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**Titulo de la ponencia:** *Drinking water crisis due to arsenic contamination in Bangladesh: public health consequences, mitigation strategies and sustainability*

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**Resumen**
Access to safe drinking water is a fundamental right and indispensible for healthy life. Although Bangladesh has a plenty of surface and underground water, unfortunately water-borne diseases in surface water and recent arsenic contamination in underground (ACU) water have posed a great challenge. Presently, 97% of the rural population drinks underground water through millions of hand-pump tubewells.

Long term exposure to excessive level of arsenic (>0.05 mg/l) is highly toxic and affects all organs and systems of the body. An array of adverse health outcomes is associated with drinking arsenic contaminated water (DACW). Continuous use of DACW may increase the risk of several cancers e.g. skin and liver. Higher concentration of arsenic was first indentified in 1993 and it is estimated that 35 million populations are at risk of DACW in Bangladesh. Several thousands of arsenicosis patients have already been identified with the prospects of rapid increase in the future.

To provide arsenic-free drinking water in affected areas, the Bangladesh government in cooperation with international and national organizations has already tested several alternative options, but none of them was found to be feasible and sustainable of the grounds of acceptance, maintenance, cost and health concerns. However, some prevention strategies based on significant factors associated with DACW could improve the overall situation. Briefly this paper provides a comprehensive overview about ACU water, sources of contamination, health consequences, mitigations, preventions, and implications for Bangladesh.

**Palabras clave:** Drinking underground water, arsenic contamination, health consequences, prevention strategies, Bangladesh

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## Introduction

Provision of safe drinking water and the effective removal of bodily waste are vital for human health and well-being (Watson, 2006). Unfortunately about 3.4 million people die each year from different illnesses such as cholera, dysentery, and malaria associated with contaminated water (Watson, 2006). Although access to safe drinking water is a fundamental human right (Watson, 2006) and providing such a facility is also an important national goal in Bangladesh like other developing countries (Hoque et al, 2006, 137; Hoque et al, 2004), ironically many populations in both urban and rural areas of Bangladesh have been facing difficulties in getting such a quality water. Bangladesh has a plenty of surface and underground water (Safiullah 2006; Hoque et al, 20000) because it is mostly a flat deltaic land formed by the motor action of the great Himalayan rivers- the Ganges, Brahmaputra and Meghna (Safiullah, 2006). Unfortunately both surface and underground water are highly contaminated in Bangladesh and pose a great challenge to the nation particularly from the public health point of view. Water-borne diseases namely diarrhoea and cholera are still the major killers of infant and child mortality in this populous nation consisting of approximately 145 million populations living in 145,000 square kilometers only.

This article will provide comprehensive information about switching from the surface to underground water around 1970s followed by arsenic contamination, possible sources of contamination, health consequences of drinking arsenic contaminated water for a long time including social problems associated with arsenicosis patients, mitigation activities in relation to arsenic-free alternative water sources including their feasibility and sustainability, and other prevention strategies. Available scientific literature including books and other gray literature were used to prepare this article.

## Switching from surface water to underground water in Bangladesh

An overview regarding drinking water in Bangladesh is depicted in Figure 1. Until around the 1970s, people of Bangladesh used to use surface water for drinking and cooking purposes. As that water was highly polluted by many sources including micro-organisms, both infant and child mortality was very high, mostly attributed to water-borne diseases such as diarrhoea, cholera, and dysentery (Spallholz et al, 2004; Caldwell et al, 2003). To reduce the incidence of such diseases including childhood mortality, in 1971 the World Bank and United Nations Children's Fund (UNICEF) began addressing the problem of surface water contamination and motivating people to sink tube wells into the underlying aquifers of Bangladesh which were free from micro-organisms causing water-borne diseases (Jones, 2007; Spallholz et al, 2004). Initially it was difficult to bring a change in their usual habits of using surface water. Therefore, extensive technical, social, financial and motivational efforts at local and international levels were also given to turn them from the surface water to underground water practice (Hoque et al, 2000). Due to these endeavors, people started to drill tube wells into underground aquifers to have microbiologically clean water (Spallholz et al, 2004).

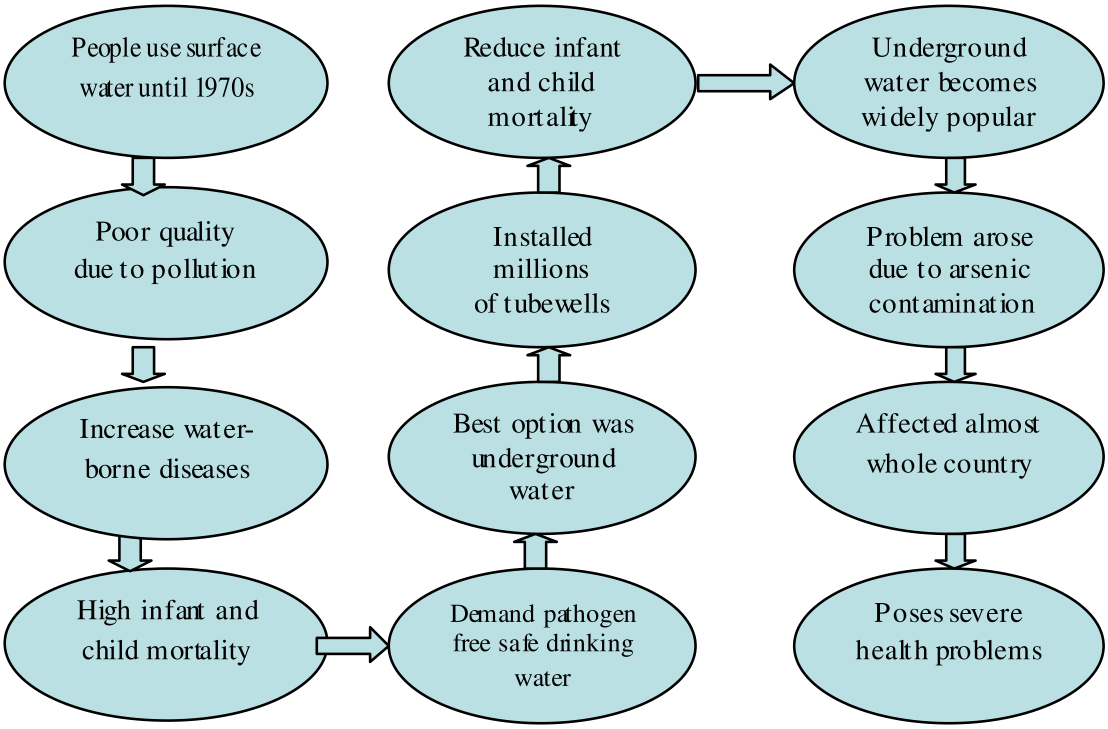


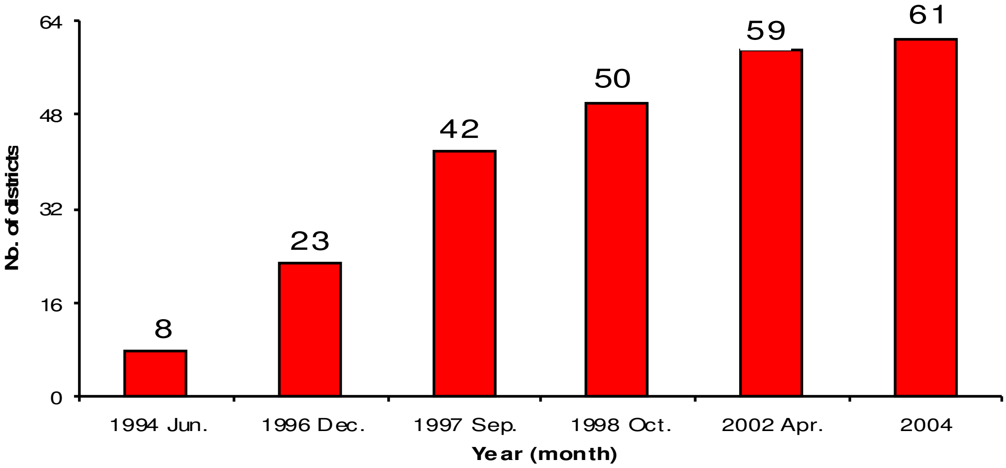

Figure 1: Water consumption before and after 1970 in Bangladesh

Presently at least 10 millions tube wells are functioning and about 97% of the rural population is using pathogen-free underground water (Caldwell et al, 2003, 260). Tubewell (Figure 2) is a 2-inch (5.08 cm) metal pipes with an attached hand pump that are drilled to underground to access aquifers (Jones, 2007). The depth of the tubewell varies, although most of the tubewells use shallow aquifers. People adopted this option because underground water has obvious advantages over surface water often contaminated by micro-organisms (MacDonald, 2003). This option is also very popular because most of the families irrespective of socio-economic status can afford the cost. The tubewell saves time and is easy to maintain.

Figure 2: Tubewell used in Bangladesh

According to recommendation of the World Health Organization (WHO), the maximum permissible level of arsenic in drinking water is 0.05 mg/L in Bangladesh, although for many other countries this limit is 0.01 mg/L (Khan et al, 2007). Based on the present guideline, drinking water is contaminated by arsenic if water contains this element more than 0.05 mg/L. The contamination spreads very quickly all over the country since its first identification in 1993 and presently 61 districts out of 64 (except hilly regions) are affected by excessive level of arsenic in groundwater (Figure 3) (Khan et al, 2006; Khan et al, 2003). This trend may suffer from detection bias, because it was not unlikely that the underground water was contaminated before 1993 but not detected through an investigation. Since 2000, nearly 5 million wells were tested for arsenic in Bangladesh, of which approximately 29% were arsenic contaminated (Khan et al, 2006). Although several estimates are available in Bangladesh, according to recent studies about 35 million people are chronically exposed to arsenic in drinking water (Mahata et al, 2008). Thus the provision of tubewells tapping the shallow aquifer substituted one public health risk (e.g. diarrhoeal diseases) by another (e.g. from arsenic) (Howard et al, 2006). Without doubt, the arsenicosis problem is a major public health problem in Bangladesh (Khan et al, 2003; Khan et al, 2006; Khan et al, 2007).

Figure 3: Arsenic contaminated districts over time in Bangladesh

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Like Bangladesh, the arsenic catastrophe in drinking water has also been reported in many countries in the world including West Bengal, India (Mukherjee et al, 2006; Jones, 2007; Khan et al, 2003). However, the recent calamities are increasingly reported in Asian regions. For instance, the groundwater of Bangladesh, India (mainly the West Bengal part adjacent to Bangladesh), and some parts of China were affected by arsenic before 2000. Between 2000 and 2005, such problems have emerged newly in Cambodia, Myanmar, Afghanistan, Korea and Pakistan (Mukherjee et al, 2006). Comparatively Bangladesh is the most affected country by arsenic in human history. This means the magnitudes, consequences and severities of arsenicosis problems are unparallel in Bangladesh as compared to any other affected country reported since 1938 (Khan et al, 2003).

**Arsenic and human exposure to it**

Arsenic is a natural metallic element which is virtually available in low concentrations everywhere in the environment (e.g. water, air, soil, plants, and foods) (Jones, 2007). It is released into the environment by smelting of various metals, combustion of fossil fuels, as herbicides and fungicides in agricultural products (Vahidnia et al, 2007; Jones, 2007). Although arsenic is known to occur in both surface and underground water quite extensively under varied geographical conditions on a global scale, surprisingly neither the government nor the international agencies bothered to look carefully for the presence of arsenic in underground before motivating people to turn to it. Even the British Geological Survey (BGS) failed to report the presence of arsenic in groundwater while assessing water quality in Bangladesh (Safiullah, 2006).

Its applications throughout history are wide and varied (Vahidnia et al, 2007; Jones, 2007). For instance, arsenic compounds are used as medicines e.g. in treating syphilis (Jones, 2007) and asthma (Khan and Ahmed, 1997). These are also used in agriculture (e.g. pesticides, insecticides, and herbicides), forestry and industrial processes (Jones, 2007; Khan and Ahmed, 1997). Human exposure to inorganic arsenic may occur through inhalation and ingestion.

Inhalation usually occurs occupationally or during cigarette smoking. Exposure to arsenic through ingestion occurs mainly by drinking contaminated water (Khan et al, 2003), followed by consumption of foods contaminated via irrigation and cooking.

**Possible sources of arsenic in groundwater in Bangladesh**

Several hypotheses were proposed to explain the presence of arsenic in groundwater in Bangladesh, but many did not get wider support in the absence of adequate evidence. Presently, two hypotheses- namely (a) pyrite oxidation (oxidation hypothesis) and (b) iron oxy-hydroxide reduction (reduction hypothesis)- prevail in Bangladesh (Fazal et al, 2001; Khan et al, 2007). According to the oxidation theory, the arsenopyrite in aquifer sediments is oxidized releasing both sulphate and arsenate in the underground water. But dissolved oxygen and sulphate content was found to be very low in groundwater which provided evidence against the oxidation theory. In contrast, both the groundwater and aquifer sediment have a high content of liable organic matters for facilitating reduction. The significant presence of bicarbonate, redox, and ammonium ion (a product of peat fermentation) in the groundwater also indicate a reducing environment in the groundwater. Arsenic is released to the groundwater from the sediment due to reduction of the solid state carrier phase of arsenic (iron oxy-hydroxide) by organic matter. It is the biogeochemical reduction involving organic matter like peat that gives rise to mobilization of arsenic from the solid to the aqueous phase (Safiullah, 2006). Thus, the reduction hypothesis serves as a generic model for arsenic contamination of aquifers where waters are anoxic, particularly where organic matter is abundant (Safiullah, 2006). The reduction hypothesis is also feasible because arsenic rich sediments derived from the Himalayan Mountains and the foothills of the Shillong plateau are deposited in the Gangetic delta of Bangladesh. The major rivers and frequent flooding carry an annual average of 2.5 billion tons of sediment much of which retained inland by the flowing fluvial processes: (i) deposition on the floodplains, (ii) filling up of the numerous oxbow lakes, and (iii) formation of sand bars. Since the formation of oxbow lakes and their subsequent filling is a continuing and widespread phenomenon, the occurrence of peat and detrital organic matter at or near the surface is very common in Bangladesh (Safiullah, 2006).

**Health consequences due to drinking arsenic contaminated water for a long time**

The excessive level of arsenic intake is toxic and can affect all the organs and systems of the body (Khan et al, 2007). An array of adverse health outcomes associated with long term arsenic exposures through drinking water (Mahata et al, 2008; Khan et al, 2006; Vahidnia et al, 2007; Khan et al, 2007; Yoshida et al, 2004; Mandal and Suzuki, 2002) are shown in Figure 4. The most visible problems are the skin problems (please see the pictures given in Figure 5). However, manifestations of arsenic related health problems depends on many factors such as chemical (e.g. valence and solubility) and physical (e.g. gas, powder, and solution) form of the compound, dose, duration of exposure, the route of exposure, age, gender, socio-economic and health status, dietary levels of interacting elements and genetic factors (Jones, 2007; Mukherjee et al, 2006; Khan et al, 2003; Khan et al, 2006). Social uncertainty, social injustice, social isolation, limited access to health care services, and problematic family issues are also reported. Because of space limitation, possible mechanisms of arsenic-related specific health problems are not explained here. However, some of the explanations are reported elsewhere (Khan et al, 2005; Khan et al, 2006).

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| **Dermatological:**<br>-Melanosis<br>-Keratosis<br>-Hyperkeratosis<br>-Itching and burning | **Respiratory:**<br>-Cough<br>-Bronchitis<br>-Shortness of breath | **Haematological:**<br>-Anaemia<br>-Bone marrow depression | **Reproductive:**<br>-Still birth<br>-Low birth weight<br>-Abortion |
| **Gastrointestinal:**<br>-Nausea<br>-Abdominal pain<br>-Diarrhoea<br>-Anorexia | **Neurological:**<br>-Head ache<br>-Muscle weakness<br>-Drowsiness<br>-Numbness | **Renal:**<br>-Hematuria<br>-Proteinuria<br>-Kidney failure<br>-Cortical necrosis | **Mental health:**<br>-Depression<br>-Insufficient sleep |
| **Cardiovascular:**<br>-Hypertension<br>-Myocardial infarction<br>-Gangrene | **Hepatic:**<br>-Jaundice<br>-Cirrhosis<br>-Elevated liver enzymes | **Malignancies:**<br>-Skin<br>-Lung<br>-Liver<br>-Kidney/bladder | **Mutagenesis:**<br>-Chromosomal aberration<br>-DNA damage<br>-Inhibited DNA repair |

Figure 4: Reported health consequences related to arsenic in drinking water for a long time

Figure 5: Skin problems of arsenicosis patients living in rural areas in Bangladesh (2006)

## Mitigation strategies taken in Bangladesh

The impact of arsenic in drinking water in Bangladesh is huge and complex. The principal arsenic mitigation strategy in Bangladesh is the provision of water supplies with acceptable levels of arsenic among exposed populations (Howard et al, 2006). Considering the severity and magnitude of the problem, a number of alternative arsenic-free water supply technologies are identified and tested in several affected areas of Bangladesh (Howard et al, 2006; Hoque et al, 2000) by government agencies aided by international organizations. Mitigation activities focused on activities to provide arsenic-free safe water. Broadly safe water options can be grouped as: (i) using arsenic-contaminated water after removal of arsenic and (ii) using arsenic-safe water that may or may not require other treatments (Hoque et al, 2004). Some of the principal options tested in Bangladesh to date are (i) pond sand filters (PSF), (ii) rainwater harvesting, (iii) improved dug wells, (iv) deep tubewells, and (v) taped water. Unfortunately all these options are limited by one or more problems like seasonally varies bacterial contamination, high health risks, less acceptance, difficulties in maintenance due to cost, time and labour and uncertainty (Howard et al, 2006; Hoque et al, 2004; Hoque et al, 2000). For instance, dug wells and pond sand filters were associated with intense microbial contamination and the estimated burden of disease was high. Even in the dry season, when contamination is expected to be lowest, over 90% of samples from these two technologies exceeded the Bangladesh standard for thermotolerant coliforms (Howard et al, 2006; MacDonald, 2003). Rainwater was of good quality in the monsoon but not in the dry season. Although deep tubewell water contained very low microbial contamination (8%) in the dry season, it increased up to 50% in the monsoon season (Howard et al, 2006). Although deep tubewell is considered as the best option with an overall rating of good quality (Howard et al, 2006), recently this option is also reported to be arsenic contaminated and hence exists some uncertainty about this option (Khan et al, 2007).

In brief, all possible alternative options based on surface water, dug well and rain water are not feasible and sustainable because most of the affected people did not accept these options for the above-mentioned concerns (Hoque et al, 2004). Thus the provision of mitigation options still remains a major challenge in Bangladesh (Howard et al, 2006). Understanding the risk substitution is also critical to the technology selection based on surface water and rain water. Consideration must be given to the degree of public-health risk substitution that may result from the intervention of alternative water supplies. Risk substitution means the risks associated with disinfection by-products resulting from e.g use of chemicals to reduce arsenic (Howard et al, 2006). Financial, environmental and social aspects are also important to consider because most of the population affected by arsenic were poor and around 40% lives under the poverty line.

**Prevention activities except activities related to arsenic-free water supply**

In the present situation, several prevention activities could improve the overall situation. The prevention should not be too technical and time consuming. Among the prevention strategies, identification of a nearby tubewell with low arsenic concentration, labeling of red (arsenic contaminated) and green (not contaminated) tubewells, motivating people to share/switch arsenic-free tubewells, installation of community tubewells, close down highly contaminated tubewells, increasing education, increasing awareness, media campaign, community involvement, technical assistance for the affected people, and selection of vulnerable areas are important (Khan et al, 2007). Periodic screening is also important as the arsenic concentration varies over time. As arsenic affects mostly poor and malnourished people, they should get more facilities from health care services. Interventions should target the most vulnerable areas. Health sectors should be trained to identify the patients properly and provide proper services. As switching rate (from red to green tubewells) is high in Bangladesh, we should put emphasis on this issue. However, all the tubewells (irrespective of marked and unmarked status) should be tested periodically due to changing pattern. Water policy, management and groundwater extraction should be regulated by strict policy. Social motivations are needed to accept arsenic affected people without any discrimination. Laboratory facilities and easy access to them are also necessary for testing arsenic periodically.

**Concluding remarks**

Without any doubt, arsenic is one of the biggest public health problems in rural Bangladesh. However, Bangladesh with international cooperation has made a remarkable progress in facing the problem. For instance, a nation wide study indicated that only about 8% of the population is drinking arsenic contaminated water, although many studies reported that about 50% of the populations are at risk. We should put emphasis on prevention activities rather than mitigation activities. Health sectors and other stake holders should work in a coordinated manner. Finally, the combined forces of politicians, public health experts, epidemiologists, statisticians, and scientists from many other disciplines including social sciences and geosciences are needed.

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