75 million people are at risk[10]. It has been estimated that at least 1.2 million people are exposed to arsenic poisoning. The reported number of patients seriously affected by arsenic in drinking water has now risen to 8500[11]. As the people are getting arsenic also from food chain such as rice, fish and vegetables, the problem is growing more severe. The current statistics of arsenic calamity given in Table 2 and the arsenic crisis map shown in Fig. 1 present the severity of arsenic contamination in Bangladesh.

Table 2: Statistics of Arsenic Calamity in Bangladesh[10]

Total Number of Districts in Bangladesh	64
Total Area of Bangladesh	148,393 km^2
Total Population of Bangladesh	125 million
GDP Per Capita (1998)	US$260.00
WHO Arsenic Drinking Water Standard	0.01 mg/l
Bangladesh Arsenic Drinking Water Standard	0.05 mg/l
Number of Districts Surveyed for Arsenic Contamination	64
Number of Districts Having Arsenic above 0.05 mg/l in Groundwater	59
Area of Affected 59 Districts	126,134 km^2
Population at Risk	75 million
Potentially Exposed Population	24 million
Number of Patients Suffering from Arsenicosis	8,500
Total Number of Tube-wells in Bangladesh	4 million

Total Number of Affected Tube-wells	1.12 million

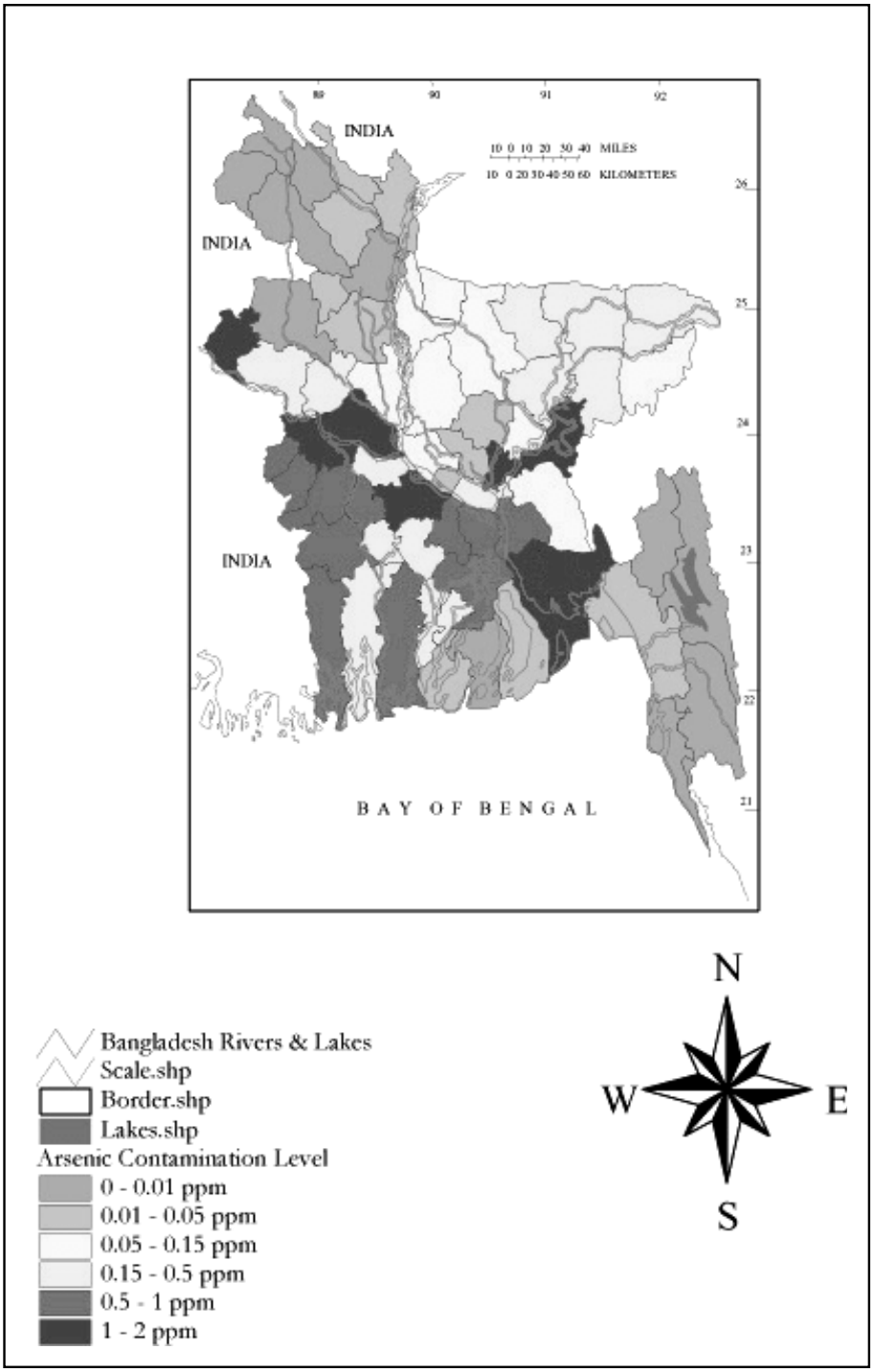

Fig. 1: Arsenic Crisis Map of Bangladesh[10]

In fact, the severity of arsenic contamination has caused a serious panic for the people in Bangladesh. It is felt that the magnitude of arsenic problem in Bangladesh surpasses the aggregate problem of all the twenty countries of the world where groundwater arsenic contamination has been reported. This is the worst case of mass poisoning the world has ever experienced. Alarm bells are now ringing in Bangladesh since arsenic in groundwater has emerged as a serious problem across the country. The problem is made more complex by the fact that the contamination is occurring below the ground where it cannot be easily identified.

CAUSES OF ARSENIC CONTAMINATION

Intermittent incidents of arsenic contamination in groundwater can arise both naturally and industrially. The natural occurrence of arsenic in groundwater is directly related to the arsenic complexes present in soils. Arsenic can liberate from these complexes under some circumstances. Since arsenic in soils is highly mobile, once it is liberated, it results in possible groundwater contamination.

The alluvial and deltaic sediments containing pyrite has favored the arsenic contamination of groundwater in Bangladesh. Most regions of Bangladesh are composed of a vast thickness of alluvial and deltaic sediments, which can be divided into two major parts – the recent floodplain and the terrace areas. The floodplain and the sediments beneath them are only a few thousand years old. The terrace areas are better known as Madhupur and Barind Tracts and the sediments underlying them are much older than the adjacent floodplain. Most of the arsenic is occurring in the younger sediments derived from the Ganges Basin. The investigators found that there is a layer containing arsenic compound at a depth of 20 to 80 meters[12]. This layer is rich in arseno-pyrite, pyrite, iron sulfate, and iron oxide as revealed by the geological investigation. The researchers also inferred that, although arsenic is occurring in the alluvial sediments, the ultimate origin of arsenic is perhaps in the outcrops of hard rocks higher up the Ganges catchment. These outcrops were weather-beaten in the recent geological past and then the eroded soil was deposited in West Bengal and Bangladesh by the ancient courses of the Ganges[13]. Arsenic in sediment or water can move in adsorbed phase with iron, which is available in plenty in the Himalayas. Here about 100 to 300 mg/kg arsenic combined with iron oxides can be found in the sediments under aerobic conditions[14]. When these sediments were deposited in Bengal basin under tidal environment, it came under anaerobic condition. The sulfate available in Bengal basin was reduced to hydrogen sulfide in presence of sulfur reducing bacteria. Iron minerals and hydrogen sulfide rapidly tie together to form iron sulfide. Arsenic had been absorbed on the surface of iron sulfide and produced arseno-pyrite. This mineral usually remains stable unless it is exposed to oxygen or

nitrate. In aerobic environment, arseno-pyrite is oxidized in presence of oxygen and arsenic adsorbed with iron sulfide becomes mobilized.

The groundwater in Bangladesh has declined progressively due to the excessive extraction of water for irrigation and domestic water supply, lack of water management and inadequate recharge of the aquifer. The groundwater declined beyond 8 meters in 12% areas of Bangladesh in 1986. This extent rose to 20% areas in 1992 and 25% areas in 1994[15]. The study on forecasting groundwater level fluctuation in Bangladesh indicated that 54% areas of Bangladesh are likely to be affected up to 20 meters in some areas particularly in northern part of the country[13]. Excessive groundwater extraction may be the vital reason for creating a zone of aeration in clayey and peaty sediments containing arseno-pyrite. Under aerobic condition, arseno-pyrite decomposes and releases arsenic that mobilizes to the subsurface water. The mobilization of arsenic is further enhanced by the compaction of aquifers caused by groundwater withdrawal.

MECHANISM OF ARSENIC CONTAMINATION

Presently, there are two well-known theories about the mechanism of arsenic contamination in groundwater. These are oxidation and oxyhydroxide reduction theory. The oxidation theory is so far the accepted theory. According to this theory, arsenic is released from the sulfide minerals (arseno-pyrite) in the shallow aquifer due to oxidation[16]. The lowering of water table owing to over exploitation of groundwater for irrigation has initiated the release of arsenic. The large-scale withdrawal of groundwater has caused rapid diffusion of oxygen within the pore spaces of sediments as well as an increase in dissolved oxygen in the upper part of groundwater. The newly introduced oxygen oxidizes the arseno-pyrite and forms hydrated iron arsenate compound known as pitticite in presence of water. This is very soft and water-soluble compound. The light pressures of tube-well water break the pitticite layer into fine particles and make it readily soluble in water. Then it seeps like drops of tea from the teabag and percolates from the subsoil into the water table. Hence, when the tube-well is in operation, it comes out with the extracted water. This mechanism is portrayed in Fig. 2.

The alternative hypothesis on the arsenic contamination is the oxyhydroxide reduction theory proposed by Nickson et. al.[17]. This theory has been accepted recently by some scientists and researchers as main the process for mobilization of arsenic in groundwater. According to this theory, arsenic is derived by desorption from ferric hydroxide minerals under reducing conditions. Ferric hydroxide minerals are present as coatings in the aquifer sediments. In anaerobic groundwater, these sedimentary minerals release its scavenged arsenic.

The oxidation of arseno-pyrite could be the main mechanism for the groundwater arsenic contamination in Bangladesh but there is not enough hydrological and geochemical data to validate the process completely. The validity of oxyhydroxide

reduction theory is also questionable due to the lack of comprehensive sampling and systematic analysis of iron oxy-hydroxides in the affected areas.

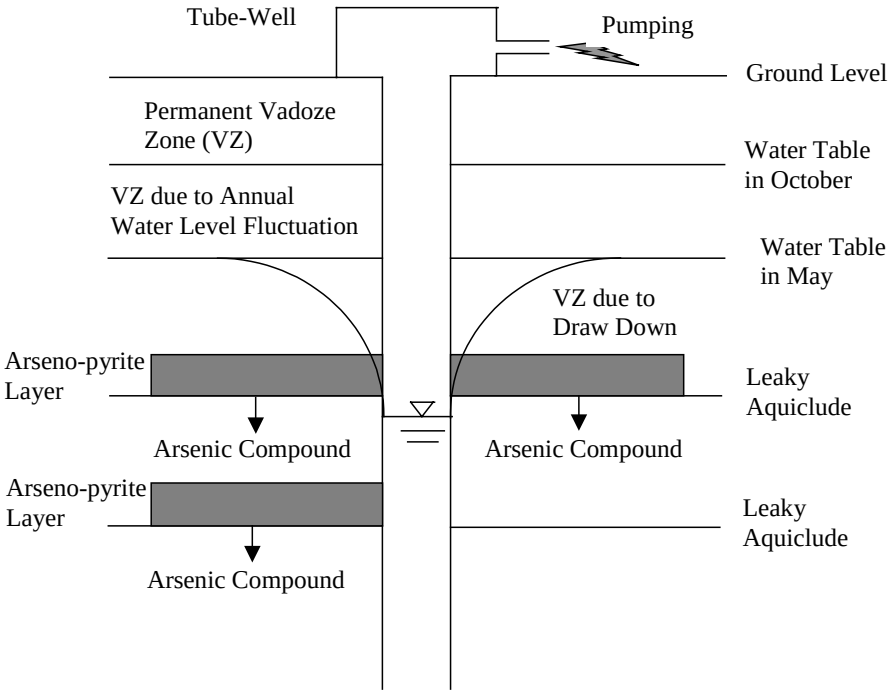

Fig. 2: Aerobic Condition in Groundwater around a Heavy-Duty Tube-Well[13]

EFFECTS OF ARSENIC CONTAMINATION

Effects on Human Health

The data collected by the governmental bodies, NGOs and private organizations reveal that a large number of populations in Bangladesh are suffering from melanosis, leuco-melanosis, keratosis, hyperkeratosis, dorsum, non-petting oedema, gangrene and skin cancer[18]. Melanosis (93.5%) and keratosis (68.3%) are the most common presentations among the affected people. Patients of Leuco-melanosis (39.1%) and hyper-keratosis (37.6%) have been found in many cases. Few cases of skin cancer (0.8%) have also been identified among the patients seriously affected by the arsenicals (arsenite and arsenate). Fig. 3 and Fig. 4 show skin lesions on palm and soles, respectively.

The occurrence of arsenic diseases depends on the ingestion of arsenic compounds and their excretion from the body. It has been reported that 40% to 60% arsenic can be retained by the human body[19]. It indicates that the level of hazards will be higher with the greater consumption of arsenic contaminated water. The daily consumption of arsenic contaminated water is very high in Bangladesh, especially in villages. The villagers consume about five liters water per day due to manual labor. Moreover, they consume plenty of rice-water and all of their foods are also cooked using arsenic polluted water. Therefore, the people of villages in the affected areas are getting more arsenic than expected. So far SOES and DCH[8] had analyzed 11000 hair, nail, urine and skin-scale samples collected from the affected villages in Bangladesh. The analysis shows that around 90% of people have arsenic in their hair, nail and urine above the normal level. The normal concentration of arsenic in hair is 0.08-0.25 mg/kg and 1 mg/kg indicates the toxic level[20]. The normal arsenic content in nails is 0.43-1.08 mg/kg[21] and the normal amount of arsenic in urine ranges from 0.005 to 0.040 mg/day[20]. Table 3 shows that the arsenic contents in hairs, nails, urine and skin scales of the affected people are very high in Bangladesh.

Table 3: Survey Results of Arsenic Contents in Hair, Nails, Skin Scales and Urine[8]

Field Survey from August 1995 to February 2000 (239 Days)	
Total Hair Samples Collected from 210 Arsenic Affected Villages	4386
Percentage of Samples Having Arsenic above Toxic Level	83.15%
Total Nail Samples Collected from 210 Arsenic Affected Villages	4321
Percentage of Samples Containing Arsenic above Normal Level	93.77%
Total Urine Samples Collected from 20 Arsenic Affected Villages	1084
Percentage of Samples Having Arsenic above Normal Level	95.11%
Total Samples of Skin Scales	705
Percentage of Samples Containing Arsenic above Toxic Level	97.44%
Field Survey from April 1999 to February 2000 (27 Days)	
Total Hair Samples	1054
Percentage of Hair Samples Having Arsenic above Toxic Level	89.35%
Total Nail Samples	1000
Percentage of Nail Samples Containing Arsenic above Normal Level	94%
Total Urine Samples	41
Percentage of Urine Samples Having Arsenic above Normal Level	97.50%

Total Samples of Skin Scales	115
Percentage of Samples Containing Arsenic above Toxic Level	100%

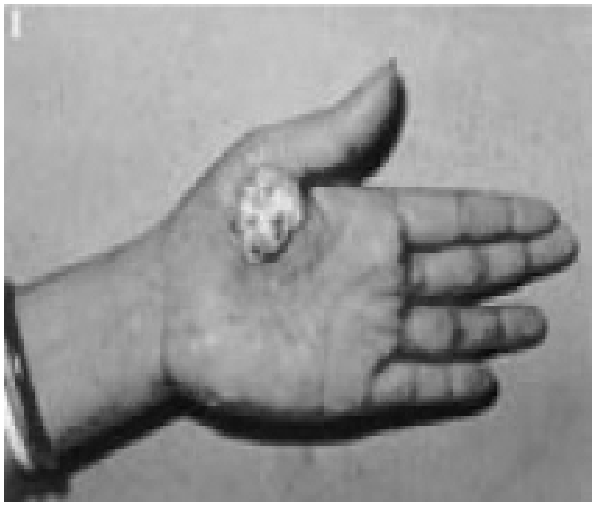

Figure 3: Skin Lesions on Palm due to Arsenic Intake in Drinking Water[16]

Figure 4: Skin Lesions in Soles due to Arsenic Intake in Drinking Water[4]

There are several factors may have been responsible for triggering off the arsenic-related diseases in Bangladesh. The primary reason appears to be the malnutrition, a state that describes 80 percent of the population of Bangladesh. Having less immunity, a huge number of people are suffering from the chronic arsenic poisoning. Many People have died, many are dying and many will die of arsenic diseases. In brief, the majority of the people in Bangladesh are grappling with the massive health crisis caused by the arsenic diseases.

Social Effects

Although what is causing arsenic contamination in groundwater is not clear indisputably, its effect on people is well known. The sudden increase in arsenic related diseases has panicked the local people. The native people consider the arsenic diseases contagious. In many instances, the people suffering from arsenic diseases have been ostracized by neighbors, friends and relatives. The affected people are either avoided or discouraged to appear in public places. The affected children are often barred from attending schools and the adults are discouraged from attending offices and any public meetings. Qualified persons are refused jobs when found suffering from arsenicosis. Those affected with a higher level of contamination are considered incapable of working and hence victimized by the growing poverty. The situation is worse for women. The women suffering from arsenic diseases are increasingly facing ostracization and discrimination. Young women suffering from arsenicosis are often compelled to stay unmarried. Married women affected by arsenic are no longer considered acceptable as wives due to skin lesions and sent back to their parents with children. Thus, the unaffected parents and children are also suffering socially with the affected females. Above all, the affected people are losing their as usual social relation with the neighbors and relatives.

REMEDIATION

The situation of groundwater arsenic contamination in Bangladesh is so serious that the immediate steps should be taken to find and deliver adequate potable water to all seriously affected areas for drinking and cooking purposes. The following measures should be implemented depending on the cost effectiveness:

1. Alternative sources of drinking water: innovative alternative sources such as pond sand filters, infiltration galleries, or Ranney wells, and in some places even rainwater harvesting can be adopted to alleviate the arsenic disaster.

2. Use of surface water: Existing surface water could be purified by filtration and chlorination, and even by ultraviolet disinfection or solar radiation and can be used in drinking and other house hold purposes.

3. Removal of arsenic by chemical precipitation: Coagulants such as the salts of aluminium and iron should be used to remove the arsenic from domestic drinking water.
4. Removal of arsenic by oxidation: Oxidants such as free chlorine, ozone, permanganate, hypo-chlorite, and Fenton reagent (H_2O_2/Fe^{2+}) should be used to remove arsenic from drinking water.

5. Extraction and distribution of arsenic free groundwater from deep aquifers: If other alternatives are costly and complicated potable drinking water can be extracted and distributed from deep aquifers.

6. Removal of arsenic from water collected from the existing contaminated sources by filtration: Water filters should be used at drinking water treatment plant or at each individual household source.

7. Removal of arsenic from the existing water sources: The sources of arsenic contamination must be controlled and arsenic contaminated soil and shallow groundwater aquifers should be cleaned to prohibit the future contamination.

8. In-situ remediation of arsenic contaminated groundwater: This can be achieved by using iron filings permeable walls.

9. Implementation of efficient water supply system: A safe and long lasting efficient water supply system should be implemented for the whole country.

10. Development of sewage and waste disposal system: An efficient sewage and waste disposal system should be developed to prevent the contamination of soil and water supplies.

Principally, the best solution appears to be the restoration of natural river flow and groundwater level. The natural groundwater level that existed prior to 1975 should be restored. The flushing of arsenic contaminants may take a long time but these will be diluted by the restoration of natural rivers and groundwater aquifers. Thus, the severity of arsenic contamination will be reduced gradually. Besides, this will provide plenty of water for drinking, irrigation, and industry.

CONCLUDING REMARKS

Arsenic contamination is not peculiar to Bangladesh alone. This is a global problem. There are other countries in the world that had experienced or going through this problem. The great difference is the degree and velocity of this environmental disaster in Bangladesh for the number of people at risk is higher than other countries. Even this problem is not as severe as in the neighboring West Bengal, where the similar disaster is taking place. In fact, arsenic contamination is not as severe or as wide spread in anywhere as it is in Bangladesh. Thousands of arsenic affected patients have already been identified. If the people continue to use arsenic contaminated water, millions will lose their health or die within a few decades. Those who will survive are in a danger of carrying genetic diseases to future generation. Unfortunately, the basic facts in Bangladesh are that the people in the affected regions are still unaware of arsenic contamination and its hazardous effects. The governmental efforts are much less than needed to mitigate the crisis. Hence, the immediate involvement of international community is urgent to combat the slow onset disaster and save the poor people.

Economically and technologically, Bangladesh is not in a firm position to solve the arsenic crisis herself. She needs the help of the international community. Environmental experts and funds are desperately needed to save the lives of millions of people affected by deadly arsenic. The international community has the economic resources, environmental experts, and technologies to mitigate the arsenic contamination in groundwater. The support of United Nations, donor countries, donor organizations, agencies, and individuals is essential to save the suffering people from the devastating arsenic disaster.

RECOMMENDATIONS

Although groundwater arsenic contamination in Bangladesh has been declared a national disaster by the government, its seriousness is yet to be fully comprehended. If the following recommendations for research and development are successfully carried out, the remediation of arsenic contamination will be much easier.

1. It is highly desirable to form a research group with geologists, hydrologists, geo-chemists, water supply and environmental engineers, and public health experts to conduct in-depth investigation on the sources and causes of arsenic contamination in groundwater.

2. A comprehensive research plan should be developed to determine the geological, hydrogeological and geochemical factors controlling the chemical reactions generating and releasing arsenic to groundwater.

3. A national groundwater resources management policy be established in order to limit the indiscriminate abstraction of groundwater.

4. It is highly recommended that every donor projects in arsenic mitigation by-law ensure community participation for smooth running in future.

5. A comprehensive water distribution system should be implemented and an efficient monitoring system should be established to provide potable water and to prevent future arsenic contamination in drinking water.

6. An effective sewage disposal system should also be established to accompany any deployment of water distribution system.

7. Guidelines on the disposal of arsenical wastes should be established to minimize the contamination in soil and water.

8. An estimate of annual arsenic use in agriculture is required and the short-term or long-term environmental impact of arsenic use in cultivation should be assessed.

9. The population exposed to the arsenic contamination should be advised about the arsenic in drinking water, the sources of arsenic-free water, and the importance of compliance with treatment programs including the nutrition.

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