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United Nations University
Environment and Sustainable Development
5-53-70 Jingu-mae, Shibuya-ku,
Tokyo – 150-8925
Tel: 03-3499-2811
Fax: 03-3499-2828
Email: mbox@hq.unu.edu
Web: http://www.unu.edu/env

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Preface

Prof. Motoyuki Suzuki
Vice Rector, Environment & Sustainable Development
The United Nations University

It is my honor to contribute a few words on a very important subject. As you all are aware, the pollution of drinking water by arsenic has become a serious challenge for people living in various parts of Asia as well as Latin America. The problem, by far, is much more severe in South Asia and China. The estimated number of people drinking arsenic-contaminated groundwater are of astonishing proportions: more than 35 million in Bangladesh, more than 1 million in India and more than 100,000 in Nepal. Tens of thousand cases of arsenicosis patients have been reported in South Asia. Similarly, several thousand patients have been identified in the Shanxi Province of China.

Our awareness of this crisis has grown dramatically during the late 1990's – particularly in the context of the presence of arsenic in groundwater extracted from the alluvial aquifer underlying West Bengal and Bangladesh. Naturally-occurring and human-induced arsenic pollution in drinking water has since been discovered in many parts of the world. We can now regard it as a problem of truly global dimensions. Successfully managing such a problem requires our earnest attention and the collaborative efforts of researchers, practitioners and officials.

Through this workshop we had a gathering of many experts on the various aspects of the crisis – both at the technological and policy development level. These aspects include water treatment technologies, safe water options, fate of arsenic in the environment, treatment of arsenicosis patients, community involvement and strategic policy orientation. The speakers on these subjects highlighted the current state of knowledge, necessary actions and future needs.

In a broad sense, the arsenic crisis indicates the importance of water resource management in the Third World countries. We know that water as a resource is going to become much more precious and scarce in the next few decades. Considerable efforts are being made internationally to better understand the nature of these challenges and identify timely and successful interventions for coping with them. As an example, the Third World Water Forum is being organized here in Japan during March of the next year. The breadth of water research and policy issues will be discussed and action-oriented output is expected. It is up to the scientific community to provide necessary and important input into that process. Holding this workshop is a part of such efforts we have undertaken at the United Nations University (UNU).

Water issues have played a central role in the UNU's activities on environment and sustainable development. We have, at the moment, a number of projects that deal with international river basins, monitoring water pollution in coastal areas and research on fate of arsenic in groundwater. Other broader areas of water research such as history of water and the world lake vision are also important activities.

We, at UNU, realized the importance of the arsenic crisis earlier on and launched a project to develop household technologies in 1999. Our partners in that endeavor are the colleagues from the Bangladesh University of Engineering and Technology (BUET). After successful completion of laboratory work, UNU and BUET were able to install a number of household water treatment units in two villages. These units have been successfully running for about two years and are accepted well by the villagers themselves. In 2001, we embarked on a new initiative with BUET which will investigate the fate of arsenic in the environment. This will help fill an existing gap in our knowledge – that is, what happens to arsenic once it is withdrawn from the aquifer and used most frequently for agricultural purposes. Today, very limited information is available about uptake of arsenic into plants and its fate in our food chain. We hope that our scientific research will lead to finding some of the answers to these important questions.

I believe that Japanese researchers and development agencies can and are playing a very important role in the fight against the arsenic crisis. I hope that the outcomes of this workshop are helpful in identifying new challenges in research as well as means and ways to meet them.

Finally, I would like to thank our partners in this workshop for their support: the National Institute for Environmental Studies, working under the Japanese Ministry of Environment. The support from NIES in every stage of the arrangements for this workshop has been critical. Similarly, our collaborators – Bangladesh University of Engineering and Technology (BUET), the Chinese Academy of Preventive Medicine (CAPM) and Japan National Institute of Health Sciences (NIHS) have been instrumental in holding this workshop. I thank them for their support.

Foreword

Dr. Soichiro Iwao, MD, MPH, PhD
Director General
Environmental Health Department, Japan Ministry of Environment

Among the bureaus and departments of the Ministry of the Environment, my Department of Environmental Health has a particularly deep relation to the health effects of humans caused by environmental pollution. One of our important duties is compensation relief for those who had suffered health damages through the air and water pollution.

Environmental pollution caused various kinds of human health damage in Japan when the Japanese economy rapidly expanded. This health damage had come from lack of proper consideration for environmental protection. Japan learned the seriousness of damage that could be incurred from environmental pollution and the kind of measures necessary to cope with the damage through these experiences and then pushed forward the system building for protecting the environment. The Japan's past experience shows how serious problems the environmental pollution could cause and how long lasting the aftereffect could be. This would help you understand that taking quick measures and preventing damage beforehand are very important against environmental pollution problems.

In order to provide rapid and impartial protection of health damaged victims, The Pollution-related Health Damage Compensation Law was enacted in 1973. This law is based on the "Polluter Pays Principle," and allows the victims of pollution-related diseases to get disability compensation benefit to fulfill for income loss as well as medical expense related to the disease.

During the 1950's and 1960's in Japan, serious air pollution brought about rapid increase of patients with asthma, chronic bronchitis and emphysema in heavily industrialized areas, such as cities of Yokkaichi and Kawasaki. Also in the mid 50's, water pollution by organic mercury, as you may know, caused Minamata disease in Kumamoto Prefecture, and by Cadmium poisoning, Itai-Itai disease occurred in Toyama Prefecture.

Arsenic pollution also ocurred in Japan between 1920 and 1962. White arsenic was intermittently produced by calcinating arsenopyrite at the Toroku mine and refinery in Miyazaki Prefecture for about 28 years. ntensive investigation by the prefectural government was carried out in 1972, and patients suspected to be suffering from chronic arsenic poisoning were identified. The victims finally certified under the Pollution-related Health Damage Compensation Law and were paid medical costs and the disability compensation according to the legislation. A total of 184 patients were compensated and 73 of these certified patients are alive at present.

I have heard that the pollution of groundwater by arsenic in the world including Bangladesh, West Bengal and China is a serious human disaster of a tremendous scale. The estimated number of people potentially at risk from drinking contaminated water is more than 35 million. This number is said to exceed the current estimate of people possibly infected by the HIV virus all over the world. Taking into account the seriousness of the health damage by arsenic poisoning, this is really a huge problem to be tackled as soon as possible.

This is a very complicated problem that needs various approaches to be mitigated, such as public awareness-raising, safe and effective arsenic removal from water, treatment of the poisoned patients, nutrition improvement of the people at risk. These facts make us realize that collaborative efforts of various parties from different fields are essential in solving this problem.

One of the objectives of this workshop is: "involvement and awareness raising of Japanese researchers and the general public on the related issues". I believe this objective is important because Japan once experienced health damage by arsenic pollution. Japan may have accumulated some useful knowledge regarding arsenic problem. I think it is very meaningful if this workshop serves as a trigger to making good use of our accumulated knowledge. I believe the fruits of this workshop will play a very important role in bringing a comprehensive strategy to cope with the present arsenic crisis of unprecedented proportions.

Contents

Key Issues for Arsenic Crisis and an Approach for its Remediation: West Bengal (India) Experience

Dipankar Chakraborti[1]*, Mohammad Mahmudur Rahman[1], Uttam Kumar Chowdhury[1], Kunal Paul[1], S. C. Mukherjee[2], K. C. Saha[3], Chitta Ranjan Chanda[1], Dilip Lodh[1], Tarit Roy Chowdhury[1], Gautam Kumar Basu[1], Shankar Dey[1], Bijon Chandra Paul[1], and Pijush Kanti Roy[1]

[1]School of Environmental Studies, Jadavpur University, Kolkata, India
[2]Department of Neurology, Medical College, Kolkata, India
[3]Retired Professor of Dermatology, School of Tropical Medicine, Kolkata, India

*Author for correspondence:
Tel: 91 33 4735233, Fax: 91 33 4734266, E-mail: dcsoesju@vsnl.com

Arsenic contamination of groundwater and its human consequences in three villages from two districts of the state of West Bengal in the eastern part of India was first brought to attention in 1982. The scale of this disaster has become evident over the past twenty years. During field surveys conducted over the past fourteen years, we have identified 2900 arsenic-affected villages in 9 of the total 18 districts in West Bengal. The danger is still acute. During a preliminary field survey conducted for 4 days in Murshidabad as recently as 18-21 December 2001, we identified 931 new victims with skin lesions caused by arsenic poisoning from 29 villages. Fourteen have suspected cancer and 72 suspected Bowen's Disease. Even after twenty years, the problem is worsening. Many villagers continue to be unaware that they are drinking contaminated water, which is responsible for their skin lesions. Approximately 90% of children below 11 years of age living in arsenic affected villages show hair and nail arsenic above normal level. Infants and children (Photograph 1) might be at greater risk from arsenic toxicity because of more water consumption on a body weight basis.

Twenty years ago, groundwater arsenic contamination and symptoms of arsenic related ailments were first noticed in patients residing in three villages of two districts in West Bengal. Today, this minor arsenic incident has taken a menacing look simply due to negligence and lack of proper controlling mechanisms. A minimum of 6 million people including about 2 million children belonging to 9 out of the total 18 districts of West Bengal were drinking arsenic contaminated water which contains arsenic more than the maximum permissible limit set by WHO (which is 50 mg/l) and about 300,000 are already suffering from arsenic related diseases. About 40 million inhabitants of these 9 districts are at risk from arsenic toxicity. Many people with moderate to severe arsenical skin lesions have been found to develop cancer eventually. Previously, it was thought skin cancer is the common type of cancer caused by arsenic. But lung, liver, colon, bladder etc. cancers have been found among those suffering from chronic arsenic toxicity.

A team of about 15 researchers from Jadavpur University, Kolkata has been engaged for the last 14 years in the task of surveying the magnitude of the arsenic problem in the villages of West Bengal's affected districts. We have analyzed 105000 water samples from 9 arsenic affected districts by Flow Injection Hydride Generation–AAS.


A child who was drinking arsenic contaminated water

Photograph 1

Out of the total samples analyzed, 51 % are unsafe to drink according to WHO recommended value of arsenic in drinking water (recommended value is 10 mg/l) and 25% contains arsenic above WHO maximum permissible limit (maximum permissible limit is 50mg/l). So far we have identified 2900 villages from 74 blocks out of 9 affected districts where ground water contains arsenic above 50 mg/l and registered 9430 people from 284 villages with arsenical skin lesions.

But we feel we have been able to survey and bring to light only a negligible amount of the real and menacingly huge proportion of the calamity. With every of our subsequent survey there is an increase of both the number of affected villages and that of ailing persons. During our survey we have noticed that in some villages where a few years before after analyzing the hand tube-wells, we colored the tube-wells green (arsenic < 10 mg/l) and told the villagers to drink the water, a good percentage of those tube-wells are now no more safe to dink (arsenic > 50 mg/l). Thus with time more and more tube wells are getting contaminated. This is also true for deep tube-wells. Some time back when we realized it would take us years to find out the actual magnitude of the calamity, we decided to survey in detail 2 out of 9 arsenic affected districts of West Bengal. We have been undertaking a detail survey of North 24-Parganas and Murshidbad for the last 5 and 3 years respectively. This survey is still on.

North 24-Pargana District

The area and population of North 24- Parganas are 4094 sq.km and 7.3 million respectively. From all 22 blocks of North 24-Parganas, we have so far analyzed 38,240 water samples, and in 19 out of 22 blocks, groundwater has been above 50 mg/l and in 21 blocks above 10 mg/l. Out of total 38000 samples analyzed, 52.8% contains arsenic above 10 mg/l and 30.7% above 50mg/l. Total 22500 hair, nail and urine samples have also been analyzed at random from people of the affected 13 blocks and an average 75% of the people have arsenic in biological samples above normal level. Thus, many people are expected to be sub-clinically affected.

According to our present calculation on the basis of number of hand tube-wells we had analyzed and people drinking water from each contaminated tube-well and extrapolation of the data reveals that about 2 million people were drinking arsenic contaminated water above 50 mg/l from North 24-Prganas alone. Even today, the number of affected villages is steadily on the rise and some of the villagers are totally ignorant of the fact that they are drinking contaminated water, which in turn, is responsible for their skin lesions. During our preliminary screening of 33000 people from 13 of the said 19 blocks where groundwater contains arsenic more than 50mg/l, we have registered 2274 patients suffering from arsenic related diseases.

Murshidabad District

The area and population of Murshidabad district are 5326 sq.km and 4.8 million respectively. We have been surveying all 26 blocks of Murshidabad for the last 3 years and have analyzed 28000 water samples for arsenic. The arsenic content in groundwater in 19 of the 26 blocks exceeds the 50 mg/l limit and in 22 blocks above 10 mg/l. 22274 water samples have been tested from these 19 blocks so far where groundwater contains arsenic above 50 mg/l. Our calculation reveals that at least 1.0 million people in these 19 blocks are drinking water whose arsenic content exceeds the maximum permissible limit set by WHO. Till date, we have succeeded in partially ascertaining the number of patients in 14 blocks of the districts. We have recorded the names, addresses and description of the arsenical skin lesions of about 4000 patients.

During our very preliminary 4 days survey from 18-21 December, 2001 from 4 affected blocks of Murshidabad we have registered 931 new patients with arsenical skin lesions and out of them 14 are suspected cancer patients and 72 suspected Bowens. Our experience in the field as well as inputs given by the villagers have pointed out that we have not succeeded in recording the problems of even 10% of the suffering / affected folk. One of the reasons, during the time we are in the village, most of the adult villagers is in the field and school going folk are in schools. We also feel that affected young girls and middle-aged women did not turn up to our camp to avoid social problem. We have learned from the affected villagers that one or two members of many families had arsenic marks on their skins and had met with untimely death. A considerable number of people who have died of cancer also had arsenic lesions.

The arsenic affected villages are home to many types of problems. Young men and especially women are encountering serious difficulty in getting married because of the arsenic mark on their skins. Even persons with arsenic skin lesions are being refused jobs. Some patients are being isolated because of the mistaken notion of the lesions being leprosy. Even married women are being sent back to their parents because of lesions.

Cows and Buffaloes are eating straw containing high arsenic

Photograph 2

Arsenic in Food Chain

Although the arsenic problem is about two decades old and we are deeply concerned with the arsenic contamination of drinking water, surveys are yet to be conducted on the amount of the arsenic in irrigation water and consequent entry of the element through food into the bodies of humans and animals. We have been studying this problem for last 3 years and have come to the conclusion that huge amounts of arsenic are entering the crops through irrigation water. These crops are in turn causing the element to enter into the bodies of human being and animals. We have calculated that from the existing 3200 irrigation tube-wells in Deganga Block of North 24-Parganas are causing 6.4 tons of arsenic to be deposited on the agricultural fields. Rice, leafy vegetables, spinach, a rum and other items of daily diets have been found to have elevated arsenic concentration. It has been calculated that in Kolsur village 1/3 of the total amount of arsenic entering the body comes from arsenic affected food items. Contrary to the hope that vegetables contain lesser amounts of the more harmful and poisonous arsenic compounds (viz. arsenite and arsenate) 85% of the arsenic contained in food items from Kolsur village have been found to be in the form of these two compounds. Vegetables that grow underground contain greater amount of arsenic in them than others.

In addition to human beings domestic animals too are not being spared of arsenic contamination. They too are being forced to take in arsenic through water and food items in affected villages. Cows and buffaloes take in the greatest amount of arsenic in this fashion. These animals generally drink large amount of water (average 40 liters) and about 4 to 5 kgs of hay every day. Our test conducted in 8 hay fields show that on an average 1900 mg of arsenic are present in every kg of hay in Kolsur village. While human being take in 1200 mg of arsenic every day from Kolsur village, cow and buffaloes take about 18000 mg of arsenic daily. Elevated concentration of arsenic has been found in the hair and urine samples from cows and buffaloes in these villages (Photograph 2).

Nowadays whenever villages come to know of the high concentration of arsenic in their tube-wells, they try to drink water from other safer sources. But they can't escape from arsenic intake through food items. Currently groundwater is the main source of irrigation. It is important to note that even villagers of unaffected areas may allow the entry of arsenic into their bodies by eating rice, vegetables etc. grown in arsenic affected areas. Even Kolkata City is not safe from this threat. In the arsenic affected villages, urine samples of people drinking arsenic safe water have been found to contain arsenic in somewhat elevated level than that expected in normal people. Our calculations show that the intake of arsenic through food items is greater than the WHO maximum limit regarding drinking water. The maximum limit of daily intake is 100 mg according to WHO. This figure has been arrived at by considering by 1 liter of water as containing 50 mg of arsenic and an adult human being drinking 2 liters of water a day.

Arsenic is gradually becoming a part of our daily lives. Its presence is restricted not only to drinking water and vegetables but it has also been found in local ice creams and cold drinks in affected areas. The villages of West Bengal are about 95% dependent on groundwater reserves for drinking water. The food processing units and other units manufacturing articles using water of daily use and located in suburban areas are generally using groundwater for production. Now, if groundwater in 9 affected districts contains arsenic, and if water not treated to remove arsenic then the groundwater being used by these industries may very well contain arsenic. Our research has revealed that even if the mother is an arsenic patient her breast milk remains almost free from the element. Similarly cows may eat arsenic contaminated hay and drink contaminated water, yet their milk will remain quite free from the element. However, some time we found arsenic in elevated level in cow milk in the affected villages and that arsenic is due to contaminated tube-well water added by milkman to increase the volume of milk. This arsenic contaminated milk also comes to near by city and used by tea stalls and those making sweets from milk.

Photograph 3


Arsenic is also present in sterile water for injection ampule

Arsenic in Ampule Water for Injection

While surveying the arsenic contamination in various products in villages, suburbs, cities we have found arsenic in water ampules for injections (Photograph 3). This water is used as a solvent for many life saving medicines. Since then we have conducted arsenic test in hundreds of injection ampules from villages, suburbs of many districts of West Bengal including Kolkata. We had analyzed hundreds of water-injection ampules from 14 companies available in districts of West Bengal. We have found arsenic in the water of the ampules manufactured by some companies in West Bengal and Bihar.

We have examined many batches of each and every company and have found some batches of a particular company to contain arsenic while in other batches of the same company, the water has been found to be free of the element. This finding proves that most probably these companies are using ground water from contaminated districts for their injection ampoules and while water was purified, arsenic was properly removed in some batches, the same had not been done always. Arsenic has been found in vials manufactured by 3 companies in Bihar. These findings are very important. There can be two explanations: either arsenic is present in the water of Bihar or the ampules are being manufactured in West Bengal in the name of Bihar. Arsenic has not been found in the water ampules of Madhya Pradesh, Gujrat or Tamilnadu.

The arsenic problem in Bangladesh is more acute. After conducting tests on injection ampules manufactured by 10 companies in Bangladesh, we have found in ampules of 7 such companies arsenic exceeds recommended limit for drinking water set by WHO (10 mg/l). Although arsenic content of 10 mg makes water unfit for drinking, yet it must be taken into account that arsenic from injection ampules is directly entering the blood stream. How much it will cause damage is not the main issue, we need to ponder at this point over the degree of callousness that makes the presence of arsenic in injection ampules possible.

How to Combat the Arsenic Menace

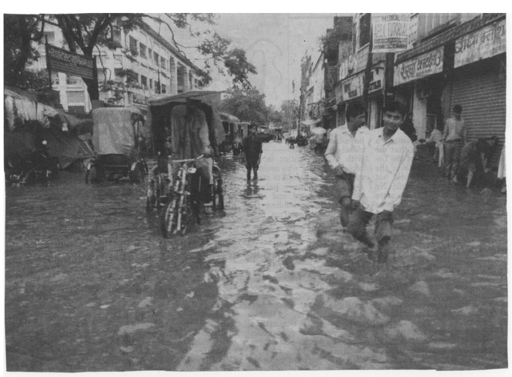
We have been trying relentlessly for the last 12 years to present the severity and future danger of the arsenic problem in West Bengal. But our efforts do not seem to have succeeded specially in drawing the attention of government officials and ministers. Many correspondences made to them have not even received a reply. During last 10 years all our efforts have received certain patent comments from the government circles. They have accused us of spreading panic among innocent citizens. They even characterized our findings as incorrect and untrue. We have been branded as self-centered people catering to our vested interest in spreading lies. On 8th March 1993 the first arsenic patient from Kolkata was identified in Jadavpur. Arsenic was found in the water of the area also. Gradually, arsenic was found in the groundwater of Lake Gardens, Bansdroni and Alipore areas of Kolkata. On every occasion the government branded our findings as lies. It was only on 22nd May 2001 the government finally accepted that even Kolkata is not free from the arsenic danger (Civic body admits arsenic presence, The Statesman, Tuesday 22 May, 2001). Had they paid heed to our warnings 10 years back when the first patients was identified from Jadavpur, then some innocent citizens of Kolkata would have been spared from drinking contaminated water. When the arsenic situation of West Bengal is so grave, the arsenic chief. Engineer, PHED, Govt. of West Bengal in an international meeting in Bangladesh during August, 2000 told that the total number of arsenic patients in West Bengal is 450 and arsenic free drinking water is now supplied to the doorsteps of the people in the affected areas through pipeline networks (Fact sheet 13 on Arsenic: A Disaster Forum Publication, Dhaka, Bangladesh, p-10). Also The health minister govt. of West Bengal in an interview on 5, April 1999 also told that the arsenic situation is much better now than what it was during 1983 (Arsenic Problem is not Serious: Medical World: Special Health day copy, 5th April 1999).


4000 sq. km of such wetlands exist in West Bengal-India

Photograph 4

We have been trying to stress the solutions to the arsenic problem for many years now. The general misconception is that it is a problem faced by poor villagers only. But this not so. The greater percentage of the patients being villagers is due to the absence of nutritious items in their daily diets. They are not aware of the extent and seriousness of their problems. When tubewell water was first made available to them in 1960, they had rejected it fearfully by branding it, “The Devil’s Water” and by running away from it. Today they are wholly dependent on that tubewell water. While we have staged a full fledged revolution with tubewell water, equal distribution of our huge available surface water i.e. river, canal, flooded river basins, oxbow lakes, lagoons, rain water has been totally neglected by us. West Bengal and Bangladesh have been referred to as the land of rivers and rains. Had we succeeded in conservation and effective distribution of these huge amounts of water then most of our water problems would have been solved (Photoraph 4).

In spite of having such an ampule supply of water, we are indiscriminately exploiting our groundwater reserves. Even in the monsoon season we resort to groundwater extraction if it does not rain for 3 / 4 days. Today, about 70 million Indians are suffering from fluorosis and fluoride contaminated drinking water is the root cause of the situation. 120 million people are at risk from arsenic problem in West Bengal and Bangladesh. By drawing up underground water we ourselves have created this problem. Even 2600 years before in the days of the Mahabharat we are aw are of the existence of the groundwater. (This is exemplified by the incident when the great warrior Bhisma lying on the bed of arrows was given underground water to drink.). But we had prevented ourselves from its exploitation and preserved the equilibrium in nature. We used groundwater in Kolkata also. But if the rain received by the city (Photograph 5) is properly stored on rooftop and subsequently used for household consumption, then we can prevent the increased use of groundwater for as much as five months in a year. A few years back, I had requested the chairman of the assembly house to issue building permissions to only those houses that would provide rainwater storage facilities on their terraces and also to exempt some income tax to those who will use their existing roof for rainwater harvest. I had also asked him to levy a water tax as would check the wastage of water at the hands of residents. But none of my proposals have been implemented so far.


Water logging in Kolkata streets after two hours of heavy rain. During rainy season (June - September) this scene is quite common in Kolkata.

Photograph 5

The primary task in our hands now is to make the villagers conscious of the terrifying nature of the arsenic problem faced by us all. We have to implement laws and rules to control groundwater extraction. We must use groundwater only as our last resort. Since independence, we have not worked hand in hand with villagers in the eradication of problems. If the arsenic menace is to be eradicated then the full cooperation of the village folk is an absolute necessity. Water management is necessary with people's participation.

Nature is our ultimate mother. We have reversed her laws, her methods of functioning, which she created from thousands of years of her experience in her laboratory, and thus violating that we have brought this curse upon us. Nature is now the only solace for the people of West Bengal and Bangladesh and we can free our selves from this curse with the help of nature. We should desist from draining groundwater the lifeblood of our mother. Surface water, Her breast milk is enough to sustain us all. All human beings living anywhere in the world should learn to respect and preserve nature's bounty.

Fate of Arsenic in the Environment

M. Ashraf Ali
Department of Civil Engineering, Bangladesh University of Engineering and Technology
Dhaka 1000, Bangladesh

Arsenic in groundwater and its fate and transport in the environment have become matters of great concern in Bangladesh, India and several other countries. In Bangladesh, an estimated 268 upazillas out of 465 have been affected with significantly high concentrations of arsenic. In Bangladesh, tubewell water extracted from shallow aquifers is the primary source of drinking/cooking water for most of its population. Besides huge quantities of water from shallow aquifer is also used for irrigation during the dry season. The dependency on groundwater for public water supplies and irrigation results in a huge quantity of arsenic being cycled through the environment each year with major implications on public health and environment. This paper provides an overview of the research needs for better understanding of the fate of arsenic in the environment.

Since its detection in late 1993 in Bangladesh, much of the research on arsenic has focused on its presence in and exposure through drinking/cooking water. However, widespread use of groundwater for irrigation suggests that ingestion of irrigated crops could be another major exposure route for arsenic. In Bangladesh, in the absence of surface water in the dry season, irrigation is heavily dependent on shallow tubewell. As shown in Figure 1, during the last fifteen years, the area under irrigation has been increased to raise food production mainly by installation of shallow tubewell, a large proportion of which yields water with high levels of arsenic. However, limited research works have so far been carried out on understanding fate of arsenic in the soil-water-plant environment.

The arsenic pumped with tubewell water can (i) undergo transformation (e.g., through redox or microbial processes), (ii) volatilize into the atmosphere as result of different biological transformations, (iv) undergo adsorption-desorption and thus become retained onto soil, washed away by surface runoff or leached into the groundwater, and (v) be taken up by plants, and subsequently enter into the food chain. Limited data suggest presence of both As(III) and As(V) as well as organic arsenic in agricultural soil and the processes of transformation/bio-transformation of arsenic are not clearly understood. Although considerable work has been done on microbial methylation (and volatilization) processes of arsenic, primarily as it applies to bioremediation of As-contaminated soils, importance of such processes in determining the fate of arsenic in agricultural fields is not clearly understood.

Adsorption-desorption of arsenic onto soil is key to the understanding of its fate in the environment. In irrigated agricultural land, water lost by evaporation and evapo-transpiration will leave arsenic along with other minerals in the topsoil. This arsenic is not likely to be dissolved or washed out by flood or rainwater in oxidized condition due to its affinity for iron, manganese, aluminum and other minerals in soil. As a result, a cumulative accumulation of arsenic in surface soils is expected and some recent data (Huq et al., 2001; Alam and Sattar, 2000; Ullah, 1998) suggest arsenic concentration as high as 83 mg/kg in topsoil, against a background concentration of 4-8 mg/kg. However, data on accumulation of arsenic on irrigated agricultural soil over time is not available. Also, there appears to be a lack of information on desorption kinetics of arsenic from soil, which is needed for better understanding of the long-term retention of arsenic on soil.

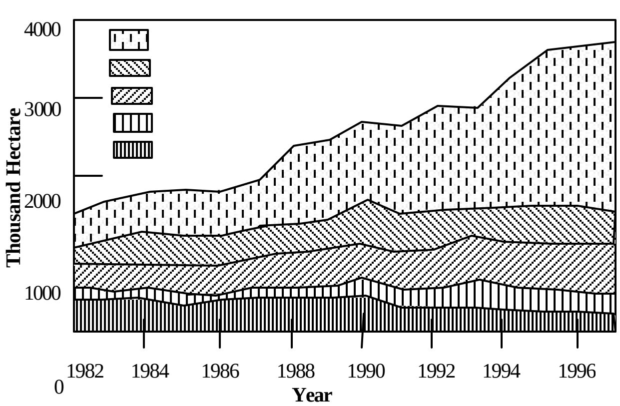


Figure 1: Increase in irrigated area in Bangladesh by different technology during 1982-1997 (WARPO, 1999).

The increased concentration of arsenic in irrigation water and in topsoil in the root zone is likely to result in increased concentration in plant and food grains. The preliminary findings of UNDP/FAO studies in Bangladesh showed that arsenic content in rice produced by irrigation with arsenic contaminated water is higher but the relative increase is not significant. The highest concentration of arsenic was found in the roots of rice plant, then comparatively a lower concentration in stem and leaves and the lowest concentration was found in rice grain. A Bangladesh rice variety BR11 irrigated with water containing 8 mg/L arsenic accumulated 0.6 mg/kg of arsenic in grain and as high as 100 mg/kg of arsenic in straw (Meharg, 2001). It appears that arsenic is not readily translocated in the rice grains. A relatively higher concentration of arsenic has been found in leafy vegetables; the concentration of arsenic in arum, a vegetable/food in Bangladesh has been found to be 20 mg/kg (Huq et al., 2001). It should be noted that very little is known about the chemical forms of arsenic (e.g., inorganic and organic) in crop/vegetable, which in turn is needed for estimating its toxicity. Limited available data suggest significant variations of arsenic content among different varieties of crop/vegetable and also among different parts of the same plant. More studies are needed to develop a better picture of arsenic accumulation in the food chain. Arsenic in the agriculture environment can be fairly complex and a good understanding of the fate of arsenic pumped with groundwater is essential for the development of good management and remediation strategy.

In addition to transfer of arsenic in the environment through pumped groundwater, fate of arsenic in arsenic-rich wastes generated from household or community-based arsenic removal units/systems is also a major concern. Majority of the arsenic-rich waste materials can be classified into: (a) wastes generated from coagulation based systems, and (b) wastes generated from systems based on absorptive filtration and others techniques (e.g., ion exchange). The waste belonging to the first category is primarily slurry containing coagulated flocs of alum or iron salt, rich in arsenic. Currently, disposal of such wastes in cow-dung bed or in nearby land is widely practiced. It has been suggested that biochemical processes in cow-dung bed and in nature result in volatilization of arsenic. However, data supporting such processes are scant. The wastes belonging to the second category are primarily spent adsorption/ion-exchange media. With increasing use of arsenic removal units, concerns have been raised regarding safe disposal and long-term stability of these wastes, and possible contamination of environment from arsenic present in the wastes. However, there is only limited data on the quantities and characteristics of these wastes and possible mobilization of arsenic from them. The widely used Toxicity Characteristics Leaching Procedure (TCLP) of USEPA used for evaluating stability of hazardous wastes may not adequately assess the long-term stability of these wastes. New test methods need to be developed for this purpose.

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Arsenic Contamination of Groundwater in Bangladesh and Its Remedial Measures

M. Habibur Rahman[1], M. Mafizur Rahman[1], Chiho Watanabe[2] and Kazuo Yamamoto[3]

[1]Department of Civil Engineering, Bangladesh University of Engineering & Technology (BUET), Dhaka, Bangladesh.
[2]Department of Human Ecology, School of International Health, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan.
[3]Environmental Science Center, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo, Japan

Introduction

Presently groundwater contamination by arsenic (As) is a major concern in Bangladesh where about 97% of the total rural population depend on tube-wells for drinking water, which is bacteriologically safe to drink. Arsenic was first detected in groundwater in the west of Bangladesh in 1993 following reports of extensive contamination of water supplies in the adjoining areas of India and of many people suffering from arsenic related diseases that had been treated medically in India. At present several thousands of people are suffering from arsenic related diseases and millions are at risk of arsenic poisoning from drinking groundwater with arsenic in excess of acceptable limit. But the total dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified.

Several methods for of treating water for arsenic reduction are available. The most commonly used methods mostly utilized principles of oxidation, precipitation/co-precipitation, adsorption onto sorptive media, ion exchange and physical separation by synthetic membranes (Cheng et al, 1999, 1994; Cliford, 1999; Emett and Khoe, 2001; Hering et al, 1996; Kartinen and Martin, 1995; Kim and Nriagu, 2000, and Oh et al, 2000a, 2000b). In consideration of lowering drinking water standards by United State Environmental Protection Agency (USEPA), a review of arsenic removal technologies was made to consider the economic factors involved in implementing lower drinking water standards for arsenic (Chen et al, 1999). A comprehensive review of low-cost well-water treatment technologies for arsenic removal with the list of companies and organizations involved in arsenic removal technologies is available in Murcott (2000).

Most of the documented experiences of arsenic removal technologies include large-scale application. In the context of prevalence of high concentration of arsenic in groundwater in Bangladesh, several methods/ technologies of treating water for arsenic reduction from drinking water have been tried. In many cases conventional technologies have been scaled down to suit them for the rural isolated households and communities to choose safe sources of water for drinking purpose.

This paper is aimed at identifying the arsenic contamination problems in Bangladesh and then an overview of technologies used for arsenic removal will be presented. The use of alternate source of water as substitute to groundwater sources will also be presented.

Arsenic Contamination in Groundwater

Arsenic in groundwater above 50 µg/L (Bangladesh standard for Drinking Water) was found in 61 districts (these includes the number of administrative areas with at least one sample exceed 50 µg/L of arsenic) out of total 64 districts in Bangladesh. This is based on the studies conducted by British Geological Survey (BGS), Department of Public Health Engineering (DPHE), Mott MacDonald Limited (MML) and Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP). BGS, DPHE and MML conducted the study in two phases and examined 3,534 distributed water samples from 61 districts (except 3 hill districts) in an approximate grid of 6km x 6km (DPHE, BGS and MML, 1999 and BAMWSP, 2001). These include an average of 58 samples per district and 8 samples per upazila(the lowest administrative unit), and 25% tested samples exceed the concentration of 50 µg/L, Bangladesh Standard but 42% tested samples exceed the concentration of 10 µg/L, provisional World Health Organization (WHO) guideline value for arsenic in drinking water. Again, the percentage of contaminated tube-wells increases if only shallow tube-wells are considered. Then 27% tested samples exceed the concentration of 50 µg/L and 46% tested samples exceed the concentration of 10 µg/L. In case of tested water samples collected from deep-tube-wells (strainer depth > 150m), only 1% and 5% samples exceed the allowable limits of 50 µg/L and 10 µg/L respectively. The Figs. 1 and 2 shows the intensity of arsenic contamination of groundwater in different areas of Bangladesh. These includes the information obtained from arsenic analysis conducted by DPHE and BGS (2001), DPHE, BGS and MML (1999), School of Environmental Studies, Jadavpur University (SOES, JU) and Dhaka Community Hospital (DCH) (2000) and Bangladesh University of Engineering and Technology (BUET), and compiled by Ahmed (2002). BAMWSP has been conducting national screening survey to identify arsenic contaminated tube-wells in two phases mostly in arsenic contaminated areas (BAMWSP,2001). In first phase, the survey conducted by BAMWSP includes 80,390 tube-wells in 6 Upazilas, and the number of contaminated tube-wells is 38,739 (48.19%). BAMWSP examined 5, 44,975 tube-wells in second phase (still ongoing) and out of which 2,52,214 (46.28%) tube-well waters have been found contaminated with arsenic.

The estimates of total population exposed to arsenic contaminated water by the DPHE, BGS and MML (1999) in phase-I is in the range of 18.5-22.7 million. But in phase-II, DPHE and BGS (2001) give two estimates of population exposure based on project population of 125.5 million in 1999. The total population exposed to arsenic contaminated water above 50 µg/L and 10 µg/L are estimated, using Kriging method, which are 32.5 million and 56.7 million respectively. Based on Upazila statistics the total population exposed to arsenic contaminated water above 50 µg/L and 10 µg/L are estimated as 28.1 million and 46.4 million respectively.

Health Effects

Arsenic is assumed to 12th most abundant element in biosphere, and said to be essential for some animal species. But any form of arsenic compound is no desirable for human consumption. The toxic effect of arsenic species mainly depends on their chemical form, route of entry, age, sex, dose and duration of exposure. The organic form of arsenic is several order of magnitudes less toxic to inorganic form. Again trivalent arsenic (As-III, arsenite) species are approximately an order of magnitude more toxic compared to the pentavalent arsenic (As-V, arsenate) species. The consumption of arsenic contaminated food and drinking water is the main concern of arsenic toxicity. Skin diseases are the common effects of arsenic poising. Long-term exposure to excessive arsenic generally causes change in skin pigmentation and hyperkeratosis, and promotes development of ulceration of skin, skin cancer and a number of internal (liver, bladder, kidney, etc.) cancer. But there is no well-established relationship between consumption of arsenic through drinking water. Using USEPA model and distribution of population exposed to different level of arsenic, Ahmed (2002) estimated the incidence of excess lifetime skin cancer for different level arsenic contamination of drinking water for the present total population of 129.25 million in Bangladesh. The incidences of excess skin cancer are 0.321%, 0.043% and 0.012% for drinking arsenic contaminated water at present level arsenic contamination, satisfying the Bangladesh Standard (50 µg/L) and satisfying WHO guideline value (10 µg/L) respectively. In BAMWSP (2001) study, the total number of identified arsenicosis patients are 1,139 (0.067% of the totals population surveyed) and 9,647(0.112% of the totals population surveyed) in phase-I and phase-II (ongoing) respectively.

Development of Water Supply Options in Arsenic Affected Areas

Arsenic toxicity has no known effective treatment, but consuming nutritious food and drinking arsenic free safe drinking water. Thus it very essential to develop arsenic free safe drinking water supply options, to minimize health hazards of arsenic poising, particularly for the rural population living in acute arsenic contaminated areas of Bangladesh, and the water supply options should be cost-effective. Depending on degree of arsenic contamination and availability of water sources, the water supply options may include:

? Treatment of arsenic contaminated water; and/or,

? Use of safe alternate sources of water, which is not contaminated with arsenic.

Treatment of Arsenic Contaminated Water

Various treatment methods exist that are capable of efficient removal of inorganic forms of arsenic from water. The following section provides a brief presentation of various methods.

Oxidation

Arsenic occurs in water in several different forms depending upon the pH and oxidation potential of the water. It is evident from different studies that arsenite (As-III) is difficult to remove from water using usually available treatment processes. So many treatment systems include an oxidation step to convert arsenite to arsenate (As–V). The commonly used oxidants are chlorine, ozone, permanganate, hydrogen peroxide and oxygen. The chemicals are more effective under wide range of conditions and air oxidation may take weeks to oxidize arsenite to arsenate. However, oxidation alone does not remove arsenic from solution and should be combined with removal processes.

Coagulation, Co-precipitation, Adsorption

This is the most commonly used treatment method of arsenic removal involving:

? alum coagulation;

- ? iron coagulation;
- ? lime softening; and,
- ? combined with iron (and manganese) removal.

Excellent arsenic removal is possible in coagulation and sedimentation/ filtration process either with ferric or aluminum salts if an oxidant is added. Alum coagulation is more effective to a pH of 7 or less, but iron precipitation is less sensitive to pH up to the value of 8.5 or less. Cheng etal (1994) reported 99% removal of arsenic in laboratory condition in coagulation process under optimal conditions, and residual arsenic concentration of 1µg/L. The best method to determine the types and dosages of chemicals for arsenic removal by coagulation/ flocculation is to conduct site-specific testing. In Coagulation process, arsenic is removed through following three main mechanisms (Edwards, 1994):

- ? precipitation;
- ? co-precipitation; and,
- ? adsorption.

Lime softening process can effectively remove arsenic at alkaline pH value of 11 or above. If an oxidant is added the efficiency of the process increases but removal efficiency is more sensitive to pH even with oxidant. Kartinen and Martin (1995) reported 80% removal of arsenic at pH 10.5 or above but the removal efficiency was very low (about 15%) up to pH=10.5. When chlorine is added the removal efficiency increased to 95% at pH=11.

A number of processes remove iron and/or manganese from water by oxidizing iron and/or manganese from their soluble state (e.g. Fe++) to a higher valance (e.g. Fe+++) to form precipitate. Therefore, arsenic can be co-precipitated with the naturally occurring iron and/or manganese. With the use of a number of chemicals, Kartinen and Martin (1995) reported 90% removal of arsenic in this process. Matthess(1981) reported in-situ oxidation of iron and arsenic in an aquifer containing high ferrous iron, high arsenite and low pH, where he injected 29 tons of potassium permanganate directly into 17 contaminated wells. This yielded a reduction of arsenic concentrations from 13,600 µg/L to 60 µg/L, where arsenite was oxidized and co-precipitated with ferric iron. Rott and Friedle (1999) reported the use of atmospheric oxygen to reduce arsenic concentration in-situ from approximately 20 µg/L to 5 µg/L, and this also lowered iron and manganese level.

Membrane

High pressure synthetic membranes such as nanofiltration (NF) and reverse osmosis (RO have pore sizes appropriate for removal of dissolved arsenic (both arsenite and arsenmate), which is in the metal ion size range. According to Waypa et al.(1997), NF membrane tested performed well comparably to the RO membranes, even the operating pressure was much lower (40-120 psi, compared to 200-400 psi). Membrane filtration requires relatively high quality influent water. Colloids, particularly organics; iron; and, manganese can foul it. In addition to arsenic it also removes other components. The main advantages of this technology are it has minimal operation and maintenance requirements, chemicals are not required and it produces no extra sludge. The main disadvantages of this system are this require high pressure, it is costly and water recovery rates are very low, often 10 to 20%. The low recovery rate is not major problem, particularly for the household system, where small amount of treated water is required for drinking and cooking purposes, and the remaining portion of water from this system can be used for other purposes.

Ion Exchange

It is adsorption process water passes through a column containing ion-exchange resins. Pre-treatment of these resins using sodium chlorides creates an abundance of chloride on the exchange sites. When arsenic-containing water passes through this resin bed, the chloride ions are exchanged for the arsenic ions that the water exiting the beds is lower in arsenic but higher in chloride than the water entering the bed. At exhaustion, the exchange site is loaded with arsenic, which can then be regenerated by passing concentrated sodium chloride solution through the column, usually in the opposite flow direction. The effectiveness of ion exchange process depends on the relative affinity of the resin for arsenic. In this process, sulfate ions compete with arsenic for the adsorption sites, and therefore, higher sulfate concentration in feed water results in shorter resin life. In low-sulfate waters, ion exchange resin can easily remove 95% of arsenate, and treat from several hundreds to over thousand bed volumes before arsenic breakthrough occurs (Johnston and Heijnen, 2001). Accordingly, USEPA recommends that ion exchange resins not be used in waters with > 120 mg/L sulfate or > 500 mg/L tital dissolved solids, and is more effective in waters with even lower sulfate level < 25 mg/L. Arsenite, being uncharged, is not removed and therefore, an oxidation step is needed as precursor to arsenic removal.

Activated Alumina
Activated alumina, a granular form aluminum oxide (Al2O3), with very high specific surface area (about 200 to 300 m2/gm) could remove arsenic from water. The mechanisms of arsenic removal are similar to those of a weak base ion exchange resin, and often collectively refereed to as 'adsorption', though ligand exchange and chemisorption are more appropiate term (Clifford, 1999). Arsenic removal is efficiency is excellent (typically > 95%), for both arsenate and arsenite, but arsenic capacity varies significantly, and is controlled by pH (Johnston and Heijnen, 2001). Arsenate removal capacity is the best in the pH range from 5.5 to 6.0, where the alumina surface are protonated, but acid ions are not yet concentrated enough to compete with arsenic for sorption site (Clifford, 1999, and Johnston and Heijnen, 2001). Phosphate and fluoride are sorbed by activated alumina, and therefore, their presence reduces the arsenic removal efficiency. Activated alumina can be regenerated by flushing with a solution of 4% sodium hydroxide, which displaces arsenic from the alumina surfaces (Johnston and Heijnen, 2001).

Overview of Arsenic Removal Technologies Used in Bangladesh

Although a number of treatment technologies exist that are capable of efficient removal of arsenic from water, but the socio-economic conditions that prevail in Bangladesh do not permit the implementation of most of them on the cost ground. In most cases, except few cities and towns, there is no centralized water supply system. Individual households or small groups have their own or community tube-wells. Therefore, solution to the problem of arsenic contamination, in most situations, in Bangladesh demands the development technology/ technologies that can be implemented at household or small community level relatively at a very lower cost. Recently a number of researches have been conducted to identify such novel technologies for arsenic removal to implement in rural isolated communities. A brief overview of some of these documented technologies is presented here.

Iron (and Manganese) Oxidation
Passive sedimentation
Since a large part of Bangladesh (about 65% areas) contains iron in excess of 2 mg/L and in many acute iron problem areas, the concentration of iron is as high as 15 mg/L, therefore, arsenic has been found to co-exists with iron in many situation. In such situation, arsenic can be removed by both co-precipitation and adsorption onto the precipitated $Fe(OH)_3$ by oxidation of this water during collection and subsequently storing them in household level. Mamtaz and Bache (2000) from their bench-scale tests demonstrated that arsenic can be removed by co-precipitation with naturally occurring iron but removal rate largely controlled by the arsenic concentration, the iron/arsenic ratio, and pH. It is evident from their test result that up to 88% of the arsenite in water could be removed by settlement over a period of 24h. Authors collected arsenic contaminated natural groundwater having very high iron content from Manikgonj area. Samples were shaken during the time of collection and transportation, and allowed to settle in the laboratory. This process removed more than 60% arsenic, where raw groundwater arsenic and iron concentrations were in the range of 150 µg/L to 713 µg/L and 8 mg/L to 14 mg/L respectively. The rapid assessment of this technology by BAMWSP, DFID and WaterAid(2001) showed that it failed to reduce arsenic to the desired Bangladesh standard for Drinking Water of 50 µg/L in most of their tested tube-wells.

In-situ oxidation
In-situ oxidation of iron and arsenic in the aquifer has been tested under DPHE-Danida Arsenic Mitigation Pilot Project where the aerated tube-well water is stored in a tank and then stored water is discharged into the aquifers through tube-well pipe under the pump head. Water collected by tube-well from such aquifers, followed by in-situ oxidation iron and arsenic, showed about 50% removal of arsenic.

Solar oxidation
In this process, transparent bottle containing water are exposed to sunlight for solar oxidation of arsenic in presence other oxidants like oxygen, followed by precipitation of arsenic with naturally occurring iron. Experiments in Bangladesh showed that the process on average could remove arsenic content of water to about one-third, and removal efficiency increased to about 45-78% when 50 µM citrate or 100-200 µL (4-8 drops) of lemon juice/L is added.

Arsenic and iron removal plants (AIRP)
The conventional small-community type iron removal plants (Fig.3), which operate on the principles of aeration of ferrous iron to convert them to ferric iron to co-precipitate arsenic. Groundwater drawn by hand tube-well drops into storage (aeration/ sedimentation) chamber for oxidation of iron and arsenic with air to co-precipitate. Water from storage chamber passes through filtration chamber due to the pressure head of aeration/ sedimentation chamber and subsequently collected into a storage tank for public uses. Filtration media comprises of brick chips, charcoal and sands. Filtration media is periodically (3 to 4 times a year) back washed, and sludge is collected in a holding pond. Iron and arsenic removal efficiencies of conventional arsenic and iron removal plants (AIRP) operating in small communities are shown in Table 1 (samples were

collected during January 2001). The average installation, operation and maintenance costs of such typical plant are presented in Table 3.

The DPHE, with support from Dutch Government, constructed 3 arsenic and iron removal plants for piped water supply system in small municipalities, where arsenic co-exits with iron in tube-well water. In these plants, groundwater is pumped over a series of cascades (Fig.4) to aerated water and then passes through filtration unit which removes iron and arsenic precipitates. Iron and arsenic removal efficiencies of 18-DTP (1999) arsenic and iron removal plants are shown in Table 2 (18-DTP, 1999). The installation costs of treatment unit and overhead tank is presented in Table 3. The operation and maintenance cost of this plant is presently not available.

Most of the AIRP plants shown here have good arsenic removal performance and have been treating water to the satisfactory level except in those areas, where arsenic concentrations are high. It is evident from field survey that these AIRP plants are well accepted by the community. Thus, some of the above described arsenic and iron removal plants have good potentials for small isolated communities and densely populated communities respectively where arsenic co-exists with iron at suitable concentrations.

Table 1 Iron and Arsenic Removal Efficiencies in Conventional AIRP

Location of AIRP Plant	Influent Fe, mg/L	Influent As, µg/L	Fe removal efficiency, %	As removal efficiency, %	As in treated water, µg/L
Manikgonj	15	540	93	90	54
Chadpur	8.9	808	92	84	129
Munshiganj	7.6	213	90	82	38
Barisal	10	456	92	80	91
Chadpur	7.6	260	84	78	57
Satkhira	6.6	188	87	77	43
Gopalganj	14	334	89	68	107
Chadpur	2.5	126	98	66	43

Table 2. Iron and Arsenic Removal Efficiencies in Three 18-DTP AIRP

Municipality	Influent Fe, mg/L	Influent As, µg/L	Fe removal efficiency, %	As removal efficiency, %	As in treated water, µg/L
Manikganj	7.6	85	99	72	24
Sathkhira Polash	5.8	68	95	67	22
Sathkhira Razzak	3.4	57	95	51	28

Bucket treatment unit

Bucket treatment unit developed by DPHE-Danida a project consists of two buckets (about 20 L capacity) placed. Chemicals (200 mg/L aluminum sulfate and 2 mg/L potassium permanganate) are mixed manually with arsenic contaminated water in upper bucket by vigorous stirring with a wooden sticks for about 30-60 seconds and then flocculated by gentle stirring for about 90 seconds. Mixed water is then allowed settle for about 1-2 hours and top supernatant is allowed to flow into the lower bucket via a plastic pipe and sand filter installed in the lower bucket. Although this technology perform well (with arsenic removal efficiencies in the range of 67% to 83%) in many situation but in some cases under rural operating condition it fails to remove to desired Bangladesh standard level. Presently, BUET modified the system and used 100 mg/L of ferric chloride and 1.4 mg/L potassium permanganate, and it perform very well with arsenic removal; efficiency up to 94%.

Steven Institute technology

This unit consists of two buckets. Chemicals (reported to be iron sulfate and calcium hypochloride) supplied in packets are mixed in one bucket and the mixture is transferred to another bucket to separate flocs by the processes of sedimentation and filtration. The second bucket has a second inner bucket with slits on the sides as shown in Fig. 5 to help sedimentation and keeping the filer sand bed in place. The rapid assessment of this technology by BAMWSP, DFID and WaterAid(2001) showed that this technology was effective in reducing arsenic levels to less than 50 µg/L in case of 80% to 95% of the samples tested.

Pitcher treatment

A pitcher filter unit (Fig.6) or small sand filters at the household level can clarify surface water containing impurities. This method of water purification was primarily in use by the rural people of Bangladesh. With the introduction of tube wells for village water supply these processes of water treatment have been phased out at household level. Pitcher filters are constructed by stacking number pitchers (Kolshis), one above the other, containing different filter media as shown in Fig. 6. Raw water is poured in the top pitcher and filtered water is collected from the bottom one. Other pitchers contain same filtration media, sands and brick chips. This system has been tried to remove arsenic from groundwater, collected from contaminated tube-wells. Sono 3-pitchers filter uses zero valent iron filling and coarse sand in the top pitcher, charcoal and fine sand in the middle pitcher. The bottom pitcher is used to store treated water. The arsenic removal efficiencies of this system are in the range of 59% to 95% but it depends on the maintenance of the system and the quality of water. But if batches are left for too long, dissolved iron concentrations become unacceptably high (Ramaswami et al, 2000). The rapid assessment of this technology by BAMWSP, DFID and WaterAid(2001) showed that this technology was effective in removing arsenic, but the system may be quickly clogged if groundwater contains excessive iron. Its initial installation cost is about US$ 4.5.

Activated Alumina

The mechanism of arsenic removal by this process has already been discussed. Water passes through the packed column of activated alumina, impurities present in water including arsenic are adsorbed on the surface of activated alumina grains. At some stage, the alumina becomes saturated and then exposing the medium to 4% caustic soda regenerates these. The residual caustic soda is then washed out and the medium is neutralized with a 2% solution of sulfuric acid rinse. Number activated alumina based sorptive media are used in Bangladesh including:

- BUET Activated Alumina
- Alcan Enhanced Activated Alumina
- Arsenic Removal Unit of Project Earth Industries Inc., USA
- Apyron Arsenic Treatment Unit

The rapid assessment of these technology by BAMWSP, DFID and WaterAid(2001) showed that BUET Activated Alumina and Alcan Activated Alumina are more effective in removing arsenic. BRAC, a non-government organization has experimented a number of alternative technologies including two Alcan Activated Alumina filter, and each unit costs about US$260 plus US$172 for media after every 120,000L of treated water.

Ion Exchange

Tetrahedron ion exchange resin filter tested under rapid assessment program in Bangladesh (BAMWSP, DFID and WaterAid, 2001) showed promising result in arsenic removal. The performance and applicability these arsenic removal units should be determined through closed field monitoring.

Membrane Technique

A nanofiltration process coupled with bicycle pumping system was examined by Oh et al (2000a) using arsenic contaminated tube-well water in rural area of Bangladesh. Arsenite was found to have lower rejection than arsenate in ionized form. Therefore low-pressure nanofiltration with pre-oxidation or reverse osmosis with a bicycle pump device can be used for the treatment of arsenic contaminated groundwater where electricity supply is not efficient or feasible. The capital and operational cost of this system is relatively high.

Other Arsenic Removal Technologies

To mitigate arsenic contamination problems in Bangladesh, number of organizations and industries have been trying to develop arsenic removal system and chemicals including:

- Bangladesh Council of Scientific and Industrial Research (BCSIR) Filter Unit
- DPHE-Danida Fill and Draw Unit
- Read-F Aresenic Removal Unit
- Sapla Filter
- Granet Home-made Filter
- Adarsha Filter
- Safi Filter
- Bijoypur Clay Filter
- Several Cartridge Filter
- Iron coated sand
- Granular ferric hydroxide
- Tourmaline mineral

The performance and applicability these arsenic removal units and chemical should be determined through closed field monitoring.

Alternative Water Supply Options

Groundwater

Arsenic free ground water is found mostly in the deep aquifers in Bangladesh except for very few places in the northwestern region. In case of tested water samples collected from deep-tube-wells (strainer depth >

150m), only 1% and 5% samples exceed the allowable limits of 50 µg/L and 10 µg/L respectively. Therefore, following technologies are adopted to extract arsenic free safe water from the respective aquifers in Bangladesh:

Deep Tube Well

Deep tube wells installed in those protected deeper aquifers are producing arsenic safe water. Two types of Deep tube wells are in use- one is small diameter ones and the other is the large diameter power operated tube wells. Since the aquifers in Bangladesh are stratified and the deep aquifers are separated from the shallow ones by impermeable layers so deep tube wells are employed to extract arsenic free water from that layer. In many places where the initially installed shallow tube wells are producing water with high arsenic content, deep tube wells are being installed as replacement but this is more expensive (see Table 3). This increases the probability of pollution of the deeper aquifers by percolation of arsenic polluted water to the deeper layers through the shrouding materials.

Reddish sand produces best quality water from the point of dissolved iron and arsenic content. Dhaka water supply is probably protected by its red coloured soil. Oxidation of iron on sand grains to ferric form produces the reddish colour of sand. Such sand does not release arsenic or iron in groundwater, rather ferric iron coated sand will adsorb arsenic from ground water. Hence, installation of tube well in reddish sand, if available, should be safe from arsenic contamination.

Shallow Shrouded Tube well (SST) and Very Shallow Shrouded Tube well (VSST)

These are low-cost handpump tube well technologies. These pumps have been designed and installed in the coastal areas. The SST/VSSTs can be convenient methods for withdrawal of fresh water in limited quantities. In many areas of Bangladesh, groundwater with low arsenic content is available in shallow aquifers composed of fine sand at shallow depth. But the depth of the aquifer and the particle size of soil are not suitable for installing a normal tube well. An artificial sand packing is required around the screen of the tube well to get water through these very fine-grained aquifers. This artificial sand packing is called shrouding. Shrouding increases the yield of the tube well and prevents entry of fine sand into the screen.

Dug Well

Dug well is the most traditional method of withdrawal of ground water. Dug wells are widely used in many countries of the world for domestic water supply. Usually no special equipment or skill is required for the construction of dug wells. In Bangladesh the wells are usually at least 1.2 metres in diameter. Larger diameter wells are constructed for community water supplies. Depth of the water table and its seasonal fluctuations determine the depth of the well.

Degradation of dug well water quality by bacterial contamination is very common. Percolation of contaminated surface water is the most common route of pollution of well water. Satisfactory protection against bacteriological contamination is possible by sealing the well top with a watertight concrete slab. Water may be withdrawn by installation of a manually operated handpump rather than the conventional bucket and rope, but the system is more expensive (see Table 3). Chlorination of the dug well is an effective means of disinfecting the water in the dug well. A large number of dug wells are found operating in the Chittagong hilly areas, Sylhet and northern parts of Bangladesh. Dug wells are not successful in many areas of Bangladesh having thick impermeable surface layer. In areas with thick clayey soil, dug wells do not produce enough water to meet the requirements.

Infiltration Gallery / Well

These are low-cost technologies. In this technology water is allowed to infiltrate through a layer of soil/sand and so it is significantly free from suspended impurities including microorganisms usually present in surface water. Infiltration Galleries can be constructed near perennial rivers or ponds. Again, surface water being the main source of water in the gallery/well, it is free from arsenic. If the soil is impermeable, well-graded sand may be placed in between the gallery and surface water source for rapid flow of water. Improvement of water quality requires good sanitary protection or disinfection by chlorinating.

Surface Water

Protected Ponds

A protected pond in a community can be the easiest source of water for drinking purpose with minimal treatment. Before and during early stage of installation of tube well, rural water supply was based on protected ponds. Lack of sanitary practices and absence of any sanitary protection have made the biological quality of water of these ponds very poor. Many of these ponds are made chemically and bio-chemically contaminated for fish culture. For improvement of quality of water surface discharges or polluting substances should be prevented from entering into protected pond.

Conventional Surface water Treatment Plant

This may include slow sand or rapid sand filtration process. Surface water is arsenic safe but often contain pathogenic organisms of immediate health concerns, and perennial water sources are not available in many places of Bangladesh. The investment cost is also high. The cost of surface water treatment plant in Hydropur is shown in Table 3.

Pond Sand Filters

Pond sand filters (PSFs, Fig.7) are basically slow sand filters for community water supplies. It is a package type slow sand filter unit used in the coastal areas of Bangladesh. It is developed to treat low-saline pond water for domestic water supply. Slow sand filters are installed near or on the bank of a pond, which does not dry up in the dry season. The water from the pond is pumped by a manually operated hand tube well to feed the filter bed, which is raised from the ground, and the treated water is collected through tap(s). It has been tested and found that the treated water from a PSF is normally bacteriologically safe or within tolerable limits. On average the operating period of a PSF between cleaning is usually two months, after which the sand in the bed needs to be cleaned and replaced. The PSF is a low-cost technology with very high efficiency in turbidity and bacterial removal. The treated water may require chlorination to meet drinking water standards. The average installation, operation and maintenance costs of a typical PSF are shown in Table 3.

Combine Filters

A combination of roughing filter and slow sand filter. It overcomes some of the difficulties encountered by PSF, which can not operate effectively if turbidity of surface water exceeds 30 mg/L. A combined unit of such filter is operating well in Samta village in Jessore district but remains idle during dry season when there is no water in the pond (AAN, RGAC and NIPSOM, 1999).

Household Filters

A pitcher filter unit (Fig.6) or a small sand filter at the household level can clarifies surface water containing impurities. This method of water purification was primarily in use by the rural people of Bangladesh. With the introduction of tube wells for village water supply these processes of water treatment have been phased out at household level. Pitcher filters are constructed by stacking number pitchers (Kolshis), one above the other, containing different filter media as discussed earlier. Raw water is poured in the top Kolshi and filtered water is collected from the bottom one. In this process, the mechanical straining and adsorption depending of the type of filter media used mainly clarify water. It is essential to avoid drying up of the filter bed. Full effectiveness of the filtration process is obtained if the media remain in water all the time. Experimental units constructed in Bangladesh and in other country show that the residual coliform bacteria present in the filtered water may vary from a few to several hundred. However, improvement of water quality by household filters is remarkable.

Rain Water Harvesting

Bangladesh is a country where water is available in abundance during the rainy season. There is heavy rainfall for about four months in a year and some form of precipitation for at least two more months. Thus rainwater harvesting comes as one of the major alternate source of water for drinking purpose. In some areas of the coastal region with high salinity problem, about 36 percent households have been found to practice rainwater harvesting in the rainy season for drinking purpose (Hussain and Ziauddin, 1989). In the present context, rainwater harvesting (see Fig.8) is being seriously considered as an alternative option for water supply in Bangladesh in the arsenic affected areas.

In the context of Bangladesh there are a number of advantages in favour of considering rainwater harvesting as an alternate technology. The quality of rainwater is usually good. However in the urban areas there might be degradation of the quality due to poor air quality and that needs further concentration for future research. Water is available at the point of demand and suitable for scattered settlements. Locally available manpower and physical resources can be utilised for development and construction of the plants. Since the water stored in the plant is situated at a higher elevation, no additional cost is involved for distribution or to send it to the users' end. There are however shortcomings regarding the quantity which is limited by the rainfall, and the system is expensive (see Table 3).

Solar Disinfection

This is a natural process of elimination of disease producing microorganisms using solar energy and can be applied to disinfect small quantity of water for drinking purpose. Water can not be used for drinking purpose if trace of pathogenic organism is observed. These organisms can be destroyed or inactivated by solar Disinfection. If solar radiation is allowed to penetrate in water in a thin layer, the water is disinfected by the combined action of ultraviolet ray and temperature. If water in a transparent bottle is exposed to full sunlight for about 5 hours the water is completely disinfected (EAWAG-SANDEC. 1998). The method is not suitable for treatment of large volumes of water containing high turbidity.

Solar Distillation

Solar distillation exploiting solar energy available in Bangladesh can be an effective method of treating contaminated water in crisis areas. The average yield of conventional solar desalination plant was about 1.4L/m2/day (Rahman, 1998). The water produced by this method is free from all chemicals including arsenic. This technology can not produce enough water at a reasonable cost. The system requires further development for cost effective use in water supply in rural areas.

Conclusions

On a critical analysis of the existing arsenic contamination problems and available water supply options that have been tried to mitigate this problem in Bangladesh, the following observations and conclusions are made.

Arsenic in groundwater above 50 µg/L (Bangladesh standard for Drinking Water) was found in 61 districts out of total 64 districts in Bangladesh. It is evident from the test results of 3,534 distributed water samples from 61 districts (except 3 hill districts) in an approximate grid of 6km x 6km that 27% tested samples collected from sallow tube-wells exceed the concentration of 50 µg/L and 46% tested samples exceed the concentration of 10 µg/L (WHO guideline value for arsenic in drinking water). In case of tested water samples collected from deep-tube-wells (strainer depth > 150m), only 1% and 5% samples exceed the allowable limits of 50 µg/L and 10 µg/L respectively. But this dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified.

The total population exposed to arsenic contaminated water above 50 µg/L and 10 µg/L are in the range of 28.1 - 32.5 million and 46.4 - 56.7 million respectively. The incidences of excess skin cancer are 0.321%, 0.043% and 0.012% for drinking arsenic contaminated water at present level arsenic contamination, satisfying the Bangladesh Standard (50 µg/L) and satisfying WHO guideline value (10 µg/L) respectively. The total number of identified arsenicosis patients, as indicated in BAMWSP (2001) study, are 1,139 (0.067% of the totals population surveyed) and 9,647(0.112% of the totals population surveyed) in phase-I and phase-II (ongoing) respectively.

It is apparent from this study that a remarkable development in arsenic removal technologies has taken during the last few years. These arsenic removal technologies mostly utilized principles of oxidation, precipitation/co-precipitation, adsorption onto sorptive media, ion exchange and physical separation by synthetic membranes. In many cases conventional technologies have been scaled down to suit them for the rural isolated households and communities to choose safe sources of water for drinking purpose.
The quality and quantity of water, reliability and convenience of collection of water from different water supply options presented here vary more widely.

This study revealed that a number of arsenic removal technological options have good potentials for their use in small isolated communities' and/ or municipalities, which depends on many factors including concentrations present before removal, speciation and co-occurring solutes. And in many situation, the use of alternate source of water as substitute to groundwater sources replace the contaminated tube-wells and ensure safe drinking water in arsenic contaminated areas in Bangladesh. But no single option can serve the whole cross-section of arsenic affected population in Bangladesh of diverse social and economic background.

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Table 3. Installation, operation and maintenance costs of selected presently operating water supply options

Technological option	Unit cost (US$)	Population served	Installation Cost (US$/person)	Operation and maintenance cost (US$/person/year)
Rainwater harvesting	106	5	21.2	0.34
Dug well	560	120 -150	4.0	0.01
Manikgonj AIRP including overhead tank	223,534	60,000	3.7	--
PSF	560	150 - 200	3.2	0.04
Small-community type AIRP	140	40 - 50	3.1	0.07
Deep tubewell	775	250 – 300	2.8	0.05
Surface water treatment plant	12,931	5,000	2.6	–
Shrouded tubewell	175	100-120	1.4	0.10
Shallow tubewell	105	120-150	0.8	0.06
Note: 1US$ = Bangladesh Taka58				

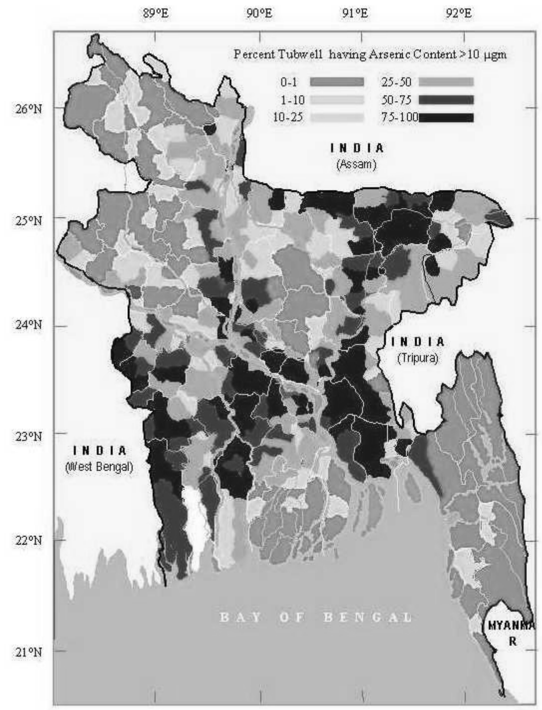


Figure 1. Intensity of Arsenic (As > 10) in Bangladesh

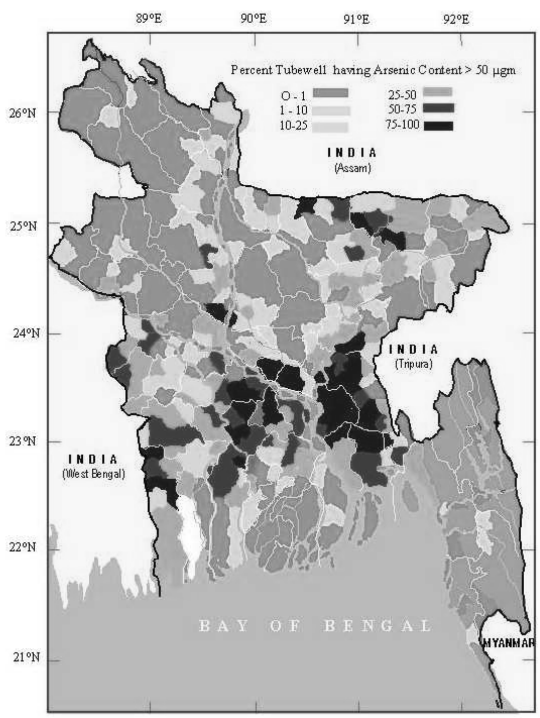


Figure 2. Intensity of Arsenic (As > 50) in Bangladesh

Figure 3. Small Community Type Arsenic and Iron Removal Plant

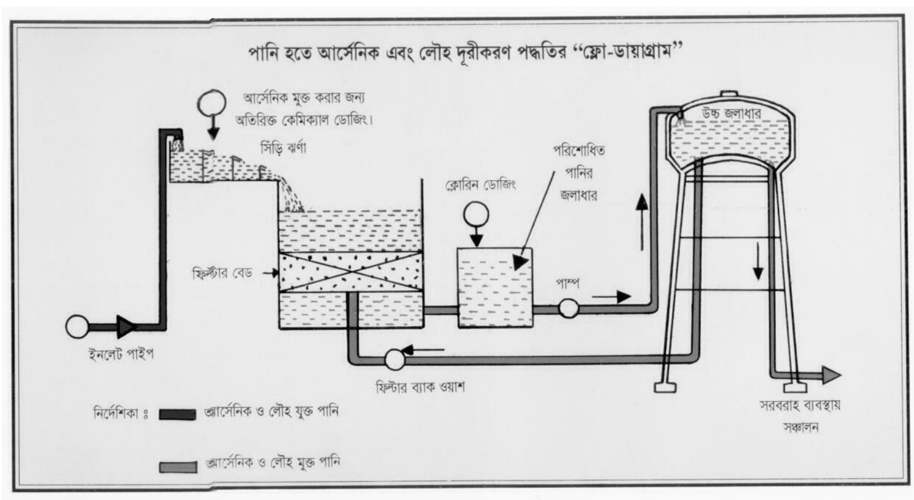


Figure 4. 18-DTP Arsenic and Iron Removal Plant

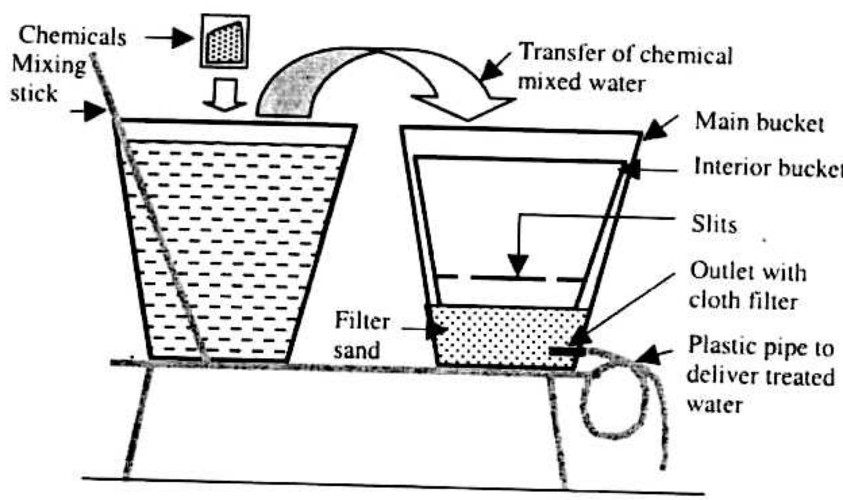


Figure 5. Stevens Institute Technology

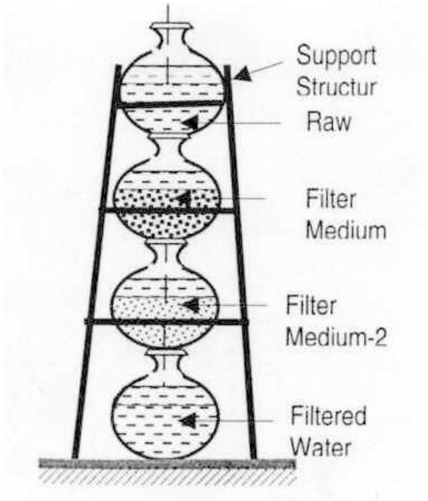


Figure 6. Pitcher Treatment Unit

Figure 7. Ponds Sand Filter

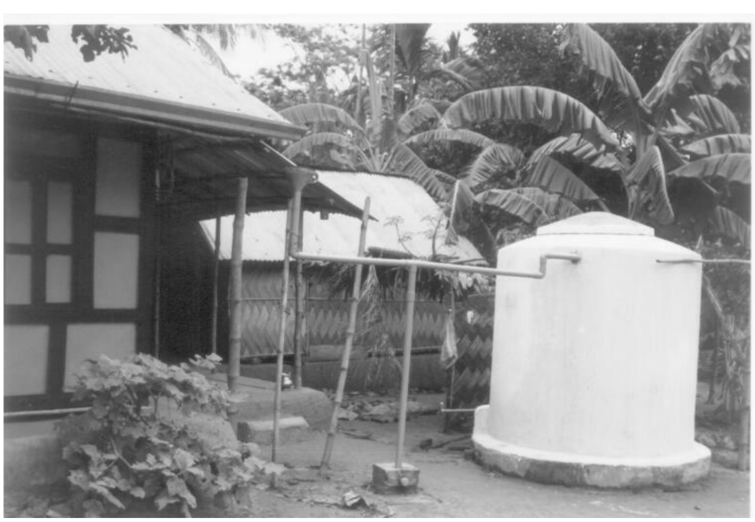


Figure 8. Rain Water Harvesting System

Risk Assessment of Skin Lesion Posed by Arsenic Contaminated Well Water in Shanxi, China

Zhang Qingxi[1], Zhang Yanping[2], Zhao, Baoxin

[1]Sanxi Center of Disease control, 0.3312, 28# Twin Towel Street, Taiyuan, Shanxi, China
[2]Taiyuan Anti-epidemic Station, 030012, 41# Xinjian South Road, Taiyuan, Shanxi, China

It has been 7 years since 1994 when we found the high-arsenic well water area located in 147 villages at Datong and Jingzhong basin belt which covered about 2000 km^2 and about 550,000 people are living within that ranges. Of them, about 100,000 people drink high-arsenic well water (arsenic concentration higher than 0.05mg/L). The overall investigation has been conducted for 5 years by researchers including epidemiologists, clinic doctors and health technicians. So far we have found 806 high-arsenic wells, diagnosed 5,897 patients. Among these patients light, moderate and serious skin lesions included skin hyperpigmentation and depigmentation, palmoplantal hyperkeratosis makes up 76.53%, 15.48% and 7.07% of the total respectively, hyperpigmentation, depigmentation and hyperkeratosis composed 68.49%, 39.97% and 18.42% respectively.

Arsenic Exposure and Population at Risk

We have collected environmental samples from well water, cereals, vegetables, soil and coal to determine the pollution sources. The result suggested: no other sources except well water with their arsenic concentration is higher than the background level. Arsenic concentration in well water ranges from 0.000 to 4.435 mg/L. The largest group well drops 0.10-0.20mg/L of arsenic concentration, which composed 34.57% of the high-arsenic wells. Concerning the exposed population, most people (98.34% of exposed population) fall in the range of 0.05-0.50mg/L, and the most seriously exposed group included 5 people, who are exposed to well water with high arsenic concentrations reaching 4.435mg/L.

Analysis of Dose-Response Relationship

The relationship between dosage of arsenic exposure and prevalence of arseniasis suggested the prevalence of serious case rose most sharply with the increasing of D (exposure dose, the comprehensive effect of both arsenic contaminated level and duration of arsenic exposure), then was the moderate one, the light one, however, went to the opposite direction, reducing its prevalence gradually with the increasing of D. We used polynomial curve fitted the relationship between D and total morbidity of skin lesion, the correlation coefficient was high at 0.9626.

Logitic regression results are listed in Table 1. The result suggests that all the regression equations are statistically significant. The comparison of standard estimates of ß revealed that exposure of arsenic has more serious effect on the hyperkeratosis prevalence when the degree of skin lesion was divided into three levels, but when we just focused on the total prevalence of different kinds of skin lesion, the biggest standardized estimate of ß belongs to hyperpigmentation.

We have conducted the study on the different effect posed by arsenic exposure on different population. The result suggested: arsenic exposure has more severe effects on children, then on female adults and then male adults. Considering the synergistic effect of smoking, we found there are greater effects during the lower dosage than higher one. But it has no statistic significance in the logistic regression equation when we introduced it as a co-variable.

Excess Case

According equation 4,8,12 and 16, combined with population exposure data, to calculate excess cases during life-time exposure in Shanxi province, the result is presented in Table 2.

Reference

Lu, Guocheng, 1992. Environmental and Occupational Quantified Risk Assessment. Beijing Medical University Press.

Table 1. Logitic regression analysis result

Skin lesion	Degree	f(d)	P	Standardized	P
hyperpigmentation	1 Light	Logit(P)=-5.4496+8.0E-05D	0.0001	0.3772	0.0001
	2 Moderate	Logit(P)=-2.9342+8.0E-05D			
	3 Serious	Logit(P)=-1.4620+8.0E-05D			
	4 Total	Logit(P)=-1.9425+1.82E-04D	0.0001	0.8545	0.0047
depigmentation	5 Light	Logit(P)=-3.9113+6.4E-05D	0.0001	0.2990	0.0004
	6 Moderate	Logit(P)= 2.3347+6.4E-05D			
	7 Serious	Logit(P)=-1.1 796+6.4E-05D			
	8 Total	Logit(P)=-1.6929+1.7E-04D	0.0001	0.8067	0.0063
hyperkeratosis	9 Light	Logit(P)=-4.9984+1.2E-04D	0.0001	0.5626	0.0001
	10 Moderate	Logit(P)=-3.2267+1.2E-04D			
	11 Serious	Logit(P)=-1 .6909+1.2E-04D			
	12 Total	Logit(P)=-1.9044+1.6E-04D	0.0001	0.7519	0.0085
total	13 Light	Logit(P)=-3.5473+9.1E-05D	0.0001	0.4247	0.0001
	14 Moderate	Logit(P)=-2.0412+9.1E-05D			
	15 Serious	Logit(P)=-1.0120+9.1E-05D			
	16 Total	Logit(P)=-1.2995+1.52E-04D		0.7145	0.0117

Table 2. The number of excess case during life-time exposure to high-arsenic well water

	hyperpigmentation	Depigmentation	Hyperkeratosis	Total
Excess cases	34599.11	42884.03	35768.58	59125.87
Percentage	12.54	15.54	12.96	21.42

A Speciation Study focused on the Identification of Proximate Toxic Arsenic Metabolites

Kazuo T. Suzuki
Graduate School of Pharmaceutical Sciences, Chiba University
Inage, Chiba 263-8522, Japan

Humans are exposed daily to arsenic mostly in the forms of inorganic arsenite/arsenate and organic arsenosugars/arsenobetaines of marine products. The former inorganic forms are more toxic than the latter organic ones, and are metabolized by consecutive reduction and methylation reactions in humans and mammals to dimethylated arsenic (DMA) (Scheme 1), which is then excreted into urine. The methylation process leading to DMA was believed to be the detoxification pathway, but recent studies document it as toxification pathway. However, the mechanisms underlying the acute and chronic toxicity of arsenic have not been explained from the viewpoint of the proximate toxic arsenic metabolites that cause the toxicity.

Trivalent arsenics (iAsIII, MMAIII and DMAIII) in Scheme I are more reactive to biological constituents than the pentavalent ones (iAsV, MMAV and DMAV) by forming conjugates through thiol groups on proteins and/or by producing reactive oxygen species/radicals. The arsenic metabolites in Scheme 1, therefore, may be present in free or bound to biological constituents, as divided into five groups in Table 1.

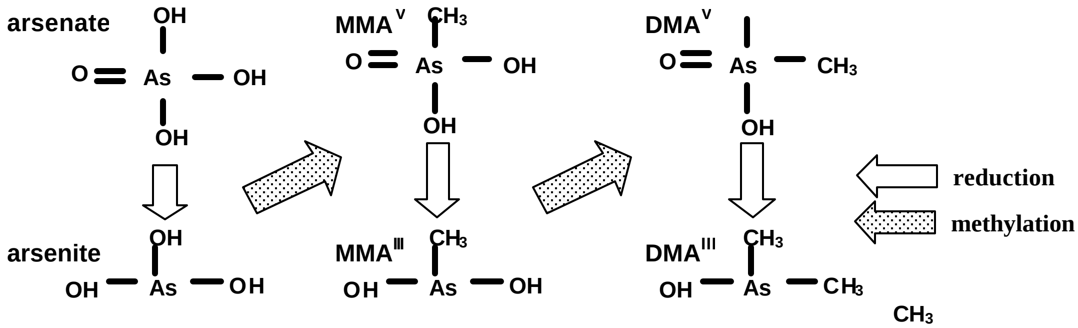
The toxicity of arsenic given in the form of arsenite is highly dependent on animal species, which certainly depends on the difference in the metabolism shown in Scheme 1.

The metabolic pathway for arsenic can be traced by detecting its chemical forms in organs/tissues and body fluids, most efficiently by the speciation study using a hyphenated technique such as HPLC-ICP MS. We have been successful in speciating the six arsenical in Scheme 1 simultaneously when they are present in free forms in the body fluids (urine and plasma) (A, B) and in the conjugated forms with glutathione (GSH) in bile (C).

Based on the speciation technique developed in our laboratory for free and GSH-conjugated arsenical, we revealed the precise metabolic pathway for arsenic in the tolerant animal species rats leading to the preferential accumulation in red blood cells (RBCs). Arsenite was effectively transformed to DMA in the liver and excreted into the bloodstream in the form of DMAIII, which is taken up and retained effectively in RBCs in rats. During the transformation in the liver, parts of iAsIII and MMAIII, but not DMAIII were excreted into the bile in the GSH-conjugated forms. Although arsenic is mostly excreted into urine in the form of DMAIII in rats with minimum excretion of other arsenic metabolites it was present in diverse forms in humans.
The chemical forms of arsenic in the organs/tissues are more complicated by conjugation of trivalent ones with biological constituents, as shown in Table 1 (D, E), and further sophisticated methods are required for their speciation to identify the proximate toxic arsenical for the acute and chronic toxicity.

Please refer to the PowerPoint presentation on page 45.

Scheme 1. Reduction and methylation reactions in the metabolism of arsenic



MMA^{V}: monomethylarsonic acid
MMA^{III}: monomethylarsonous acid
DMA^{V}: dimethylarsinic acid
DMA^{III}: dimethylarsinous acid

Table 1. Separation and subsequent analytical procedures for arsenic in the body

Soluble	
Free	
Pentavalent arsenic	**A**
(iAs^{V}, MMA^{V}, DMA^{V})	
Trivalent arsenic	**B**
(iAs^{III}, MMA^{III}, DMA^{III})	
Conjugated	
Trivalent arsenic – GSH	**C**
($iAs^{III}(GS)_3$, $CH_3As^{III}(GS)_2$, $(CH_3)_2As^{III}(GS)$)	
Trivalent arsenic - soluble proteins	**D**
Non-soluble	
Conjugated	
Trivalent arsenic - non-soluble proteins	**E**

A, B: Free arsenic can be speciated simultaneously on an anion or cation extern column by HPLC-ICPMS.
C: Trivalent arsenic conjugated with GSH can be speciated simultaneously on an anion exchange column by HPLC-ICPMS.
D: Trivalent arsenic conjugated with thiol groups of soluble proteins can be characterized on a gel filtration column by HPLC-ICP MS. However, the arsenic species and the corresponding protein have to be identified separately.
E: Trivalent arsenic conjugated with non-soluble proteins is not applicable to HPLC separation. The arsenic species can be identified after separation to free arsenic.

Policy Development for Arsenic Mitigation in Bangladesh

M. Feroze Ahmed
Civil/Environmental Engineering
Bangladesh University of Engineering and Technology
Dhaka-1000
Bangladesh

Groundwater based water supply programs that provided 'safe' drinking water in order to control diseases like diarrhoea, dysentry, typhoid, cholera and hepatitis have exposed population to arsenic related health problems in the affected areas. The population exposed to different levels of arsenic from drinking water has been computed and presented in Figure 1. The estimated total number excess lifetime skin cancer risk at present level of contamination of drinking water as shown in Figure 1 is 415,100, which is 0.321% of the population of Bangladesh. Arsenic toxicity has no known effective treatment, but drinking arsenic-free water can help affected people at early stage of ailment to get rid of the symptoms of arsenic toxicity. In order to reduce the high risk of arsenicosis, the government of Bangladesh has put greater emphasis on supplying arsenic safe drinking water to population exposed to high levels of arsenic, which involve policy development for successful implementation.

Considering the geographical distribution of contaminated tubewells, levels of contamination and density of tubewells in the country, the guiding policy decision for safe water supply includes provision of alternative water supply satisfying the Bangladesh Standards for drinking water in areas having more that 40% tubewells contaminated with arsenic. It involves motivation of the population in areas with less than 40% tubewells to use a nearby arsenic safe source of water supply. This policy decision is likely to reduce the areas of intervention from 249 Upazilas (Sub-districts) with contaminated tubewells to 119 Upazilas.

The country is broadly divided into different hydrological and hydrogeological areas requiring technological variations. No single option can serve all areas and people having different social and economic conditions. Again choices of the communities are to be given priority in the selection of technological options. Considering all these factors, alternative water supplies for arsenic mitigation are to be provided under following three categories:

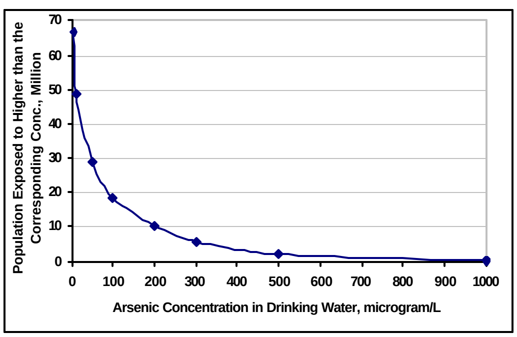


Figure 1 : Population exposed to different levels of arsenic from drinking water

Emergency Water Supply

In acute arsenic problem areas, an alternative safe water point appropriate in the area is to be provided in each village on an urgent basis following ongoing national screening program. The arsenic safe water point to be developed using an appropriate alternative option from those listed under short-term water supply to provide adequate water for drinking and cooking purposes.

Short-term Water Supply

In areas with more than 40% tubewells contaminated, water supply will be provided by any of the following technological options as found appropriate in the location from technical, social and economic considerations:

- Deep tubewell;
- Dug/Ring well;
- Rainwater harvesting;
- Treatment of surface water;
- Treatment of arsenic contaminated water.

Long-term Water Supply

The long-term option is to provide arsenic-safe water using proven safe and sustainable technologies implemented under short-term options. The ultimate long-term goal is to provide piped water supply.

An institutional arrangement with greater role of Local Government is needed for installation, operation and maintenance of alternative water supply options and monitoring of water quality at the local levels with technical assistance from Department of Public Health Engineering. Local Communities must be facilitated and empowered to make informed choices and undertake planning, implementation and management of safe water options. The NGOs should play a vital role in this process. The Private sector can play a key role in implementation of safe water options and interacting with the end users including provision of safe water through development of innovative, enterprising solutions and financing of well monitoring.

Capacity development at the local and community level, which includes technical capacity for installation, operation, maintenance and monitoring should be a key element of the national policy. Institutional capacity development for the regulatory functions and monitoring should be undertaken by the Central Government (Ministry of LGRD and Cooperatives). This should also include the capacity for information management and reporting. Knowledge and information base should be managed centrally to ensure transparency of the implementation process and accessibility of information to all stakeholders. Centers of excellence on relevant research on safe water options should be developed. These centers should focus on existing information and knowledge leading to identifying and conducting research on key areas.

Linkages of Short- and Long-term Policy Measures

Zafar Adeel
Environment and Sustainable Development Programme
United Nations University
Tokyo 150-8925, Japan

The pollution of groundwater, particularly drinking water, by arsenic has evolved as a major problem of tremendous dimensions throughout Asia. The arsenic pollution crisis is most severe in Bangladesh and India (West Bengal), but significant populations in China, Nepal, Pakistan, Thailand and Viet Nam, as well as several Latin American countries, are at risk. The number of people potentially impacted by this crisis is far greater than that for any other individual problem facing humanity today.

It is a complex problem, involving both technological and policy challenges, whose solution requires clear thinking and a comprehensive strategic response. This strategy has to explicitly involve short- and long-term measures. This paper highlights some of the considerations and linkages between the two levels of strategies.

The most obvious short-term measure is the provision of “safe” water to the affected population. “Safe” means drinking water that is arsenic-safe (at either national drinking water standards or WHO guidelines) and is free from chemical or microbiological contamination. A number of options for this are available at hand. Providing immediate medical support for the recognized patients is also a short-term measure.

Because a number of key sectors can be affected at the national scale, long-term measures have to be carefully designed and evaluated. These sectors include public health, water resources, agriculture, social welfare, and national economy.

Long-term measures should include significant development of the public health sector to cope with the long-term consequences of the large population exposed to arsenic-polluted water. Training and capacity development in remote and rural areas becomes a key concern. These measures should also address provision of water supply to affected areas in the context of a broader water resource management policy.

Welfare of the affected population and providing them sufficient social support is a key element of long-term policies. This should include awareness raising of the general public as well as providing them information about how to cope with the arsenicosis-related problems on a day-to-day basis. Having such social support would also entail long-term capacity development of in the social welfare sector.

Significant level of research and investigation is required to fully understand the impacts of the arsenic crisis on agricultural sector. Because the economies in the Asian region are largely agriculture dependent, the potential impacts on the economy can also be significant.

These long-term policies should be designed with an eye towards a gradual and progressive transition from short-term and emergency measures. Under ideal circumstances the national sustainable development framework would provide the basis for such integration. In the absence of such a framework, national governments have to establish specialized institutional arrangements that will ensure effective implementation of these strategies.

Please refer to the PowerPoint presentation on page 53.

Preventive Policy against Hazardous Effects of Drinking Arsenic-Polluted Well Water in Shanxi, China

Feng, Lizhong
Shanxi Heath Bureau,
People's Republic of China

Purpose

To research the characteristics of morbidity and the distribution pattern of endemic arsenism due to drinking water with high arsenic contamination.

Method

Analyzing the data from general investigation, clinical examination as well as intervention trials.

Results

The area with high contamination of arsenic in well water (arsenic concentration of higher than 0.05mg/l) is about 2000 km^2 where 100,000 people are living in 79 villages with high-arsenic contamination. In this area, about 5,000 patients with typical symptoms of arsenic poisoning have been found, with showing the trends of family accumulation. The morbidity increases with age, but does not differ between men and women. The skin lesions are different among different endemic districts. The peripheral nerve lesions are also significantly different ($p<0.01$). The cancer mortality in the disease areas has been several times higher than those in other areas. Arsenic concentrations of well water could be related to local geological structure as well as hydrogeology conditions.

Conclusions

The high dosage of and long exposure to arsenic through drinking well water are associated with high prevalence and severity of the related disease symptoms in disease areas of Shanxi province. But it should be emphasized that the comprehensive measurements of treating water for tackling the disease have been so effective that the morbidity rate has recently been decreasing.

Please refer to the PowerPoint presentation on page 59

Community Participation and Water Supply in Arsenic Affected Areas: A Case Study from Rural Bangladesh

Bilqis A. Hoque[1], M.M. Hoque, R. Collard, T Ahmed, S. Islam, A. Azad,
A. Mahboob, Haq A

[1]Environment and Population Research Center – EPRC
Dhaka, Bangladesh

Drinking safe water is a basic need and is a right of all the people. Since the International Conference on Primary Health Care in 1977 the United Nations Organizations and the international organizations are undertaking noticeable global and local efforts to make safe water accessible to the people. Bangladesh showed remarkable results in access to safe water during the last 2 decades; more than 90% of its people changed drinking water practice from heavily contaminated surface water to tube wells. There are millions of tube wells in Bangladesh. Almost all the tubewells are maintained by the people and more than two-third of those were installed through private and/or non-government initiatives. So the people/community have appreciably participated in the drinking water system. Unfortunately, the contamination of groundwater by arsenic has challenged millions of the people once again. Although extensive national and international initiatives are addressing arsenic mitigation, very limited achievement has been made in supply of safe water. Here we present the results from a preliminary action research project which indicates that there is a scope for effective community participation development in sustainable safe water supply.

About 12,000 people out of approximately 30,000 rural people of Srinagar were supplied with safe water during a 14-month action research project (October !999 to November 2000) of Rotary International and Environment and Population Research Center. The purpose of this project was to supply safe water based on community capacity building, people's choice and community participation in addressing their problem.

Community (local leaders and volunteers people) participated in planning, tubewell testing, creating awareness, water option selection, installation of the options, operation and maintenance of the options and sharing of the costs. About 90% of the tested water samples from approximately 1,100 tubewells showed higher than 0.05 mg/l arsenic concentration in water. Various arsenic removal options (three-kalshi filtration, emergency GARNET filter and Siedko Plant), pond sand filter, household based rain water harvesting and deep tube wells were promoted. About 500 people agreed to install the arsenic removal options and the rest selected deep tubewells with and without piped water connections.

There were about 20 household-based options and 8 community based options. The people shared about 30% of the tubewell testing and installation costs. There was high demand for piped water system. The local Government Union Chairmen provided the overall leadership while small local committees carried out all the responsibilities related to installation, fund collections and O & M of the options. The arsenic removal options were gradually abandoned by the people as the deep tubewells based options became accessible. The people did not appreciate the operation and maintenance requirements of the arsenic removal options. During a visit to the site in November 2002, it was observed that the people were satisfactorily using the piped water systems.

We strongly recommend that community capacity development and people's choice based community participation should be incorporated in arsenic mitigation. There is a need for further action research on appropriate and sustainable water options, in addition to strategic studies on community involvement. The implementing agencies should develop and maintain improved effective mechanism for interaction between them and research communities in addressing the problem.

Summary of Panel Discussion

Panelists: Prof. Feroze Ahmed (BUET), Dr. Han Haijnen (WHO), Dr. Bilqis A. Hoque (EPRC), Dr. Michinori Kabuto (NIES), Dr. Yasumoto Magara (Hokkaido University), and Prof. Motoyuki Suzuki (UNU).

Moderator: Dr. Zafar Adeel (UNU)

Summary

The key points raised in the commentary by the panelists and the ensuing discussion by the workshop participants are summarized here. The panelists emphasized the key challenges in dealing with the regional arsenic problem:

a. the availability and flow of information on the arsenic crisis is not sufficient and needs to be improved;
b. the low level of education in the people typically affected by the arsenic crisis limits the effectiveness of remedial actions;
c. the political will and governmental involvement in remedial actions often do not reach a desirable level; and
d. the remedial and treatment options offered to people often face an affordability constraint as the affected people typically live below the poverty line.

In consideration of these challenges, there were five broad areas of action identified:

1. *Quantifying the human intake of arsenic*: It was identified that arsenic can enter the body through various routes which can be food-based, water based, or air-based. The point was emphasized when considering the Chinese case where arsenic is suspected to enter the body through both food intake and air inhalation. There is a need for conduct further research to fully understand and quantify the intake of arsenic. This must also be linked to efforts to reduce the overall arsenic body burden; this has to be an essential element from a public health improvement perspective.

2. *Risk acceptability*: Once the arsenic body burden is quantified, a better risk assessment can be undertaken. This risk assessment must integrate the relative risks through various routes of exposure to arsenic. Such risk assessments and acceptability of a specific health risk are typically undertaken by national governments, but it is useful to find ways to engage the general public and the research community in this process.

3. *Development of quality standards*: The drinking water and ambient air quality standards for arsenic should cater to the local needs in Asia. This again would require a participatory approach in identifying the risk level that correlates to a particular quality standard. The new approach undertaken by the World Health Organization (WHO) in developing drinking water quality guidelines was appreciated as a step in the right direction.

4. *Effective information exchange mechanism*: The panelists highlighted the need for developing an information exchange mechanism that is transparent and widely accessible. Such effective mechanism is essential to coordinating and harmonizing remedial efforts. At the same time, it can be an important tool in warehousing research output and prioritizing key research areas.

5. *Development of a long-term perspective*: It was emphasized by the panelists that a long-term perspective in developing remedial options is a must. The long-term sustainability of these options and their acceptance by the affected population must be fully considered.

Workshop Programme

09:00-09:15	Opening Remarks - Prof. Motoyuki Suzuki (Vice Rector, UNU)

Keynote Speakers

09:15-10:00	Key Issues for Arsenic Crisis and an Approach for its Remediation: West Bengal (India) Experience - Dr. Dipankar Chakraborti (Jadavpur University, India)
10:00-10:45	The Chinese Experience in Dealing with Arsenic Contamination in Groundwater - Dr. Jin Yanlong (Chinese Academy of Preventive Medicine - CAPM, China)
10:45-11:15	*Coffee Break*

First Session:
Technological and Human Health Dimensions of the Arsenic Problem

Chairpersons:	Dr. Han Haijnen (WHO) and Dr. Hiroshi Yamauchi (St. Marianna Medical University, Japan)
11:15-11:35	Fate of Arsenic in the Environment - Prof. Ashraf Ali (BUET, Bangladesh)
11:35-11:55	Arsenic Contamination of Groundwater in Bangladesh and Its Remedial Measures - Dr. Habibur Rahman (BUET, Bangladesh)
11:55-12:15	Technological Issues in Arsenic Monitoring - Dr. Masanori Ando (NIHS, Japan)
12:15-12:35	Risk Assessment of Skin Lesions Posed by Arsenic Contaminated Well Water in Shanxi, China - Dr. Zhang Yanping (Taiyuan CDC, Shanxi, China)
12:35-12:55	A Speciation Study Focused on the Identification of Proximate Toxic Arsenic Metabolites - Dr. Kazuo T. Suzuki (Chiba University, Japan)
12:55-14:30	*Lunch*

Second Session:
Policy Dimensions of the Arsenic Problem

Chairpersons:	Prof. Kazuo Yamamoto (Univ. of Tokyo, Japan) and Dr. Roy K.Boerschke (World Bank)
14:30-14:50	Policy Development for Arsenic Remediation in Bangladesh - Prof. Feroze Ahmad (BUET, Bangladesh)
14:50-15:10	Linkages of Short- and Long-term Policy Measures - Dr. Zafar Adeel (UNU, Japan)
15:10-15:30	Preventive Policy against Hazardous Effects of Drinking Arsenic-Polluted Well Water - Dr. Feng Lizhong (Shanxi Health Bureau, China) and Dr. Jin Yinlong (CAPM)
15:30-15:50	Community Participation and Rural Water Supply in Arsenic Affected Areas: A Case Study from Rural Bangaldesh - Dr. Bilqis A. Hoque (Environment and Population Research Center - EPRC, Bangladesh)
15:50-16:30	*Coffee Break*

Panel Discussion and Formulation of Recommendations

16:30-18:00	Panelists: Prof. Motoyuki Suzuki (UNU), Dr. Han Haijnen (WHO), Prof. Feroze Ahmad (BUET), Dr. Bilqis A. Hoque (EPRC), Dr. Michinori Kabuto (NIES), Dr. Yasumoto Magara (Hokkaido University)
Moderator:	Dr. Zafar Adeel
18:00-18:15	Closing Remarks - Dr. Soichirou Iwao (Director of Environmental Health, Ministry of Environment)

Workshop Participants

Dr. Zafar Adeel
Academic Programme Officer
Environment & Sustainable Development
The United Nations University
5-53-70 Jingumae, Shibuya-ku
Tokyo, Japan 150-8925
Tel: + 81-3-3499-2811
Fax: +81-3-3406-7347
Email: Adeel@hq.unu.edu

Prof. M. Feroze Ahmed
Civil/Environmental Engineering
Bangladesh University of
Engineering and Technology
Dhaka-1000
Bangladesh
Tel: +880 (-2) -9663693
Fax: +880 (-2) –9663695
Email: itn@agni.com

Dr. M. Ashraf Ali
Assoc. Prof.
Civil/Environmental Engineering
Bangladesh University of
Engineering and Technology
Dhaka-1000
Bangladesh
Tel: +880 (-2) -8614640 , ext. 7625
Email: ashraf@bdcom.com

Dr. Masanori Ando
Division of Environmental Chemistry
National Institute of Health Sciences
1-18-1 Kamiyoga
Setagayu-ku
Tokyo 158-0098, Japan

Dr. Dipankar Chakraborti
Director and Head
School of Environmental Studies
Jadavpur University
Calcutta – 700 032, India
Tel: 91 33 4735233
Fax: 91 33 4734266
Email: dcsoesju@vsnl.com

Dr. Han Haijnen
Environmental Health Advisor
WHO – Bangladesh
Dhaka, Bangladesh
Tel: (880 2) 9343372
Fax: (880 2) 8613247
Email: whosani@citechco.net

Dr. Bilqis A. Hoque
Environment and Population
Research Center – EPRC
Dhaka, Bangladesh
Email: eprc@bol-online.com

Dr. Soichiro Iwao, MD, MPH, Ph.D.
Director-General
Environmental Health Department
Japan Ministry of Environment
Tokyo, Japan

Dr. Libor Jansky
Senior Academic Programme Officer
The United Nations University
5-53-70 Jingumae, Shibuya-ku
Tokyo, Japan 150-8925
Fax: +81-3-3406-7347
Email: Jansky@hq.unu.edu

Dr. Minichinori Kabuto
Acting Director for Health Researches
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki, JAPAN
Tel: +81-298-50-2333
Fax:+81-298-50-2571
Email: kabuto@nies.go.jp

Dr. Feng, Lizhong
Shanxi Heath Bureau, Shanxi Province
People's Republic of China

Dr. Yasumoto Magara
Professor, Environmental Risk Engineering
Graduate School of Engineering
Hokkaido University
060-8628 Kita 13 Nishi 8 Kita-ku
Sapporo, Japan

Dr. Gen Ohi
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki
305-8506 Japan

Dr. Habibur Rahman
Bangladesh University of
Engineering and Technology
Dhaka-1000, Bangladesh
Email: habibr@ce.buet.edu

Ms. Yuko Sato
Visiting Fellow, Institute of Advanced Studies
The United Nations University
53-67, Jingumae 5-chome, Shibuya-ku,
Tokyo 150-8304, Japan
Tel: +81-3-5467-2811
Fax: +81-3-5467-2324

Prof. Motoyuki Suzuki
Vice Rector,
Environment & Sustainable Development
The United Nations University
5-53-70 Jingumae, Shibuya-ku
Tokyo, Japan 150-8925
Fax: +81-3-3406-7347
Email: Suzuki@hq.unu.edu

Dr. Tsuguyoshi Suzuki
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki
305-8506 Japan

Chiho Watanabe, Ph.D.
Associate Professor,
Department of Human Ecology
School of International Health,
Graduate School of Medicine
The University of Tokyo
7-3-1 Hongo
Bunkyo-ku, Tokyo 113-0033, Japan
Phone: +81-3-5841-3487;
Fax: +81-3-5841-3395
e-mail: chiho@humeco.m.u-tokyo.ac.jp

Dr. Sombo T. Yamamura
Visiting Fellow, Institute of Advanced Studies
The United Nations University
53-67, Jingumae 5-chome
Shibuya-ku, Tokyo 150-8304
Japan
Tel +81-3-5467-2811
Fax +81-3-5467-2324
Email : yamamura@ias.unu.edu

Dr. Hiroshi Yamauchi
Associate Professor
St. Marianna Medical University
School of Medicine
Department of Preventive Medicine
2-16-1 Sugao, Miyamaeku, Kawasaki-shi
Kanagawa 216-8511, Japan
Tel/Fax: 81-44-977-0268
Email: h2yama@marianna-u.ac.jp

Dr. Jin Yinlong
Director,
Institute of Environmental Health & Engineering
Chinese Academy of Preventive Medicine
29 Nan Wei Road, Xuan Wu District
Beijing 100050
People's Republic of China
Tel: 86-1-6317-5273
Fax: 86-1-6317-5273
Email: jiniehe@public.bta.net.cn

Dr. Zhang Yanping
Centre for Disease Control
Taiyuan Anti-epidemic Station, 030012,
41# Xinjian South Road, Taiyuan
Shanxi
People's Republic of China

Appendices – Selected Workshop Presentations