# Arsenic and Fluoride Contamination in Groundwater: Mitigation Strategies

**K. J. Nath**

**Abstract** Presence of arsenic and fluoride in groundwater has been reported in many parts of the world. The anthropogenic causes of such contamination are understood, but the mechanism for release of arsenic and fluoride in the aquifer water is yet to be explained. Millions of people depending on groundwater sources are at risk with adverse health impacts due to arsenic or fluoride poisoning. To meet the challenges, mitigation strategies are suggested adjusting the most critical issues.

**Keywords** Keratosis · Mottled enamel · Defluoridation · Adsorption · Co-precipitation

## 1 Introduction

Groundwater sources like deep tube wells have generally been taken as safe, without any bacteriological contamination. However, in post-independence India, particularly during the 1960s and 1970s, contamination of groundwater sources with elevated levels of arsenic, fluoride and other geogenic and anthropogenic contaminants has emerged as a major public health concern. The current crisis in the country is primarily due to geogenic reasons. Fluorosis is endemic in 19 states of India; 65 million people including 6 million children are affected. Arsenic contamination of groundwater is most serious in West Bengal where 16 million rural and 12 million urban populations are at risk. The problem is assuming serious proportion in a number of other states in the Ganga-Brahmaputra plains. In this paper, the mitigation strategies against arsenic and fluoride contamination of groundwater are discussed.

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## 2 Arsenic Contamination: Extent and Magnitude

The most affected countries include India, Bangladesh, Myanmar, Laos, Cambodia, Thailand, Vietnam, etc. There is no report of arsenic contamination of groundwater from Sri Lanka, Maldives and Bhutan. An exact evaluation of the extent and magnitude of contamination of groundwater sources and its impact on community health is difficult in the absence of effective and regular water quality surveillance in the rural areas of these countries. Data on epidemiological assessment is also scanty. On a rough estimate, 100–150 million people might be living in the potentially and hydrogeologically risk zone.

In India, the most affected state is West Bengal, where 83 blocks out of 172 in 8 districts in the Gangetic Delta are affected (more than 0.05 mg/l). With the downwards revision of the national standard from 0.05 to 0.01 ppm, the number of affected blocks in the state now stands at 111. Reports of arsenic in groundwater have been received from six other Indian states like Bihar, Jharkhand, Uttar Pradesh, Assam, Chhattisgarh and Madhya Pradesh. The extent of the problem in these states is not yet fully known in the absence of data regarding water quality in the potentially risk areas and epidemiological information.

### *2.1 The Cause of Arsenic in Soil and the Mechanism of Its Dissolution in the Groundwater*

The arsenic contamination of groundwater in West Bengal and Bangladesh and many other South East Asian countries is basically geogenic in character. A few cases of anthropogenic contamination have also taken place in recent past. During the late 1980s, a number of tube wells in South Kolkata of West Bengal were contaminated with arsenic by the effluence from pesticide waste dump. There are also reports of anthropogenic contamination of groundwater with arsenic from coal ashes, mining activities, fertilizers, etc. However, in most of the cases, contamination is geogenic.

The concentration of arsenic in soils (sand and clay) in Gangetic belt could be anywhere between 3 and 6.5 mg/kg (reports from Bangladesh) much higher concentrations have also been reported from other countries. However, the concentration of arsenic in groundwater is not always proportional to that in soil. That is largely determined by the geochemical and environmental condition prevailing underground.

### *2.2 Health Impact*

Preliminary symptoms of chronic arsenic poisoning, when one drinks water containing arsenic above the permissible limit for a significantly long period, include hyperpigmentation, dyspigmentation and keratosis. Continuing the same could

**Table 1** Estimated incidence of excess lifetime skin cancer in Bangladesh

| Drinking water supply in Bangladesh | Estimated incidences of excess skin cancer (% of present population) |
|---|---|
| At present arsenic contamination level | 375,000 (0.290%) |
| Satisfying the Bangladesh standard of 50 ppb | 55,000 (0.043%) |
| Satisfying the WHO guideline value of 10 ppb | 15,000 (0.012%) |

Source: Prof. F. Ahmed, BUET, Dacca

cause skin cancer and internal cancer like bladder cancer or lung cancer. An epidemiological study with adequate sample size is yet to be undertaken to assess the health impact of groundwater contamination with arsenic in our country. According to the mathematical model developed by EPA to estimate lifetime risk of skin cancer, WHO guideline value of 10 ppb arsenic in drinking water is associated with a lifetime skin cancer risk 6 per 10,000 people. As per that model, the predicted lifetime skin cancer is given below (Table 1).

Limited information are available regarding the disease burden due to arsenicosis in West Bengal. In an epidemiological survey carried out by Dr. Guha Majumdar et al. (1998)$_{xii}$, in 1 of the affected districts of West Bengal (South 24 Parganas), where 7683 people were examined in 57 arsenic-affected villages, the prevalence of arsenical skin lesion was found to be 4.6%. Further, Saha (2003)$_{xvii}$ reported the incidence of arsenic-related cancer to be 5.1% among 4865 cases of arsenicosis examination during the period of 1983–2000. However, the data of the former study represented information in a highly exposed region of the state, while the later data were compiled from cases examined in a tertiary referral centre, and some scattered survey carried out in the affected districts of the state. Increasing malignancy due to arsenic contamination in West Bengal during the 1980s and 1990s were reported by Dr. K C Saha (Fig. 1).

Drinking arsenic-rich water over a long period is unsafe, as arsenic is a documented carcinogen. The commonly reported symptoms of chronic arsenic poisoning include hyperpigmentation, dyspigmentation and keratosis. Skin cancer and internal cancer can also occur which is shown in Fig. 1. A scientific epidemiological assessment of the extent and magnitude of the problem has not yet been made. High concentrations of arsenic in community water sources do not always correlate with high levels of arsenicosis symptoms in the community. According to a multistage model applied by EPA to estimate lifetime risk of skin cancer (based on an epidemiological study in Taiwan), WHO guideline value of 10 ppb arsenic in drinking water is associated with a lifetime excess skin cancer risk of 6 per 10,000 people. The same for the national standards 50 ppb, followed in India, Bangladesh and many other Asian countries, is 29 per 10,000 people (0.29%).

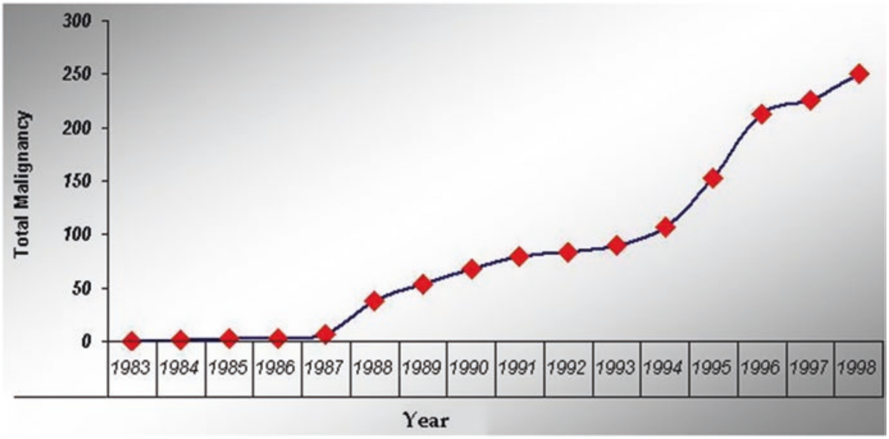



**Fig. 1** Increasing malignancy due to arsenic contamination in West Bengal. (Source: Dr. K.C. Saha, Ex-Prof. of Dermatology, School of Tropical Medicine, Calcutta)

## *2.3 Mitigation Strategies: Critical Concerns*

The basic objective and principal agenda of a mitigation strategy should include identification of unsafe sources and affected population and to arrange adequate supply of safe water to the affected people. It is often seen that in affected areas, all the tube wells are not contaminated with arsenic/fluoride in a village. If we could take up effective awareness campaign and mark the contaminated sources, most people could stop drinking water from unsafe sources. The government's capacity to supply safe drinking water in the arsenic- and fluoride-affected areas should be augmented significantly to redress the grievance of the people. Creation of a scientific GIS database and formulation of a long-term master plan for mitigation of the problem is suggested. Health Dept. should take adequate medical care of the seriously sick people. But we must understand that there is no medical cure to arsenicosis/fluorosis if the person continues to drink arsenic/fluoride contaminated water. The emerging danger of arsenic contamination of soil and crops should be studied urgently for a long-term change in agriculture and irrigation practice and restricting the use of groundwater (Fig. 2).

## *2.4 Setting National Standard*

WHO guideline value for arsenic in drinking water is 0.01 mg/l. India has very recently adapted the same as its national standard. However, many countries are still adhering to the standard of 0.05 mg/l. Table 2 depicts the standards for arsenic in groundwater in various countries.

**Fig. 2** Arsenic affected patients

**Table 2** Standard for arsenic in groundwater in various countries

| Countries | Standard (mg/L) | Countries | Standard (mg/L) |
|---|---|---|---|
| Australia | 0.007 | Bolivia (1997) | 0.05 |
| European Union (1998) | 0.01 | China | 0.05 |
| Japan (1993) | 0.01 | Egypt (1995) | 0.05 |
| Jordan (1991) | 0.01 | India | 0.05 |
| Laos (1999) | 0.01 | Indonesia (1990) | 0.05 |
| Mongolia (1998) | 0.01 | Oman | 0.05 |
| Namibia | 0.01 | Mexico | 0.05 |
| Syria (1994) | 0.01 | Philippines (1978) | 0.05 |
| USA (2001) | 0.01 | Saudi Arabia | 0.05 |
| Canada | 0.025 | Sri Lanka (1983) | 0.05 |
| Bahrain | 0.05 | Vietnam (1998) | 0.05 |
| Bangladesh (1997) | 0.05 | Zimbabwe | 0.05 |

## *2.5 Technology Options*

Appropriate technology options are the most important and critical precondition for successfully addressing the problem of arsenic contamination in groundwater. Initially in many countries, it was attempted to sink tube wells in the deeper aquifer more than 150 m depths, which is more or less arsenic-free. However, this option has a risk of leaking of arsenic-contaminated water from the upper carboniferous aquifer to the deeper aquifer.

Another option is to supply arsenic-free water from alternate arsenic-free water sources like rivers, lakes, etc. However, this option requires that the water from surface sources should be appropriately treated for removal of pathogenic microbes. Often, as in case of West Bengal, large treatment plants are constructed for the water treatment, and the same is carried by trunk water main for distribution to distant villages. However, this approach is capital intensive and often faces chronic O&M problems. A more decentralized and cost-effective alternative could be to use the water of local ponds, canals, dug wells, etc. for supply to the people. This approach requires capacity building in the villages for installation and operation of low cost and user-friendly for quality upgradation of pond water. This will be ideal solution if rain water harvesting is combined with the same to make the pond sustainable.

Another alternative is to remove arsenic from the groundwater and distribute the same to the nearby villages by designing mini-piped water scheme. For removal of arsenic from groundwater, various technologies have been used like adsorption, co-precipitation (oxidation, coagulation, filtration) and ion exchange. For adsorption, various kinds of media are being used like activated alumina, iron oxide, laterite and nanomaterials. Among various emerging technologies, the application of various kinds of nanomaterials for arsenic removal appears to be most promising (Figs. 3 and 4).


**Fig. 3** Arsenic Treatment Units with hand pump operated tubewells

**Fig. 4** Large surface water-based plants – PHED, Govt. of West Bengal

# 3 Fluoride in Groundwater: Extent and Magnitude

The contamination of groundwater with excessive fluoride has become a huge health problem in many states of India.

- Fluorosis is endemic in 22 states (200+ districts and 1 lakh+ villages) of India. Sixty-five million people, including 6 million children, are affected.
- Fluoride levels in India's groundwater vary from 1 to 48 mg/l (The WHO guideline for maximum permissible level of fluoride in drinking water is 1.5 mg/l).
- A 1999 study by New Delhi-based Fluorosis Research and Rural Development Foundation has identified 59,111 problem villages with fluoride levels above 1.5 mg/l.
- 1997 study by the Rajasthan Voluntary Health Association shows that almost 35,000 people in the state are consuming water having more than 10 mg/l of fluoride.

## *3.1 Health Impact*

People drinking fluoride for a long time are likely to suffer from dental fluorosis (drinking water having fluoride marginally above 1 mg/l). When fluoride level in drinking water exceeds 3 mg/l, the crippling skeletal fluorosis might result. Skeletal fluorosis creates pain in the joints finally crippling the patients. There have been reports that drinking water with fluoride level above 3 mg/l might also cause gastro-intestinal problems, allergies and urinary tract problems. WHO guideline suggests the maximum level of fluoride in drinking water at 1.5 mg/l.

### 3.2 Fluoride Control Options

(a) In fluoride-affected area, firstly one should attend to use drinking water from alternate sources which do not fluoride above permissible limit.
(b) Transporting water from a distance source.
(c) Use of dual water sources
(d) Rain water harvesting
(e) Use of defluoridation technologies for removal of fluoride from water.

### 3.3 Defluoridation Technologies

Defluoridation technologies can be broadly classified into three categories according to the main removal mechanism:

- Chemical additive methods
- Contact precipitation
- Adsorption/ion exchange methods

### 3.4 Reverse Osmosis Technology

In recent years, reverse osmosis (RO) technology which uses membrane with fine pores for removing dissolved substances from the water is being used widely for water purification purposes. This process is not specific for particular substance. Along with undesirable elements like fluoride/arsenic, these would also remove all other dissolved substances and bacteria from water, including some beneficial minerals. One of the critical operational problems faced by RO units is clogging of fine pores. The process involves significant wastage of water with elevated concentration of dissolved impurities.

## 4 A Decentralized Low-Cost Approach Based on Traditional Rural Surface Sources (Ponds, Rivers, etc.) in Arsenic/Fluoride Endemic Areas

International Academy of Environmental of Sanitation and Public Health (a subsidiary of Sulabh International Social Service Organization) has successfully demonstrated that the water from the rural surface sources like ponds, rivers, etc. could be treated in a simple treatment plant as depicted in Fig. 5 and the same could be

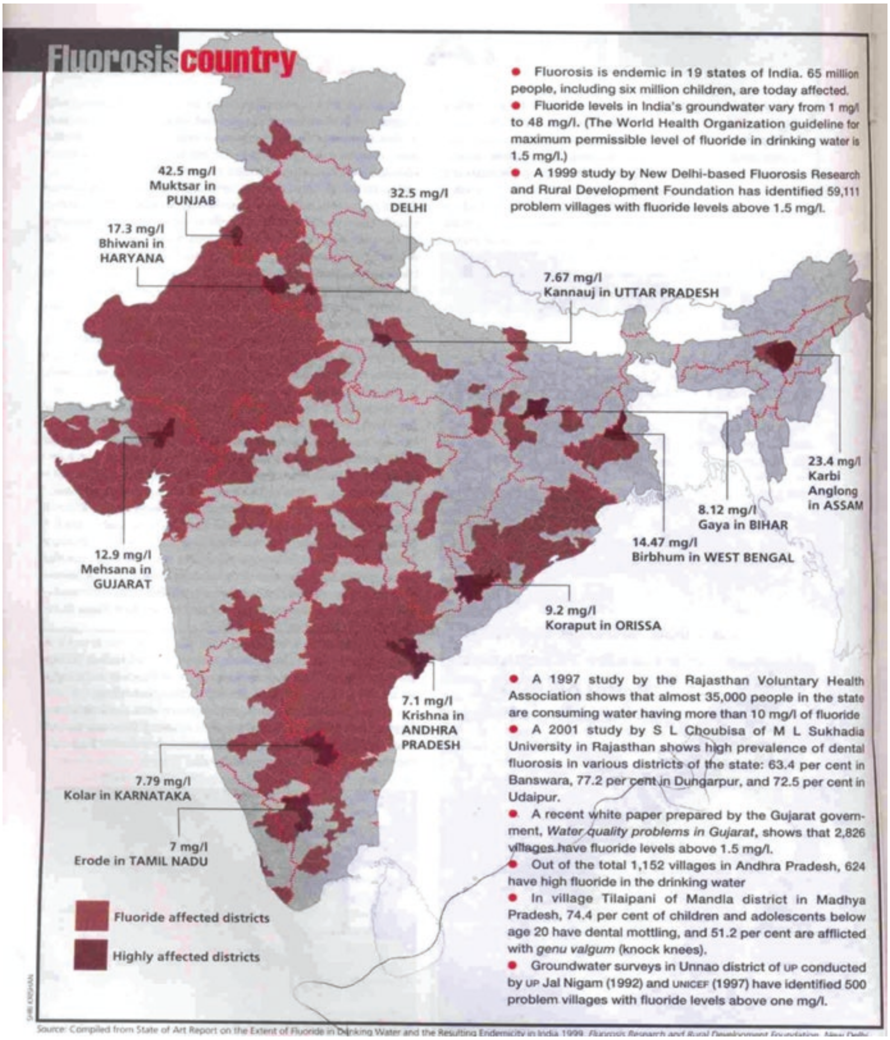



**Fig. 5** Fluoride-affected states of India

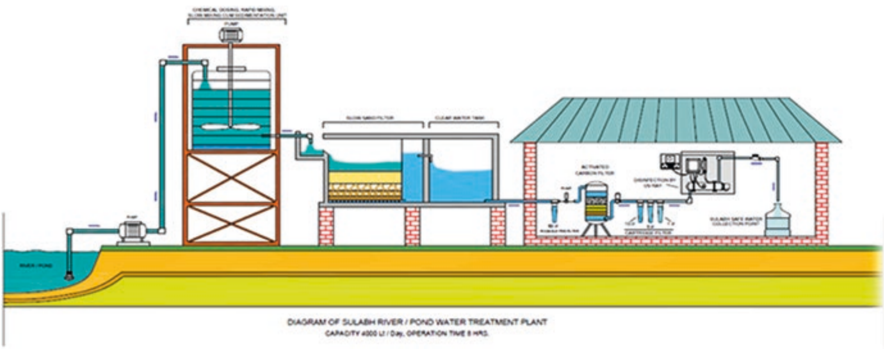
**Fig. 6** Fluorosis-affected patients

operated, maintained and managed at the village level. This could be a cost-effective and people-friendly approach for safe drinking water supply in the arsenic/fluoride endemic areas. Salient features of the treatment plant including the operation, maintenance and capital cost is given below. The example of capacity building (Fig. 6) at the grass root level and empowering the rural people would be an ideal solution in many of the arsenic and fluoride-affected villages.

In West Bengal and other states in the planes of river Ganga in eastern India, the annual rainfall is quite satisfactory, and there are many perennial and sustainable water sources like pond and canals in the rural area. Unfortunately, these are often abused by human behaviours and as a result get heavily contaminated, resulting in epidemics of diarrheal diseases and endemicity of the same in the community. A low-cost and community-friendly treatment process which could be successfully operated and maintained by trained rural workers would provide the rural community absolutely safe and free from arsenic/fluoride (Figs. 7 and 8).

## 5 Conclusion

Given the experience in the developing countries of Asia, where arsenic in groundwater is posing a great challenge to the health of a large number of people, the following could be mentioned as the major factors impeding the progress of the projects to address the problem:




*1: Pump; 2:Chemical Dosing, Rapid Mixing; slow mixing cum sedimentation; 3: Slow sand filter; 4: Clear Water Tank; 5:60 μ Rinsable Pre-Filter; 6: Pump; 7: Activated Carbon Filter; 8: Cartridge Filter (10 μ, 5 μ, 1μ); 9: Disinfected by UV Ray; 10: Sulabh Safe Water Collection Point*

**Fig. 7** Flow sheet of Low-cost rural water supply from ponds/rivers

Capacity: 800 Litres/Day
Population: 2000
Operation and Maintenance Cost: Rs. 25,000/- per month
Production Cost: 15p/Litre

Capital Cost: 12 Lakhs

**Fig. 8** Capacity building at the grass root level and empowering the people

- Gap between the perceived need of the people and approach of the implementing agencies.
- Long period of completion for large capital-intensive government project/lack of interim relief.
- In general, rural populations are largely unaware of the technologies developed by various institutions and organizations due to poor promotional activities.
- Lack of knowledge among the people regarding the health impact of the arsenic problem.
- Lack of facilities at the grass root level for water quality monitoring.

Central and state governments have invested significant amount of resources for the mitigation of arsenic and fluoride programme, but implementation of the same is facing a number of constraints. Lack of people's participation in the programme is a critical concern. There is an acute need for generating awareness among the beneficiaries regarding the arsenic/fluoride contamination of groundwater and its health impact. We need to be objective and realistic in making technical and economic decisions in relation to the current problem of arsenic and fluoride contamination of groundwater.

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