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Issues of water quality, health and poverty: the Indian scenario

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Abstract India faces a significant challenge from environmental pollution as almost 85% of the most prevalent diseases are water-borne due to microbiological or chemical contamination. In Rajasthan, the country's largest state, about 50% of the potable water sources are contaminated with total dissolved solids, fluorides and nitrate in excess of the prescribed national standards for human health. This paper presents an overview of the major water quality problems faced by India and especially the state of Rajasthan, and summarizes some recent developments in the field of fluorosis and nitrate toxicity along with the technologies devised to remove these chemicals from drinking water supplies, as a result of recent research.

Key words drinking water quality; human health; microbiological contamination; fluorosis; nitrate toxicity; new pathophysiologies

INTRODUCTION

Water is crucial for sustainable development, including the preservation of our natural environment and the alleviation of poverty and hunger. As a resource, water is also indispensable for human health and well-being. The United Nations General Assembly of December 2003, proclaimed the years 2005 to 2015 as the International Decade for Action "Water for Life". The primary goal of the Water for Life Decade is to promote efforts to fulfill international commitments made on water and water-related issues by 2015. Substantial effort is required during this decade to fulfill these commitments and extend access to these essential services to those who remain unserved, the majority of whom are poor people.

Water as a resource is unevenly distributed in space and time. Societies have not managed it in a sustainable way over the past few decades. The global water scenario is increasingly a cause for concern and the Indian scenario is still worse.

In India, the major rainfall occurs during the monsoon (only 75 days) season. The highest mean monthly rainfall (1901–2003) occurs in July, 286.5 mm, and contributes 24.2% of mean annual rainfall (1182.8 mm). The August rainfall is slightly lower and contributes 21.2% of annual rainfall. The June and September rainfall contributions are 13.8 and 14.2% of annual rainfall, respectively (Guhathakurta & Rajeevan, 2006). India occupies 2% of the Earth's surface but contains 16% of its population and only 4% of the average annual runoff of the world's rivers. The livelihood of about 70% of the population depends on agriculture and 25% of the GDP is derived from farming, which in turn, depends upon water resources. The situation is even more serious in the state of Rajasthan, which has access to only 1% of the national water resources despite occupying 10% of the land area. In Rajasthan, 196 149 km^2 (58% of the state) is classified as arid 121 016 km^2 (36%) as semi-arid and 21 248 km^2(6%) as sub-humid. Rainfall distribution is highly variable, both in time and space. Annual rainfall varies from more than 900 mm in the southeast to less than 100 mm in the west. Only the Mount Abu region receives more than 1593 mm of rain a year due to its elevation (Rathore, 2005). Thus, this state has a water problem encompassing issues of both quantity and quality. In most parts of Rajasthan, groundwater is either saline or has excess fluoride or nitrate content. Groundwater is the major source of potable supplies, meeting about 90% of the drinking water demand.

A state-wide survey of all villages/habitations was carried out by the Public Health Engineering Department (PHED) Rajasthan and water quality data were compiled in 2001–2004. A total of 75 266 water samples from different sources, including tube wells, open wells and hand pumps were analysed. Of these, 42 352 samples (56.27%) were found to contain total dissolved solids, fluorides and nitrate in excess of the respective prescribed limits of 1500, 1.5 and 45 mg/L.

These data underscore the gravity of the situation in Rajasthan state as far as the chemical quality of water is concerned (Dhindsa, 2006).

In tandem with the new millennium goals of the World Health Organization (WHO), to provide every rural person with adequate safe water for drinking, cooking and other domestic basic needs on a sustainable basis, the Government of India has made it mandatory under the National Drinking Water Mission, that every individual be provided with 8 litres of water daily that meet the minimum water quality standards prescribed by the Bureau of Indian Standards. This initiative has resulted in a reduction of the safe rural drinking water coverage in Rajasthan by almost half, since the remaining sources do not meet the chemical quality prescribed in IS 10500 (1991). This reduction in the coverage of safe drinking water supplies has renewed the challenge to tackle water quality problems related to three key parameters, namely; salinity, fluoride and nitrate. This paper presents an overview of the water quality situation in India, and particularly the Rajasthan region, summarizing some recent developments in the field of fluorosis and nitrate toxicity, along with the technologies devised to remove these chemicals from drinking water through research carried out at the Malaviya National Institute of Technology (MNIT) Jaipur with other institutions of the state.

WATER QUALITY AND HEALTH – THE NATIONAL CONTEXT

There is an intimate relation between water quality and human health. Despite advances in the field of medicine, the health of an average Indian still faces a significant challenge from environmental pollution as 85% of the most prevalent current diseases have some relationship to contaminated water. The widespread pollution of water has started interfering with the health of people in every perceptible manner. This issue calls for developing comprehensive environmental policy guidelines for the sustainable management of this precious resource and for promoting people’s health. The Government runs several “Health for all” programmes that include educating rural women and children with regard to maintaining a good level of personal hygiene, but in a country where almost 90% of the diseases have some relationship with environmental factors, no such programmes can be successful unless aspects of environmental hygiene are also integrated with such measures. Mitigating the environmental problems faced by the modern era can alone carve a future road map for a healthier society.

The relationship between water and health can be divided into many categories, including:

1. Water as a direct vehicle of transmission of microorganisms that cause infectious diseases (waterborne diseases).
2. Water serving as a habitat for vectors that transmit disease producing organisms (indirect role).
3. Water as a vehicle for transmitting a variety of toxic chemicals.

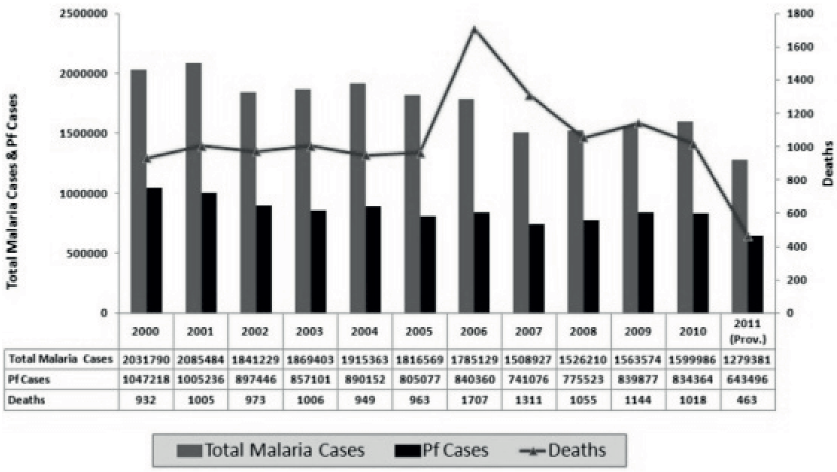
Water has a profound influence on human health. At the most basic level, a minimum amount of water is required for consumption on a daily basis for survival and therefore access to some form of water is essential for life. However, water has much broader impacts on health and wellbeing and the quality of the water supplied is important in determining the health of individuals and indeed whole communities. The first priority must be to provide access for the whole population to some form of improved water supply. However, access may be restricted by low coverage, poor continuity, insufficient quantity, poor quality and excessive cost relative to the ability and willingness to pay. Thus, in terms of drinking-water, all these issues must be addressed if public health is to improve and be sustained. The microbiological quality of water is important in helping to prevent ill-health. Poor microbiological quality is likely to lead to outbreaks of infectious water-related diseases and may cause serious epidemics. Chemical water quality is generally of lower importance as the impacts on health tend to be chronic long-term effects and time is available to take remedial action. Acute effects may be encountered where a major pollution event has occurred or where concentrations of specific chemicals are high.

Various classical water-borne diseases are caused by the ingestion of contaminated faecal material transmitted by the faecal–oral route. Infectious agents of all types may be transmitted by the faecal–oral route via water, including viruses (such as infectious hepatitis, rotavirus and

Norwalk agent); bacteria (such as cholera, typhoid and dysentery); and parasites (such as *Giardia*, *Cryptosporidium* and *Entamoeba*). Faecal pollution of drinking-water may be sporadic and the degree of faecal contamination may be low or fluctuate widely. The critical role of sanitation in preventing such diseases has been well recognized and a programme entitled "Total Sanitation Campaign (TSC)" was launched by the Government of India with the help of UNICEF in 1999–2000, which emphasized the need for more information, education and communication (IEC), human resource development, and capacity development activities to increase awareness among the rural population and to generate demand for improved sanitary facilities. Research has been carried out at MNIT Jaipur to develop some verifiable performance indicators for assessing the efficacy of this programme in three districts of Rajasthan: Jodhpur, Rajsamand and Ganganagar (Joshi & Gupta, 2012). Recent research on the efficacy of chlorine against coliforms and the limitations of using UV against the RNA virus has resulted in the development of new research streams and practices in the field of water/sewage disinfection (Kumar *et al*., 2011; Sharma *et al*., 2012).

Role of water as a habitat for vectors of diseases – the case of malaria

Areas of India which are highly endemic for malaria include the northeast region and tribal forested and hilly areas of several states including Maharashtra, and certain non-tribal districts. Nearly one quarter of all reported cases were from Orissa State, and 80% of these cases originated from 20% of the population (World Malaria Report, 2005). The National Malaria Control Programme operates under five-year strategic plans and coordinates strategic decisions with the National Technical Advisory Committee on Malaria and with state health authorities. The website of the National Vector Borne Disease Control Programme, Directorate General of Health Services, Ministry of Health and Family Welfare, India (http://www.nvbdcp.gov.in/) presents detailed data related to the state-wise prevalence of malarial cases in India, including the malaria control strategies adopted by the Government in both rural as well as urban areas. Figure 1 shows details of the malaria cases reported in India from 2000 to 2011.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011 (Prov.)
Total Malaria Cases	2031790	2085484	1841229	1869403	1915363	1816569	1785129	1508927	1526210	1563574	1599986	1279381
Pf Cases	1047218	1005236	897446	857101	890152	805077	840360	741076	775523	839877	834364	643496
Deaths	932	1005	973	1006	949	963	1707	1311	1055	1144	1018	463

Fig. 1 Trends in total and Pf (*Plasmodium falciparum*) cases.

The National Health Policy of 2002 reinforced the commitment to malaria control and set as goals the reduction of malaria mortality by 50% by 2010 and the efficient control of malaria morbidity. The data from Fig. 1 indicate that there was a significant impact of the programme after 2006 resulting especially in a sharp reduction in number of deaths due to malaria, although the reduction in the number of cases of malaria was smaller.

Malaria control in India relies heavily on active case detection; every year nearly 100 million blood smears are taken from fever cases identified in the home, and patients are treated promptly if a diagnosis of malaria is confirmed. Malaria is currently under control in vast areas of India, covering almost 80% of the population, despite increasing population density and aggregation, rapid and unplanned urbanization and increased migration. Under the MoH's Enhanced Malaria Control Project, which aims to control malaria in eight states including Gujarat, Andhra Pradesh and Maharashtra, malaria morbidity dropped in the project districts by 46% compared to 1997. Before 2004, approximately 1.8 million ITNs (insecticide-treated nets) were distributed and over the project duration, the population covered by IRS (indoor residual spray) decreased by more than 50%. The Ministry of Finance allocates funds to the Ministry of Health and Family Welfare for the various national health programmes, including malaria, with some additional assistance from the World Bank.

Effects of fluoride ingestion on human beings

Fluorosis, though a common endemic problem in India is more widespread and acute in the state of Rajasthan where all the 33 districts have been declared as fluorosis prone. While the WHO standards and IS 10500 (1991) permit only 1.5 mg L^{-1} as a safe limit for human consumption, people in several districts in Rajasthan consume water with fluoride concentrations up to 24 mg L^{-1}.

Fluorides in drinking water may cause skeletal fluorosis, clinical fluorosis, dental fluorosis, or non-skeletal manifestations, or any combination of the above, while in the final stages it may cause premature aging. Effects on teeth include discoloration, delayed eruption, chipping of edges and pitting, etc.; some of these manifestations are shown in Fig. 2.

The effects of fluoride on bones include symptoms like heel pain, painful and restricted joint movements, deformities in limbs, and in very severe cases the patient may develop a hunch back as shown in Fig. 3. Other clinical effects include paralysis, muscular wasting and premature aging among affected individuals.

Fluoride and aluminium have a high chemical affinity and both have been shown to result in osteotoxicity. High incidence of fluorosis has been found in Rajasthan, Andhra Pradesh, Uttar Pradesh, and a few other states of India. There are some clusters in Rajasthan where the incidence of extremely severe fluorosis has been observed compared to that in nearby villages receiving

Fig. 2 Fluoride effects on teeth (from Gupta *et al.*, 2001a).

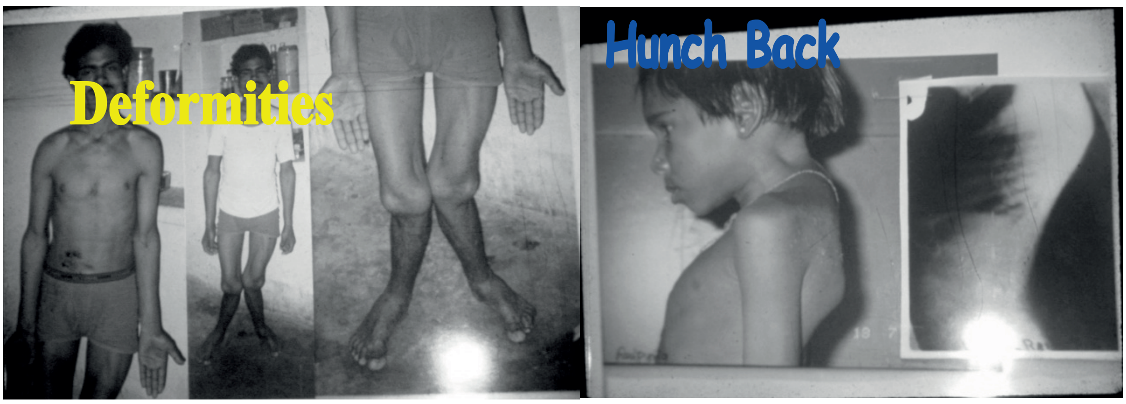


Fig. 3 Effects on bones and joints (from Gupta *et al.*, 2001a).

similar levels of fluoride content in drinking water. It was hypothesized that in these cases the problem of fluorosis was aggravated due to the presence of aluminum. Our study of Chaksu block in Jaipur district, established the synergistic effect of aluminum in the aggravation of fluorosis. Both dental and clinical manifestations were found to be statistically aggravated, at 95% confidence, under the presence of relatively higher aluminium (0.02–0.03 mg L^{-1}) in drinking water compared to that in the control supply (not traceable). These findings are of extreme importance in view of the fact that most of the defluoridation techniques used in the field employ aluminium-based salts (Gupta *et al*., 2011).

Recent research by our team in Rajasthan has resulted in the formulation of a detailed patho-physiology of fluorosis and has also shown the scope for its successful treatment (Gupta *et al*., 1994, 1996, 2001, 2012). This study involved evaluation of the effect of a combination of calcium, vitamin D_3 and ascorbic acid supplementation in fluorosis-affected children. During this study 25 children were selected from an area consuming water containing 4.5 mg L^{-1} of fluoride. All the children were in the age group 6–12 years and weighed 18–30 kg. They were graded for clinical, radiological and dental fluorosis and relevant biochemical parameters. Grade I skeletal fluorosis and all grades of manifestation for dental and clinical fluorosis were observed. These children were given ascorbic acid, calcium and vitamin D_3 well below the toxic dosages in a double-blind manner using lactose as a placebo. The results of the study indicated partial to complete reversal of various grades of dental fluorosis in children, some of which are shown in Fig. 4.

Fig. 4 Reversal of dental fluorosis (from Gupta *et al*., 2001a).

The two commonly used field defluoridation techniques in India are the Nalgonda process and the activated alumina process. The Nalgonda technique contains residual aluminum in the range 2.1–6.8 mg L^{-1} under various operating conditions. This concentration of uncomplexed aluminium in treated water for drinking purposes can result in a grave public health problem as aluminium is a neurotoxin and a concentration as low as 0.08 mg L^{-1} of aluminium in drinking water is reported to have caused Alzheimer's disease. The activated alumina technique depends on chemisorption of fluoride on to a bed of granular alumina. It is an expensive process and the reactivation of filter material is cumbersome. This process also results in moderately high residual aluminium in treated water ranging from 0.1 to 0.3 mg L^{-1}. George *et al*. (2009, 2010) extensively modelled the defluoridation process in Nalgonda and activated alumina treated waters for both residual fluorides and aluminum. A new, low cost defluoridation technology has been developed by the authors of this paper (Agrawal *et al*., 1999; Gupta *et al*., 1999) that could avoid the major shortcomings of the above technologies. The use of aluminium compounds for fluoride removal should be made very judiciously to avoid the ill effects of residual aluminium. In addition, dietary interventions play a major role in combating the menace of fluorosis.

Recent advances in the field of nitrate toxicity

Excessive nitrate concentrations in drinking water are reported to cause methemoglobinemia in infants up to six months of age. The WHO has prescribed maximum permissible limits in drinking water of 50 mg L^{-1}. While a few cases of methemoglobinemia in infants have been reported to be associated with water nitrate levels of less than 50 mg L^{-1}, most cases occur with nitrate levels of 90 mg L^{-1} or more. In several developing countries, including India, consumption of water containing high nitrate concentrations, at times up to 500 mg L^{-1}, is not uncommon. A nationwide review of nitrate concentration in groundwater indicated that these values ranged 0.1–870 mg L^{-1}, with an average of 65 mg L^{-1} in India. Gujarat, Rajasthan and West Bengal were the states with highest nitrate content in groundwater (Subramaniyan, 2004). A survey of water quality in Rajasthan showed that 20 659 villages/habitations had potable water supplies with nitrate concentrations exceeding 45 mg L^{-1} (IS 10500 desirable limit) and 7675 villages/habitations had concentrations exceeding 100 mg L^{-1} (IS 10500 permissible limit) constituting 22% of the state's villages/habitations (Dhindsa, 2006). The strategies for combating nitrate pollution in India have been described by Prakasa Rao & Puttanna (2006), with special reference to the prevailing agricultural practices. Given the seriousness of the nitrate contamination problem in Rajasthan, an epidemiological investigation entitled "Epidemiological evaluation of nitrate toxicity and DPNH dependent diaphorase activity in infants" was undertaken at the S.M.S. Medical College, M.R.E.C. (now MNIT Jaipur) and NEERI Regional Laboratory Jaipur to evaluate the toxicity of inorganic nitrate ingestion. It yielded results explaining the mechanism of nitrate toxicity, the defence system in the human body to counteract this toxicity, and some other manifestations of nitrates apart from causing methemoglobinemia (e.g. recurrent stomatitis, recurrent diarrhea and recurrent respiratory tract infection) among children, which could be of significant importance to the field of environmental health. In brief, the following conclusions were drawn as a result of this study:

Methemoglobinemia – a problem of all age groups (Gupta *et al.*, 2000) During the investigations clinical symptoms and signs of methemoglobinemia were also noticed in the sample population in the age group above 1 year (children and adults). It was therefore decided to enlarge the scope of the study to the entire population. Methemeoglobinemia was prevalent among all age groups with infants and higher age groups (>45 years old) being the most susceptible.

Cytochrome b_5 reductase adaptation (Gupta *et al.*, 1999a) High nitrate concentrations are causing methemoglobinemia in infantile (below 1 year) and older (over 45 years) age groups. The reserve of Cytochrome b5 reductase activity and its adaptation with increasing water nitrate concentration to compensate methemoglobinemia is higher in younger age groups (1–18 years old) compared to infantile and older age groups. The adaptation peaks at about 95 mg L^{-1} nitrate concentration and falls back to the base line level at about 200 mg L^{-1}.

Recurrent diarrhea in children (Gupta *et al.*, 2001b) There is a strong interdependence between nitrate concentration, methemoglobin levels, Cytochrome b_5 reductase activity and recurrent diarrhea in the 1–8 years old age group. The primary variable, the nitrate concentration, alone accounts for about 80% of the variation observed in recurrent diarrhea cases. Nitrate thus seems to initiate diarrhea and under such conditions, if the oral rehydration solution is prepared with the same high nitrate containing water, may lead to fatal results.

Recurrent respiratory tract infection in children (Gupta *et al.*, 2000a) There is a significant interdependence between nitrate concentration in drinking water, methemoglobin levels, Cytochrome b_5 reductase activity and recurrent ARI in children of up to 8 years of age. Methemoglobinemia appears to be the primary cause for recurrent ARI.

Recurrent stomatitis (Gupta *et al.*, 1999b) There is a significant interdependence between drinking water nitrate concentration, Cytochrome b5 reductase activity and recurrent stomatitis. Increased Cytochrome b5 reductase activity primarily caused by high nitrate concentration in drinking water appears to be the cause for recurrent stomatitis.

The detailed pathophysiology of nitrate: its fate and metabolism in the mouth, stomach and intestine; formation of N-nitroso compounds; endogenous synthesis of nitrate and nitrite; fate of free radicals like nitric oxide (NO.) and free oxide (O.); effect of nitrate on respiratory, cardiovascular, and gastrointestinal systems; the preventive and treatment aspects, etc., have been extensively reviewed by Gupta *et al.* (2010) and throws open many areas for future research.

Thus the use of fertilizers in rural areas should be carefully regulated to avoid large-scale health problems that may persist due to potable water contamination. Rajasthan is already facing the problem of high nitrates in groundwater in all districts. Nitrogen removal from sewage at affordable cost is another challenge for which much work has been carried out using specialized bacteria (Gupta, 1997; Gupta & Gupta, 1999).

CONCLUSION

The National Drinking Water Mission has set up a major challenge for the Public Health Engineers of Rajasthan in India to supply drinking water free from fluorides, nitrates and salinity at affordable cost to the communities. This challenge continues to require major research inputs from academic institutions along with other research organizations and wholehearted support from the national Government.

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