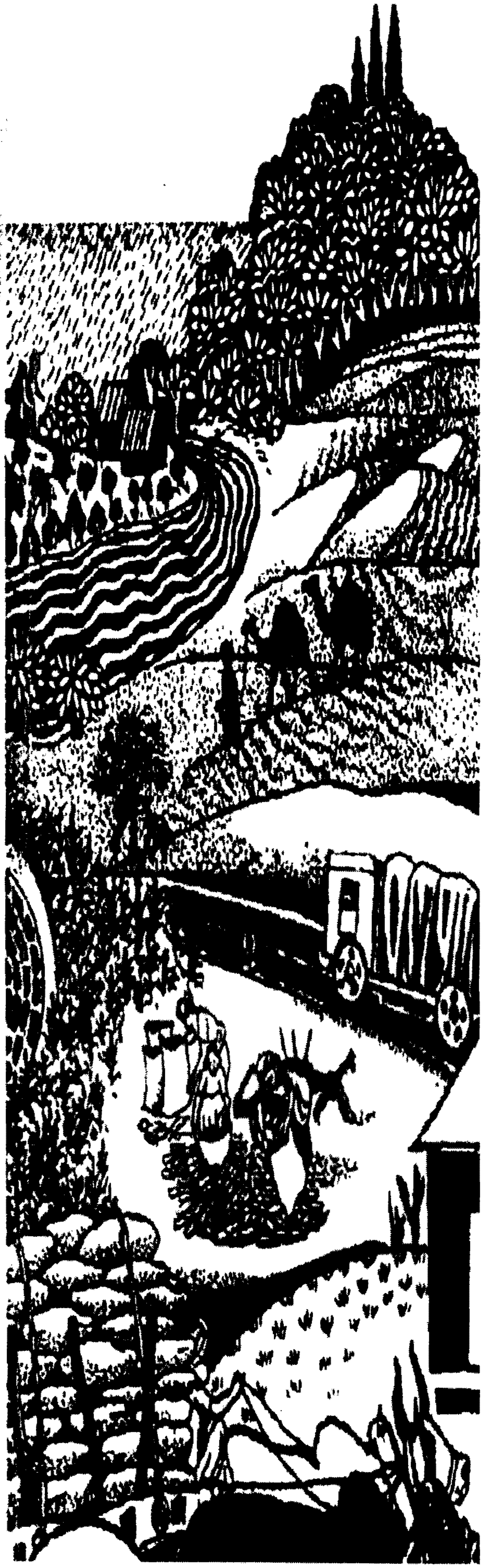

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Groundwater Pollution and Contamination in India: The Emerging Challenge

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Groundwater Pollution and Contamination in India: The Emerging Challenge

M. Dinesh Kumar and Tushaar Shah[1]

1.0 INTRODUCTION

Role of groundwater in India's irrigation, boosting its agricultural production and sustaining growth of its rural economy is well-documented. But the crucial role it plays as a decentralized source of drinking water to hundreds of millions rural and urban families cannot be overstated. According to some estimates, it accounts for nearly 80% of the rural domestic water needs, and 50% of the urban water needs in India (World Bank, 1998). Groundwater is generally less susceptible to contamination and pollution when compared to surface water bodies. Also, the natural impurities in rainwater, which replenishes groundwater systems, get removed while infiltrating through soil strata. Therefore countries like Russia have reserved the use of groundwater exclusively for water supply to rural and urban communities and banned its use for irrigation and other purposes. But, In India, where groundwater is used intensively for irrigation and industrial purposes, a variety of land and water-based human activities such as irrigated farming, and disposal of trade effluents on land and in surface water bodies are causing pollution of this precious resource. Its over-exploitation for agriculture and other purposes is causing aquifer contamination in certain instances, while in certain others its unscientific development with insufficient knowledge of groundwater flow dynamic, geo-hydrochemical processes and mass transport has led to its mineralization. Exposure to water containing high levels of salinity, fluorides and arsenic, and toxic pesticide and fertilizer residues and industrial effluents are causing public health hazards.

The paper, based on an extensive review of available published and grey literature, and limited primary research, attempts to: assess the nature and extent of groundwater contamination in India including pollution and their impacts; identifies the challenges involved in tackling groundwater pollution and contamination, which are technical, financial and institutional; discuss the emerging preventive measures for reducing human health impacts; and discuss the institutional challenges in implementing the preventive measures.

2.0 THE NATURE AND EXTENT OF GROUNDWATER CONTAMINATION AND POLLUTION IN INDIA

2.1 Nature and Extent of Groundwater Contamination

The major sources of groundwater contamination in India, so far detected, are fluoride, salinity, iron, nitrate, arsenic and heavy metals.

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Incidence of fluoride above permissible levels of 1.5ppm occur in 14 Indian states, namely, Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal affecting a total of 69 districts, according to some estimates. Some other estimates place 65% of India's villages exposed to fluoride risk. Incidence of high levels of salinity in groundwater are reported from all these states except West Bengal and also the NCT of Delhi, and affects 73 districts and three blocks of Delhi (source: http://wrmin/resource/cont.gw/htm). Progressive decline in groundwater quality, in terms of high TDS and salinity, are encountered in North Gujarat with increase in pumping depths (Kumar, 2002). Iron content above permissible level of 0.3 ppm is found in 23 districts from 4 states, namely, Bihar, Rajasthan, Tripura and West Bengal and coastal Orissa and parts of Agartala valley in Tripura. High levels of arsenic above the permissible levels of 50 parts per billion (ppb) are found in the alluvial plains of Ganges in six districts of West Bengal. Presence of heavy metals in groundwater is found in 40 districts from 13 states, viz., Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal, and 5 blocks of Delhi (source: http://wrmin/resource/cont.gw/htm).

2.2 Nature and Extent of Pollution Problems

Disposal of industrial effluents and pesticide and fertilizer application in cultivated areas are the two major sources of groundwater pollution in India. Pollution from agricultural activities is one of the greatest threats to fresh groundwater ecosystems, while public health sector also uses some pesticides which are potential causes of pollution. This is precisely because pollution caused by fertilizers and pesticides is non-point, dispersed over large areas and as a result source remains difficult to detect.

Intensive use of chemical fertilizers in farms and indiscriminate disposal of human and animal waste on land result in leaching of the residual nitrate causing high nitrate concentrations in groundwater. High concentrations of nitrates in groundwater are reported from many parts of India (Moench and Metzger 1992; WRI 1995). Its concentration is above the permissible level of 45 ppm in 11 states, covering 95 districts and two blocks of Delhi (source:http://wrmin/resource/cont.gw/htm). DDT, BHC, carbamate, Endosulfan, etc. are the most common pesticides used in India. Leaching of fertilizers from irrigated paddy fields causes severe nitrate pollution in high water table areas in Muktsar district of Punjab (source: http://www.tifac.org.in/itsap/water4.htm). But, the vulnerability of groundwater to pesticide and fertilizer pollution is governed by soil texture, pattern of fertilizer and pesticide use, their degradation products, and total organic matter in the soil (Ali and Jain, 1998).

Pollution of groundwater due to industrial effluents and municipal waste in water bodies is a major concern in many cities and industrial clusters in India (Kittu, 1995). A 1995 survey undertaken by Central Pollution Control Board identified 22 sites of 16 states of India as critical sites for groundwater pollution (Biswas and Sharma, 1995), the primary cause being industrial effluents. Groundwater in the whole of *Golden Corridor* (Vapi- Ankleshwar-Surat-Baroda belt) is severely polluted by effluent from chemical industries (Kittu, 1995). A recent survey undertaken by Centre for Science and Environment from eight places in states, viz., Gujarat, Andhra Pradesh and Haryana, reported traces of heavy metals, such as lead, cadmium, zinc and mercury. Shallow aquifer in Ludhiana city, the only source of drinking water in the city, is seriously polluted by effluents from 1300 odd industries disposed off into the stream which recharges it. Excessive withdrawal of groundwater from coastal aquifers has led to induced pollution in the form of intrusion of seawater in the coastal aquifers. Examples are coastal Kachchh and Saurashtra in Gujarat, Chennai and Calicut in Kerala. Some of the districts reported as "salinity affected" fall under this category, while the rest have inherent salinity.

A recent survey undertaken in the cities of Surat and Ankleshwar in Gujarat, which involved testing of chemical quality of groundwater from several wells, showed high levels of contamination of groundwater in Ankleshwar city with concentration of contaminants exceeding permissible levels for most parameters in Ankleshwar (Chaitali and Trivedi, 2005).

2.3 Potential Impacts of Groundwater Pollution

As there are no comprehensive assessments of the extent of groundwater pollution and the population affected, there are no estimates of its public health consequences. It is important to acknowledge here that such a task is ardous and involves several methodological complexities and logistical problems. It is also important to remember that the level of toxicity varies with the type of pollutant.

Mercury is reported to cause impairment of brain functions, neurological disorders, retardation of growth in children, abortion and disruption of the endocrine system (http://rainwaterharvesting.org.Crisis.Groundwater.pollution.htm), whereas pesticides are by nature toxic to one or more life forms. They are tissue degradative, relatively stable compounds, and also toxic or carcinogenic in nature. Generally, pesticides damage the liver and nervous system. Tumour formation in liver has also been reported. Endosulfan, Mirex, Malathion, Chlordane and DDT are carcinogenic, while Aldrin attacks the nervous system, damages the liver (source: based on Table 5 in Ali and Jain (1998)). High levels of nitrates in drinking water harmfully effects human babies by converting hemoglobin in blood into methemoglobin, severely affecting blood circulation. This poisoning leads to a condition called "blue baby".

2.4 Impacts of Groundwater Contamination

Unlike TDS, salinity and alkalinity, the presence of which can be detected or traced by "tasting", fluoride presence in water cannot be detected without the help of water quality testing equipment. The presence of high fluoride content in groundwater is often detected from its manifestations in such symptoms on human beings as yellowing of teeth, damaged joints and bone deformities, which occur from long years of exposure to fluoride containing water. Due to these reasons, the communities in many regions were exposed to drinking water containing high levels of fluoride for a long period of time without being much aware of it. By the time the communities realized the "menace", a large section of the population had already been affected. A recent IWMI survey in north Gujarat showed 42% of the people covered in the sample survey (28425) affected by some form of fluorosis. While 25.7% were affected by dental fluorosis, 6.2% were affected by muscular skeletal fluorosis and 10% by both.

The biological and toxicological effects associated with the use of water containing fluoride for drinking and cooking are yet to be fully explored. But if the available scientific knowledge is any indication, the potential effects are dangerous. Studies on fluorotic human populations of North Gujarat carried by Sheth FJ, Multani AS and Chinoy NJ (1994) revealed an increase in frequency of sister chromatic exchange in fluorotic individuals as compared to the control indicating that fluoride might have genotoxic effect. Fluoride had been reported to cause depressions in DNA and RNA synthesis in cultured cells (Strochkova *et al.*, 1984). A study by Patel and Chinoy to evaluate the effects of fluorides on nucleic acid and protein levels in the ovary and the fertility impairment in mice under experimental fluorosis showed significant reductions in DNA and RNA levels (Patel and Chinoy, 1998). Inhibition of DNA and RNA synthesis may result in delayed mitotic and meiotic cycles including chromosomal breakage (Vorishilin *et al.*, 1973). Several human conditions including ageing, cancer, and arteriosclerosis have been associated with DNA damage and its disrepair.

The presence of iron in drinking water is not a health hazard, though iron can cause reddish brown staining of laundry, dishes, porcelain, utensils, and glassware (http::/ianr.unl.edu./puls/water/gl280.htm). Long periods of consumption of water containing high levels of salts (above the permissible levels of 500 ppm) can cause kidney stones, a phenomenon widely reported from north Gujarat, whereas highly saline water for bathing can cause skin rashes in human body. Exposure to arsenic contaminated water causes a disease called arsenicosis, for which there is no effective treatment, though consumption of arsenic free water could help affected people at early stages of ailment to get rid of the symptoms of arsenic toxicity (Ali *et al.*, undated). Arsenic contamination of groundwater in deep aquifers is by far the biggest mass poisoning case in the world (*Down to Earth*, October 15, 1996) putting 20 million people from West Bengal and Bangladesh at risk (McArthur *et al.*, undated) though some other estimates put the figure at 36 million people (see for instance Ali *et al.*, undated).

3.0 CHALLENGE OF TACKLING GROUNDWATER CONTAMINATION AND POLLUTION PROBLEMS

3.1 Technical Issues

Addressing groundwater contamination and pollution issues has two aspects: 1] preventing pollution and contamination of the resource; and 2] curing the contamination or pollution of the aquifers using in situ treatment measures. The issues concerning these are discussed here.

The first step towards evolving measures to preventing and curing groundwater quality deterioration is generating reliable and accurate information on water quality and the causes. This is because both the preventive measures against pollution/contamination and the "in-situ" treatment measures for quality improvement depend on proper water quality monitoring to understand the actual source/cause, type and level of contamination. There are four important issues associated with water quality monitoring (WQM).

First: there are a few observation stations in the country that cover all the essential parameters for water quality and hence the data obtained are not decisive on the water quality status (Biswas and Sharma, 1995). Second: WQM involve expensive and sophisticated equipments that are difficult to operate and maintain; and require substantial expertise in collecting, analyzing and managing the data. In a country like India, where water technology is still not advanced, it is very likely that the available data on water quality is less reliable (Biswas, 1996). Third: the existing methodology for WQM is inadequate to identify the various sources of pollution and contamination of water (Moench and Metzger, 1992). Fourth: available water quality data are hardly integrated with data on water availability of water supplies. But, such integration is very important not only from a purely physical science perspective, but also from the point of view of assessing water availability for meeting various social, economic and environmental objectives (Moench, 1995).

Over and above, the outcomes of water quality tests depend heavily on the sampling procedure, time of testing, testing instruments and procedure and the way results are interpreted. In the absence of any strong stringent norms on water quality testing, this can change from agency to agency.

Treatment of wastewater and reuse is a major step towards prevention of aquifer pollution, especially in view of the fact that huge amounts of wastewater, which cities generate is not treated and is disposed off into natural streams and rivers or diverted for irrigation. Both have hydrological implications. These natural streams often meet with shallow aquifers contaminating them. On the other hand, the return flows from irrigated fields also percolates down to reach groundwater systems. Groundwater contamination in Pune, Kolar and Ahmedabad are examples of such incidences.

Israel's water company "Mekorot" reclaims about 68% of its effluents generated from DAN region comprising an agglomeration of 10 cities in the country through preliminary, primary and secondary treatments (waste stabilization pond) totaling about 190 MCM of water annually for agriculture. The treated wastewater from cities is then used for recharging the aquifers in the vicinity of the treatment plants using soil aquifer treatment (SAT), and the same is pumped out at high rates to create cones of depression so as to prevent mixing of this lower quality water with the natural groundwater for used for drinking. The Soil Aquifer Treatment reduces both biological and chemical contamination. This water put into the national water system and is reused for irrigation by farmers (source: http://www.matimop.org.il/newrdinf/company/c2029.htm). But in India, the wastewater situation is quite alarming. Out of the total 26254 MLD of wastewater generated, only 7044 MLD is treated and disposed. Going by city categories, only 29% of wastewater generated in Class I cities (and 3.7% of the wastewater generated in Class II towns is treated (Bhardwaj, 2005). Therefore, the small towns can pose major challenges in future if the situation w. r. to treatment continues to remain the same.

Now let us examine technical issues in mitigating contamination and pollution. In the case of seawater intrusion, artificial recharge techniques are available for different geo-hydrological environments and tried out successfully in India too. Monitoring undertaken by Shri Vivekananda Research and Training Institute in their project area in coastal Kachchh had shown substantial reduction in groundwater salinity after recharge interventions. If scientifically executed, artificial recharge could push seawater-freshwater interface seawards (Raju, 2004). The technique can also be used to reduce the levels of fluoride, arsenic or salinity in aquifer waters on the principle of dilution (cgwaindia.com/arsenic.htm). But, the issue is mainly of availability of surplus fresh water for recharging, particularly in arid and semi arid regions like Peninsular and Western India that would make perceptible difference in water quality given the regional extent of aquifers that are contaminated.

In the case of industrial pollution, the issues are of three types: pumping out polluted water from the aquifer; treated this water to safe limits; and replenishing the depleted aquifer with freshwater. Technically feasible methods to clean polluted water often dot exist due to highly toxic substances in trade effluents as seen in a case in Rajasthan where a sulfuric acid manufacturing unit rendered drinking water source in 22 villages useless. Finding enough freshwater for replenishment was also a problem there.

3.2 Financial Issues

Even when it is technically possible to clean aquifers, they are not economically viable in Indian context. In the case of arsenic, methods for in situ treatment have already been in use in developed countries. In the United States, zero-valent, iron permeable reactive barriers (PRBs) are used in situ to remove chromium and several chlorinated solvents in groundwater and are tested successful for removing arsenic (Smyth *et al.*, undated). The country is too poor to afford some of the technologies that are successfully tried out in the west, especially United States that are prohibitively expensive. Cleaning polluted aquifers is often prohibitively expensive. The cost of cleaning the aquifer in the Rajasthan case was estimated to be 40 crore rupees, where as the amount that was generated by auctioning the manufacturing unit was a mere five lac rupees.

This apart, there are practical issues in enforcing stringent pollution control norms and implementing court decision against violators, especially large number of small polluting units. In developing countries such as India, local economic growth and livelihood concerns over-ride concerns of long term sustainability of economic growth and environment, and often local communities do not support legal actions like "closure" of production units as they form their sources of livelihood. Nevertheless, there are recent examples which show otherwise. People from Plachimada in Palakkad district of Kerala had on their own have forced coca cola plant to close down their production, through litigation. This is a situation where the local economy is at a level where people can forgo small economic gains for the cause of their ecology and environment, which pay dividends in the long run. On the other hand, when it comes to municipalities and local self governments, they often lack resources to invest in environmental management projects like wastewater recycling units in urban areas, which serve common interests.

3.3 Institutional Challenges in Preventing Pollution and Contamination

In India, groundwater quality monitoring is primarily the concern of the Central Ground Water Board and the state groundwater agencies. Each of them set up their network monitoring groundwater levels and quality. But there are several issues concerning adequacy of scientific data available from such monitoring. *First*: the network of monitoring stations is not dense enough. *Second*: only limited parameters are covered in water quality analysis (such as TDS, fluoride and nitrate), and it excludes some of the critical parameters that help detect fertilizer and pesticide pollution, and pollution by heavy metals and other toxic effluents. There is also lack of consistency across agencies engaged in data collection vis-à-vis time and periodicity of data collection, number of parameters covered, testing equipments used and interpretation of results.

Though the issue of groundwater pollution had been a source of many controversies recently, the available scientific data, particularly that of pollution from industrial effluents and fertilizer/pesticide residues is of civil society institutions. In our country, there is a dearth of civil society institutions that are capable of carrying out such professionally challenging and technologically sophisticated, and often politically sensitive tasks.

Central Pollution Control Board (CPCB) and the State Pollution Control Boards (SPCBs) are the pollution watchdogs in India. Monitoring of groundwater quality has come under its purview, though with a limited objective, only in the recent past. The SPCBs monitor water quality under two programs- GEMS (Global Environmental Monitoring System) and MINARS (Monitoring of Indian National Aquatic Resources System) as per CPCB guidelines. Under the GEMS program the water quality of the major rivers of the state is monitored. Under the MINARS project also the water quality of the Rivers is being monitored. Monitoring, however, does not cove "non-point" pollution caused primarily by agricultural activities.

An analysis of the performance of Gujarat State Pollution Control Board (GPCB), with particular reference to Sabarmati river basin, showed that of the four priority areas identified by the Board for operations, its performance has been below satisfactory, in all except the first one, i.e., identification of areas facing severe pollution problems (Kumar and Nagar, 2001). The monitoring ability itself is doubtful as the agency maintains only two observation wells for groundwater quality monitoring in the basin having a drainage area of 21,000 sq. km. The GPCB also lacks adequate staff to carry out its functions, including pollution monitoring and environmental auditing (GPCB, 1996). As regards agricultural pollution, and pollution caused by the municipalities, there is not enough clarity about the jurisdiction of the Board.

There are problems associated with institutional design itself. The SPCBs perform the dual functions of monitoring pollution and enforcing pollution control norms for industries. But, the fact that regular WQM and its proper dissemination itself could question the existence of the Boards as an enforcement agency creates a disincentive for them to perform the first function meaningfully. Another important factor which weakens the institutional capability of the agency is that the user cost of polluting is less than the cost of treatment, primarily because the SPCBs lack legal teeth and administrative apparatus to penalize polluters. This creates disincentive for effluent treatment. On the other hand, the Boards are not mandated to execute projects such as those for aquifers cleaning, and water treatment/recycling.

Another problem which compounds the low cost of pollution is the ridiculously low prices people pay for water, due to the populist measures adopted by elected governments. In most Indian cities, urban water supply through public systems is not metered and water tax is attached to property tax. This leaves no incentive for people to use water efficiently and reduce wastewater generation. On the other hand, low water prices mean low revenue for the water utilities to invest in clean water production systems. But in situations where water supply is metered and where the volumetric price of water is prohibitively high, users resort to recycling. The best example is the industries in Chennai, which have installed treatment systems to recycle their water. Their cost of treatment was estimated to be less than that of the price they have to pay to Chennai Metro Water.

Now, let us look at the option of preventing groundwater contamination. Occurrence of fluorides, arsenic and salinity are most often the result of geo-hydro chemical processes, activated by hydrological stresses caused by pumping, whereas seawater intrusion in coastal aquifers occurs due to reversal of hydraulic gradient between sea level and water level in aquifers, occurring due to excessive pumping. Once contamination starts, very little can be done to check it except a total ban on pumping to prevent further deterioration.

But this is a very difficult option, as hundreds of millions of rural families in India depend on groundwater for sustaining irrigated agriculture and livelihoods (Shah *et al.*, 2003). In West Bengal, the biggest challenge in arsenic poisoning is that irrigation water is extracted through hundreds of thousands of tube wells from shallow aquifers, which have high levels of arsenic, and is also the main source of water for drinking (Ali *et al.*, undated). Any legal/regulatory interventions to ban pumping can be done only by depriving communities of their traditional rights. Though *de jure* rights in groundwater are not defined, land owners enjoy *de facto* right to extract groundwater underlying their land.

While nitrate pollution of groundwater is a great threat in intensively irrigated, green revolution areas like Punjab, the same can be properly controlled through practices such as applying only recommended dosages of fertilizers, crop rotation, timing of fertilizer application to correspond to crop use, and use of organic manure instead of chemical fertilizers. But, there are no institutional regimes governing fertilizer use and dumping of animal waste by farmers. The Netherlands, which faces a serious threat from animal waste, has been successful in checking nitrate pollution through strict regulations on livestock holding size and biomass use.

4.0 EMERGING PREVENTIVE MEASURES FOR REDUCING IMPACTS ON HUMAN HEALTH

The technological and institutional issues in preventing groundwater contamination and pollution are too important in today's context to be ignored. Greater is the challenge in initiating curative measures, posed mainly by lack of finance. Hence, there is a need to focus on measures for reducing or nullifying the ill effects, of which the priority today is that on human health.

4.1 Demineralization Technologies for Cleaning Groundwater

Escape route from deadly ions and organisms besides pesticides being noticed in unacceptable proportions lies in water demineralization systems. Reverse Osmosis (RO) is the process to get rid of all the impurities in drinking water. Under RO-systems water is made to pass through semi permeable polyamide membranes having a pore size of 0.0001micron (1 micron=1/1000th mm). Pore size being small, pressure (about 8-10 kg/cm^2) needs to be applied to make pure water molecules pass through them. Only 5-10% of the ions are able to slip across these membranes in spite of such a high pressure. These 5-10% ions are well within acceptable levels as per all standards including WHO, BIS, etc.

Contrary to the common perception that RO systems are only suitable for desalination, it is suitable for removing several of the toxic substances present in water in dissolved form, including fluoride, fertilizer and pesticide residues, and heavy metals. The cost of demineralization using RO system depends on: 1] the plant capacity and the level of capacity utilization; 2] the level of salinity and other impurities in raw water and the required quality of treated water; and 3] the distance from the source of water and the safe disposal sites. Higher the level of impurities in raw water and the quality required for treated water, higher will be the cost of membrane and operating cost. The cost of desalination could vary anywhere between Rs.0.03 per litre (for brackish water) to Rs.0.10 per litre (for seawater). Normally, the cost of treating brackish water would be in the range of Rs.0.04-Rs.05/litre.

Research done by Central Salt and Marine Chemical Research Institute, Bhavnagar shows that if the salinity of the raw water is below 6000 ppm, desalination using RO system will be more cost effective, with cost per litre of water in the range of Rs.0.017-Rs.0.02. Again, their research shows that if the salinity level of the raw water is below 5000 ppm, the technique called electro-dialysis can be used for desalination. It is far less expensive than RO technique by virtue of the lower capital cost and consumption of electricity for plant operation. The cost of producing water would be in the range of Rs. 0.003-Rs.0.006/litre of water, if the salinity levels of 3000-5000 ppm (IRMA/UNICEF, 2001). There are many regions in India, which face problem of high salinity along with high fluoride in groundwater, but the salinity levels remain far less than that of sea water. Low cost desalination systems, which can bring down TDS and fluoride to below permissible levels, could be used for providing high quality drinking water.

4.2 Low Cost Technologies for Removing Arsenic from Groundwater

Low cost filters for removal of hazardous chemicals such as arsenic and fluorides are under various stages of research, development, replication and production across the world. One of the household arsenic treatment methods is ferric chloride coagulation (alum and iron coagulation) system. This involves precipitation of arsenic by adding a packet of coagulant in 25 litres of tube well water, and subsequent filtration of the water through a sand filter. Field experiments showed arsenic concentration of treated water to be nearly 20 parts per billion (ppb) or 0.02 mg/litre, while the raw water had an arsenic concentration of 400 ppb. It also showed the efficiency of removal of arsenic increased with increasing doze of ferric chloride and setting time. The cost of chemical (ferric chloride) for treatment is Rs.0.09 per litre of raw water to be treated.

The second method for removal of arsenic is based on "sorptive filtration based on iron coated sand bed". But this system has a pre treatment system for removal of excess iron from raw groundwater. Water is first put in a bucket and stirred for some time to accelerate precipitation of excess iron. It is then allowed to pass through a sand filter where the excess iron is filtered out. Finally the water is passed through an iron coated sand filter. Experiments with different thickness of sand filters (20cm, 40cm) showed that the efficiency of removal of arsenic reduced drastically beyond a certain bed volume with the arsenic concentration of treated water crossing the permissible limit of 50 ppb. With a 40 cm thick iron-coated sand bed, nearly 300-350 bed volume of water could be treated before the break even point of 50 ppb and by maintaining a flow rate of 10-15 ml/minute for the treated water (Ali *et al.* undated)

The third method involves filtration of arsenic from raw water by passing it through a gravel media containing iron sludge. The iron sludge is prepared by using compounds, viz., ferric sulfate, ferrous sulfate, and ferric chloride. The pH value of the respective iron salts is first raised by adding sodium hydroxide. A study carried out by Ali *et al.* (undated) to evaluate the performance of these three alternate arsenic removal methods showed the first two systems to be superior, with the first one found to be most acceptable to the villagers.

5.0 INSTITUTIONAL CHALLENGES IN IMPLEMENTING PREVENTIVE MEASURES

5.1 Building Technical and Management Skills Available with Water Supply Agencies

This is an important issue when it comes to running sophisticated water treatment systems. The available treatment systems work on the principles in physics and chemistry. Hence, their efficiency depends heavily on maintaining certain specified operating conditions. This would call upon qualified technical manpower to be engaged in system operations, and regular O & M. The experience of Gujarat with desalination systems illustrates this. The Gujarat Water Supply and Sewerage Board (GWSSB) had set up 28 desalination systems for provision of safe drinking water in salinity-affected villages. All of them became dysfunctional within a very short span of time due to several reasons (source: GWSSB, 2004). Desalination plants in Tamil Nadu also met with the same fate. Most of the 117 desalination plants commissioned in eight states by government agencies are non-operational. The most important reasons being: lack of technical manpower for operation and maintenance of the system, and improper selection of membrane without enough considerations to quality of raw water (GOI, 1999). To prepare the agencies to take up the challenge of providing safe drinking water, it is important to: expose and orient them to physical and economic aspects of water purification technologies; build their capacities to design and implement them to suit the local physical and socioeconomic conditions: and to develop sufficient technical manpower for their O & M within or outside the agency.

5.2 Making People Pay for Safe Drinking Water Supply Services

Most of the treatment systems available for drinking water such as demineralization systems have to be tried out at the community level to be cost effective and affordable. Since governments have to invest heavily for or have already invested in domestic water supply services in both rural and urban areas, with no major revenues being accrued from those services due to heavy subsidies and poor recovery, additional investment for provision of safe water for drinking and cooking is going to induce unprecedented financial burden. Therefore, it will be more appropriate for the line agencies to build and operate water treatment systems on the principle of full cost recovery. The water supplied from the system has to be affordable to all classes of the society. Affordability is important because access to water for drinking is essential for survival and therefore has to be treated as a fundamental right. Therefore, unit cost of production should be minimized. For treated water, a price of Rs.0.10/litre (with a production cost of Rs.0.05/litre and 100% profit margin) should be affordable for any family, which will spend around 30 rupees per month.

In Mehsana district, people in towns are buying water at a price of Rs.0.35-Rs.0.41/litre from private RO operators and such markets covered only 0.4% to 5.0 % of the urban population in different towns. A study of 14 plants showed that their production cost varied from Rs.0.14/litre to Rs.0.45 per litre with varying capacity utilization (Indu, 2002). To an extent, the unit cost of production could be brought down by running the plant at peak capacity, which means creating sufficient demand. Higher demand make selling price of water for achieving commercial viability lower. Offering water at lower cost itself can create more demand and ensure affordability across classes. Whereas the unit cost of production of water reduces with increase in plant capacity (GOI, 1999), this lowers the chances of running the plant at full capacity, which means higher operating costs. Hence, optimal plant design, proper selection of membrane etc. are important from the point of view of bringing down the cost of production.

Level of professional inputs that go into management of public water supply systems would be far less than adequate to manage these systems, especially village communities have to be made aware of the benefits of consuming treated water and demand has to be generated. This is evident from the fact that out of the 11 demineralization plants set up by the state government have become dysfunctional, primarily because of the lack of demand (Indu, 2002). Over and above, operating costs for government run systems are likely to be high due to high administrative overheads. As a result, new techno institutional models need to be evolved to manage the system in order to make them self sustaining. Involving private sector in provision of clean and safe drinking water would be crucial to achieve the multiple objectives of reliability, adequacy, water quality, financial sustainability, commercial viability, and affordability.

5.3 Strengthening Civil Society

In many instances, people's perceptions about drinking water quality are wrong and concern mostly with taste and colour of water rather than its chemical constituents. This includes urban areas as well. Mostly, people raise alarm about poor water quality only after seeing or detecting ill-effects of consuming contaminated or polluted water. By the time, enough damage would have already been created. The civil society/institutions need to be strengthened to be able to respond to water quality problems quickly. This is possible through better knowledge and information about the nature of groundwater contamination, potential sources of threats to groundwater quality in their region and degrees of vulnerability, the ill-effects of using contaminated water, and the possible preventive measures.

They can in turn help them put pressure on the line agencies like the Pollution Control Boards, State Water Supply Agencies, and Panchayats to perform. Emphasizing on the róle of civil society institutions is particularly important because groundwater quality variations in nature are often sporadic; pollution involve complex considerations of soil characteristics, nature of pollutant, and geo-hydrological environment; and as a result it is extremely difficult for monitoring agencies to be pro-active, through establishing elaborate network of WQM stations, due to the high financial/material resources and technical manpower required. Given the absence of complete information about quality of water in various sources, it is also not possible for them to think about treatment measures. Also, the willingness of people to pay for water is directly linked to their own perceptions about drinking water quality and the knowledge and awareness about ill-effects of drinking contaminated/polluted water. Credible and technically competent civil society institutions can play a big role in generating the vital database on groundwater quality, and could complement the activities of the government.

6.0 CONCLUSIONS AND POLICY INFERENCES

The major issues involved in preventing and taking curative measures against groundwater contamination and pollution concern availability of adequate scientific data, and technical feasibility of curative measures; financial capability, and institutional adequacy for water quality and pollution monitoring and control. Hence, preventive and curative measures against pollution and contamination of groundwater may continue to receive low priority for years to come. The short tem priority would be technological measures to prevent the ill effects on human health.

Demineralization using RO system can remove all forms of impurities from drinking water and would be cost effective in many situations where groundwater TDS, nitrate and fluoride above permissible levels and are becoming increasingly cost effective. The cost of production of water can vary anywhere between Rs.0.017-Rs.0.10/litre of water, and is falling rapidly. Saudi Arabia meets 20% of its total water needs from desalinated sea water, and Saudi technologists believe desalination costs would fall so rapidly over the coming decades that desalination will be cheaper than pumping coastal aquifers. This being the case, de-fluorination will for sure emerge as a powerful option to reduce human misery due to consumption of poor quality groundwater. The issue is appropriate management of the technology.

New institutional models for managing decentralized treatment systems could be thought about with emphasis on financial viability, commercial viability and affordability. Three-way collaboration amongst NGOs, line agency of the government and a private agency having expertise in plant design and operation, could be an idea to work on. Literature shows at least three, alternative low-cost filtration technologies for removal of arsenic from groundwater. Ferric chloride coagulation for precipitation of arsenic and subsequent filtration using sand filters is an effective and user friendly one. It is possible to set up these filters at household level.

There are, however, three challenges in implementing technological measure by water utilities. First: building technical and managerial skills of water supply agencies to design, install, operate and manage sophisticated water treatment systems. Second: make people pay for treated water to make the approach commercially viable and financially sustainable. Third: build knowledge and awareness about potential threats to groundwater quality, ill effects of consuming contaminated water, and treatment alternatives. For the long run, policies need to be focused on: 1] building scientific capabilities of line agencies concerned with groundwater quality monitoring, water supplies, and pollution control such as state pollution control boards, and groundwater planning and development agencies, for improving their WQM system; and 2] reorienting or restructuring them to perform WQM and enforcing pollution control norms more effectively and to be able to perform new tasks of implementing projects on pollution control and aquifer cleaning. But, for the immediate future, the emphasis of water supply line agencies has to be on promoting decentralized water treatment systems for safe drinking water supplies and institutional models to ensure commercial viability, financial viability and affordability.

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