ISSN:2319-2607 IISUniv.J.Sc.Tech. Vol.2(1),98-106 (2013)

GENERAL ARTICLE

Chemical Contaminants in Drinking Water and their Health Effects

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Abstract

Safe drinking water is essential for healthy life, yet it has been observed that worldwide, millions of people are deprived of this. Microbial pathogens (Bacteria, virus and protozoa) and harmful chemicals are the two major pollutants that can contaminate drinking water. Former usually leads to immediate adverse health effects whereas the effects from latter are generally associated with long term exposures. Chemicals in drinking water can cause serious health problems. A number of chemical contaminants like heavy metals (arsenic and lead), fluoride, iron, disinfection by-products (trihalomethanes), agricultural chemicals (nitrates and pesticides), hydrocarbons particularly from petroleum oils and radioactive chemicals like radon have been identified in drinking water. These contaminants reach drinking water supplies from various sources, including urban, rural and agricultural run-off, industrial and municipal discharges, natural geological formations, drinking water distribution materials (pipes) and treatment (chemical treatment) process of drinking water. The adverse health effect induced by these contaminants includes respiratory problems, various cancers, adverse reproductive outcomes, neurological and cardiovascular diseases. Therefore delivering safe and acceptable water is prerequisite in improving public health in both developed and developing countries. For removal of chemical contamination, technologies such as sorption, ion exchange and aeration are typically used. Also regular monitoring of water supply and proper management of water resources (surface or ground water) is needed for cleaner and healthier environment.

Keywords

Drinking water, Pollutants, Chemical contaminants, Health effects

Introduction

Water is a natural resource essential for survival of human beings. It has been observed that safe drinking water is not available to million of people worldwide. Surface and ground water are the two major sources used for drinking purpose. Ground water accounts for 65% of Europe's drinking water (Holt, 2000) whereas in India, 30% of urban and 90% of rural households depend completely on untreated surface or groundwater (Kumar *et al*, 2005).

Microbial pathogens (Bacteria, virus and protozoa) and harmful chemicals are the two major pollutants that can contaminate drinking water. Former usually leads to immediate adverse health effects whereas the effects from latter are generally associated with long term exposures. In India around 195,813 habitations are affected by poor water quality due to disturbed chemical parameters (Srikanth, 2009). Both surface and groundwater are at risk. Therefore in both developed and developing countries water quality continues to be a major health concern (World Development Report, 1992).

Chemical contaminants reach drinking water supplies from various sources, including municipal and industrial discharges, urban and rural run-off, natural geological formations, agricultural run-off, drinking water distribution materials (pipes) and the drinking water treatment process (Calderon, 2000). Chemical contamination in water causes serious health effects. Therefore to ensure public health and environment safety, national standards or international guidelines have been prepared to judge the quality of drinking water. WHO, guidelines are the most important for drinking water quality. However, guidelines are now based on water safety plans that encompass a much more proactive approach to safety from source to tap (Thompson *et al*, 2007).

Common Sources of Chemical Contaminant in Drinking Water

Natural waters contain a wide range of organic and inorganic chemicals. The inorganic chemicals are derived

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from the rocks and soil through which water percolates or over which it flows, whereas organic chemicals are derived from breakdown of plant material or algae and the other microorganisms growing in the water or on sediments (WHO, 2004). Presence of natural occurring chemical constituent is of concern depending on the geology, physical and chemical conditions affecting solubility (WHO, 2004).

Chemical contamination in water might be due to natural disturbances and also the result of human activities. Presence of chemical substances in water sources (surface and ground water) depends on the number of factors, including how and where the substance emitted, volume, release pattern and the transformation (biodegradation, hydrolysis, photolysis) processes (Holt, 2000). Surface water can be contaminated through direct or indirect emissions and groundwater can be contaminated by leaching from the soil. Climate also has an important role in affecting the way the rocks are broken down and extent to which minerals are leached into rivers or groundwater.

Water demands had been increased due to excessive industrialization, urbanization, intensified agricultural activity and has resulted in release of contaminants in the environment water (Holt, 2000). Industrial activities like manufacturing, processing and mining, water treatment and distribution activities like water treatment chemicals, corrosion of and leaching from storage tanks and pipes are responsible for pollution in water sources (US EPA, 2006). For example, heavy metals and solvents such as tri and tetrachloroethene are sometimes found in groundwater and hydrocarbons, particularly from petroleum oils (WHO, 2003). Domestic waste water, industrial effluents containing phosphorus and nitrogen, agricultural and fertilizer run-off and manure from livestock operations, increase the level of nutrients in water bodies. This may results in eutrophication in the lakes and rivers (Sujatha *et al*, 2012).

Agricultural activities like application of manure, fertilizers, and pesticides, human settlements like, sewage and waste disposal, urban runoff and fuel leakage are responsible for release of chemicals in the environment (WHO, 2004). In the urban areas, most common reason for water contamination is the presence of leaky water pipe joints in areas where the water pipe and sewage line pass close together (WHO, 2008).

Potential Health Effects of Chemical Contaminants

Quality of drinking water and health risk associated with it vary throughout the world. Chemical contamination has more serious impact on health of population and occupational people (Demin, 2007). Some regions show high levels of chemical contaminants like arsenic and fluoride whereas in some regions they are very low and present no health problem. Some of these chemicals and their health effects are discussed here.

Inorganic Chemicals

Inorganic chemicals like fluoride, arsenic and to a lesser extent selenium are naturally occurring chemicals that have been responsible for severe health effects. Arsenic and fluoride are present as groundwater contaminants in many developed and developing countries. Both of these toxicants are introduced into the environment by natural and industrial sources (Tseng *et al*, 2005; Mittal and Flora, 2007). Permissible limit (WHO and ISI) for some of the inorganic chemicals are shown in Table 1.

Table 1. WHO and Indian Standard (ISI) specifications for Drinking water

Constituents	WHO (mg/L)	ISI (mg/L)
Fluoride	1.5	0.6-1.2
Nitrate	10	45
Selenium	0.01	-
Iron	0.1	0.3
Manganese	0.1	0.1
Arsenic	0.05	0.05
Lead	0.05	0.10

(APHA, 2005; Kumar and Puri, 2012)

Fluoride

Excessive fluoride concentrations have been reported in groundwaters of more than 20 developed and developing countries (Meenakshi and Maheshwari, 2006). Fluoride can cause dental and skeletal fluorosis. The latest estimates suggest that around 200 million people, from 25 nations worldwide are under the dreadful fate of fluorosis. India and China, the two most populous countries of the world, are the worst affected (Ayoob and Gupta, 2006). In India 25 million people in 8700 villages are consuming water having high fluoride (Tailor and Chandel, 2010). Fluorosis, turns out to be the most widespread geochemical disease in India, affecting more than 62 million people including 6 million children less than 14 years age (Susheela and Majumdar, 1992). In recent years, increase in fluoride contamination can be attributed due to an increase in the number of industrial production of fluorinated compounds including fertilizers, pharmaceutical drugs (Mittal and Flora, 2007; Peter and Roger, 2004) and even coal combustion (Chouhan and Flora, 2010). Fluoride poisoning has been steadily increasing affecting millions of people worldwide.

Nitrate

It is naturally occurring element and occurs widely throughout the world in both surface and groundwater. Factors such as type of soil, climate, water table depth and the use of irrigation determine the rate and extent of nitrate transport into ground water and surface water (Sumner and McLaughlin, 1996). Excessive use of fertilizers, leaching from septic tanks, sewage and erosion of natural deposits is responsible for presence of nitrate contamination in drinking water. Excessive intake of nitrate in drinking water leads to serious illness in infants below the age of six months and if untreated, leads to death. Excessive intake of nitrogen above concentration of 50 mg/L leads to methaemoglobinaemia (blue- baby syndrome) (Avery, 1999).

Selenium

Discharge from petroleum, metal refineries and mines as well as erosion of natural deposits is common source of selenium contamination in drinking water. High selenium intake can give rise to loss of hair, weakened nails and skin lesions. It causes more serious changes in peripheral nerves and decreased prothrombin time (Barceloux, 1999).

Iron and Manganese

Iron and manganese are chemically similar metals and cause similar problems. Both iron and manganese can occur at high concentrations in some waters sources that are anaerobic (WHO, 2003). When the water is aerated they are oxidized to oxides that are of low solubility. These cause significant discoloration and turbidity at concentrations well below those of any concern for health. They may, however, cause consumers to turn to alternative supplies which may be more aesthetically acceptable but which are microbiologically unsafe.

Harmless bacteria in soil, shallow groundwater supplies and some surface waters secretes large amounts of red-brown (iron) or black-brown (manganese) slimes that stain toilet tanks. A colony of these bacteria has a mat-like, fibrous appearance and may clog water treatment systems or distribution pipes (Lemley *et al,* 2005). This results in presence of iron and manganese in household water

Arsenic

Arsenic occurs naturally or is possibly aggravated by over-powering aquifers and by phosphorus from fertilizers. High arsenic concentrations in water can have an adverse effect on health. It is a major cause of disease in many parts of world. It can cause cancers of skin, lung and bladder (IPCS, 2001; IARC, 2003). Clinical manifestations of chronic arsenic poisoning include hyper and hypo-pigmentation, hypertension, keratosis, cardiovascular diseases and diabetes. The current WHO recommended guideline value for arsenic in drinking water is 10 μg/ L (WHO, 2011), whereas in many developing countries like India value of 50 μg/ L (BIS, 2009) is considered to be permissible for arsenic in drinking water. It has been estimated that tens of millions of people are at risk exposing to excessive levels of arsenic from both contaminated water and arsenic-bearing coal from natural sources (Ng *et al*, 2003). Morales *et al* (2000), in his study of 42 villages of Taiwan, suggests that the current standard of 50 μg/L for arsenic is associated with a substantial increased risk of cancer and is not sufficiently protective of public health. Also, epidemiological evidence indicates that arsenic concentration exceeding 50 μg/ L in the drinking water is not public health protective (Morales *et al*, 2000).

Lead

Lead is a metal which has no significant biological role for human. Therefore, lead contamination in drinking water may lead to several health problems (WHO, 1993). Presence of Lead in drinking water is a consequence of pipes, service connections of household plumbing systems and lead containing metal fittings in buildings. It causes delay in physical or mental development in infants and children. Children could show slight deficits in attention span and learning abilities. In adults it leads to kidney problems and high blood pressure (WHO, 1993).

Organic Chemicals

Many of the 100,000 synthetic compounds in use today are found in the aquatic environment and accumulate in the food chain. POPs or Persistent organic pollutants are the most harmful element for the ecosystem and for human health, for example, agricultural pesticides and industrial chemicals. Covaci *et al* (2012), has reported effect of selected emerging organic contaminants in environmental matrices (air, dust, food, water, etc.) on human health and human matrices like blood urine, or tissues on their exposure. The organic pollution caused due to chlorinated aliphatic hydrocarbons, monocylic aromatic hydrocarbons, halogenated aromatic hydrocarbons, organochlorine pesticides and other pesticides and polycyclic aromatic hydrocarbons (PAHs) in some water samples of shallow aquifer sediments and groundwater around Zhoukou landfill in China have been recently reported (Han *et al,* 2013). The most dominant organic pollutant among above pollutants is PAHs, phenanthrene, fluorine, and fluoranthene which are detected in most of the groundwater samples (Han *et al,* 2013).

Pesticides

In agriculture fertilizers and other chemicals for control of insects, weeds and fungal pathogens are intensively used to increase crop yield (Aktar *et al*, 2009). These chemicals have been found to be present in food chain (DDT) and have long term affects in both health and environment.

The organophosphates and the carbonates present in pesticides damage the nervous system and can cause cancer (Pandey, 2008). Some of the pesticides contain carcinogens that exceed recommended levels. They contain chlorides that cause endocrinal and reproductive damage. Polychlorinated biphenyls (PCRs) and its metabolites, dibenzofurans, dioxins, polybrominated diphenyl ethers (PBDEs) and heavy metals (Sonawane, 1995; Hooper and McDonald, 2000) are most often found in breast milk. Highest level of contaminants are seen in women in agricultural areas of developing world that are extensively treated with pesticides (Hooper *et al*, 1999) and those who depend mainly on marine food chain like seals and whales that accumulate heavy burden of persistent organic pollutants (Dewailly *et al,* 1993). These are the consequence of decades of inadequately controlled pollution of the environment by toxic chemicals. Finding of these chemicals in breast milk raises a series of important issues for pediatric practices, for practice of public health and for environmental health research community (Landrigan *et al,* 2002).

Sewage

In developing countries, untreated or inadequately treated municipal sewage is a major source of groundwater and surface water pollution. The organic material that is discharged with municipal waste into the water courses uses substantial oxygen for biological degradation thereby upsetting the ecological balance of rivers and lakes (Sujatha *et al*, 2012). Bad odour, taste and gastrointestinal problems in humans are basically associated with contamination from sewage. Microbial pathogens carried by sewage are majorly responsible for causing waterborne diseases worldwide.

Radionuclides- Uranium and Radium

Ground water associated with granitic rocks and other mineral deposits are major source of uranium. It is toxic for kidney, associated with increase in fractional calcium excretion and increased microglobulinurea. It is a current topic of research with regard to exposure through drinking water (WHO, 2003). Radium 226 and radium 228 is added to water due to erosion of natural deposits and had lead to increased risk of cancer. The quality of the water in a uranium-ore-mining area located in Caldas (Minas Gerais State, Brazil) and in a reservoir (Antas reservoir) that receives the neutralized acid solution leaching from the waste heaps generated by uranium mining was investigated. In this study water was found to be contaminated with uranium (Rodgher *et al*, 2013).

Nosov *et al* (1999), reported the concept of "maximum safe concentration", "maximum concentration of radionuclides in bottom sediments" and "reference monitored concentration" of radionuclides in water, for determination which they used the basic public health principle established in NRB-96: to not exceed the limit of an effective dose of 1 mSv/y for external and internal radiation exposure for a critical population group, considering overall water use.

Disinfection Byproducts

Processes used for drinking water treatment, not only removes microorganisms but also chemical contaminants. Methodology used for water treatment use different chemicals like chlorine (most commonly used) and others like chloramines, chlorine-dioxide and ozone. Removal of contaminants results in formation of other contaminants such as trihalomethanes and haloacetic acids from reaction of chemical oxidants with natural occurring organic matter (Fawell and Nieuwenhuijsen, 2003).

Drinking water byproducts (DBP) have been associated with cancers of bladder, colon, rectum and adverse birth outcomes such as spontaneous abortion, (low) birth weight, stillbirth and congenital malformations in epidemiological studies (IPCS, 2000; Nieuwenhuijsen *et al*, 2000; IARC, 2003). Although drinking-water disinfection by-products (DBPs) have been studied for the last 30 years due to which significant concerns have emerged. Adverse reproductive and developmental effects had been recently observed in human populations. Drinking-water utilities are changing their primary disinfectant from chlorine to alternative disinfectants (e.g., ozone, chloramines and chlorine dioxide), which generally reduce regulated haloacetic acid and trihalomethane levels, but can increase the levels of other potentially toxicologically important DBPs. Bromo-trihalonitromethanes, iodo-trihalomethanes, dihaloaldehydes, MX (3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone) and brominated forms of MX are some of the examples of DBPs (Richardson, 2003) that are formed at higher levels when alternative disinfectants were used to treat drinking water. Presence of pharmaceuticals, organotins, methyl-*tert*-butyl ether

(MTBE) and perchlorate toxins in drinking water are some of the emerging concerns (Richardson, 2003).

Pharmaceuticals and Personal Care Products

Presence of pharmaceuticals and personal care products (PPCPs) in drinking water is an emerging area of concern during recent years (Fick *et al,* 2009). More than 150 active pharmaceutical ingredients (APIs) in nano and microgram concentrations per litre have been detected in surface waters. Excretion with urine and feces as well as inappropriate disposal of unused drugs is the main sources of contamination (Nikolaou *et al*, 2007; Williams and Cook, 2007).

Pharmaceuticals drugs detected in drinking water comprises of steroids, antibiotics, blood lipid regulators, antineoplastic agents, analgesics/anti-inflammatory dugs, tranquilizers and antiseptic agents (Daughton and Ternes, 1999).

Steroids like oral contraceptives and antibiotics like macrolides, sulfonamides, penicillins, and tetracyclines have been mostly detected in groundwaters/surface waters (Hirsch *et al*, 1999). Antibiotics in environment water not only affect the microbial community but also spread resistance in bacteria (Levy, 2002).

Blood lipid regulators like Clofibric acid is one of the most frequently reported PPCPs in monitoring studies. Clofibric acid levels have been reported upto concentrations of 10 and 165 ng/L (Stan *et al*, 1994) as well as 270 ng/L (Heberer and Stan, 1997) in drinking water samples.

Antineoplastic agents or antitumor agents (oxazaphosphorines, ifosfamide and cyclophosphamide) are the chemicals primarily used within hospitals for chemotherapy. These compounds have the potential to act as mutagens, carcinogens, teratogens and embryotoxins and thus can produce higher risk for any organism (Daughton and Ternes, 1999).

Antiseptic agent like triclosan has been widely used in commercial products like footwear, hospital handsoap, acne creams (e.g., Clearasil). Triclosan has also been regarded as a biocide. It has been detected in concentration ranging from 0.05 to 0.15 pg/L in water samples (Okumura and Nishikawa, 1996). Analgesics and anti-inflammatory drugs like diclofenac, indometacine, ibuprofen, naproxen, ketoprofen and phenazone have been detected in surface waters (Stumpf *et al*, 1996) and tranquilizer like diazepam is mostly detected in groundwater samples (Genicola, 1999). For limiting the levels of pharmaceuticals in wastewater or drinking water no federal regulations are currently present. Due to recent increase in the presence of these contaminants in drinking water, United States Environmental Protection Agency (US EPA) has added some pharmaceuticals to contaminant list (US EPA, 2009) to protect public health.

Personal care products comprises of bath additives, shampoos, skin care products, hair sprays, setting lotions, hair dyes, soaps, sun screens, perfumes and aftershaves. Many of these substances are used in very large quantities. These products in comparison to pharmaceuticals are released in large amounts directly into recreational waters or volatilized into the air (e.g., musks) and therefore can by pass possible water treatment processes (Daughton and Ternes, 1999).

Personal care products like pharmaceuticals drugs are capable of causing severe health effects like common sunscreen ingredients, 2-phenylbenzimidazole-5-sulfonic acid and 2-phenylbenzimidazole, can affect DNA breakage when exposed to UV-B (Stevenson and Davies, 1999). Benzotriazole and tolytriazole present in dishwasher powders are xenobiotic compounds and can have long term health effects (Janna *et al*, 2011). Parabens (methyl, propl, butyl and ethyl) used in shampoos, soaps, moisturizers, and other personal care products are endocrine disruptors. These compounds may cause adverse reproductive health effects including sperm count decline, hypospadias and cryptorchidism, and cancer of the breast and testes (Fawell and Nieuwenhuijsen, 2003).

Removal of Chemical Contaminants

Various techniques are used for removal of chemical (organic and inorganic) from drinking water. Some of these techniques are discussed here.

Sorption

Sorption technologies are used for the removal of organics and inorganic contaminants like heavy metals (Das *et al*, 2008). When a substance is incorporated into another substance, the process is called absorption. Adsorbents used at drinking water plants include: activated carbon, activated alumina and iron-based media. The contaminants physically adhere or bond to the surface of these adsorbents and thus remove contaminants.

Water Softening

Calcium, magnesium and certain other metal cations (positively charged ions) concentration in water can be reduced by the method of softening. Ion exchange is the most common method of softening used in drinking water treatment. This technology removes arsenate, selenate, nitrate and chromate from municipal water (US EPA, 2013). It selectively removes charged inorganic species from water using an ion-specific resin. When water is passed through a resin column, charged functional groups present on resin surface hold undesired ions present in water by electrostatic attraction. Because of its higher treatment cost compared to conventional treatment technologies, the ion exchange is mostly used by small, medium, and point-of-entry systems. Chemical flocculation transforms dissolved contaminants into an insoluble solid that is easily removed from the water by sedimentation (contaminants settle out of the water and come to rest) or filtration. Chemical precipitation uses treatment chemicals to form particles that remove contaminants and settle them (US EPA, 2013).

Other technologies include Aeration and Electrodialysis. Aeration technologies are typically used for removal of volatile organic compounds and excess carbon-dioxide. It is the process of mixing water with air by cascading or spraying. In this process chemical to be removed is transferred from the water to the air stream. There are two types of Aeration, open and closed. Former uses pressure to remove molecules whereas later uses gravity to remove gases. Electrodialysis is a process in which ions are transferred through ion-selective membranes by means of an electromotive force from a less concentrated to a more concentrated solution. This technology is found to be very effective in removing nitrates and fluorides. It can also remove barium, cadmium, and selenium (US EPA, 2013).

Also Carbon nanotube (CNT) adsorption technology along with point of use (POU) based treatment approach can be used for removal of bacterial pathogens, natural organic matter (NOM), and cyanobacterial toxins from water systems. CNT technology has been more effective than conventional water treatment plants in treating biological contaminants (Upadhyayula *et al,* 2009).

Pharmaceutical can be removed from drinking water by chlorine, chlorine-dioxide and ozonation processes. Chlorine treatment has been found efficient in removing drugs like triclosan, bisphenol A, and nonylphenol (Alum *et al,* 2004, Westerhoff *et al*, 2005). Removal of sulfamethazine, sulfamethoxazole, estrone, roxithromycin, erythromycin, and diclofenac can be achieved by chorine-dioxide (Huber *et al,* 2005).

Ozone doses greater than 2 mg/L have been found to be very effective in the transformation of many pharmaceuticals (sulfamethoxazole, oxithroymcin, diclofenac, and naproxen) and steroids (estrone, 17β-estradiol, 17α-ethinylstradiol) (Ternes *et al,* 2002; Alum *et al*, 2004; Huber *et al*, 2005; Westerhoff *et al*, 2005). Pressure membranes, such as reverse osmosis (RO) and nanofiltration (NF), are also found to be very effective in the physical separation of a variety of pharmaceuticals from water (Bellona *et al,* 2008).

Preventive Measures

Waterborne epidemics and health hazards in the aquatic environment are mainly due to improper management of water resources. In Minamata, Japan, discharge of MeHg (methyl mercury) lead to environment pollution which not only affects the organisms in sea (fishes) but also the residents of the area. Experience of this disease showed that health and environment should be equally considered and integrated in the process of economic and industrial development. Thus, regular monitoring of water supply and proper management of water resources (surface or ground water) is needed for cleaner and healthier environment.

Management strategies should consider national and local disease surveillance data and epidemiological studies. Also risk management strategies for chemicals in drinking water should consider alternative routes of exposures (e.g. Food) that equal or surpass the importance of exposures through drinking water (WHO, 2004; WHO, 2006).

Adequate precautions should be taken by the people to prevent spread of water-borne diseases, water supply of city should be properly checked and regularly monitored. Water pipes should be regularly checked for leaks and cracks. At home, the water should be properly filtered, boiled or other methods and necessary steps taken to ensure that it is free from infection.

Good agricultural practices can help in reducing the amount of nitrates in the soil and thereby lower its content in the water. Use of biofertilizers should be emphasized.

Government should keep a regular check on industries, on their methods of proper waste management and disposal. If any of the industry is found guilty in polluting the environment, serious action should be taken against them. Government should also set guidelines to limit the levels of pharmaceuticals and personal care products in drinking water samples.

Conclusion

Chemical contaminants enter into drinking water supplies from natural to anthropogenic sources (agriculture, industry and household). Long term exposures of these chemicals (inorganic, organic, radionuclide's and disinfection byproducts, pharmaceuticals and personal care products) not only cause environment pollution but also lead to serious health effects like ailments developing in skin , respiratory system, cardiovascular system and cancers in humans. Therefore it is very essential to regularly monitor the presence of these chemicals in drinking water. If any of the above mentioned contaminants is found to be above the prescribed limit given by WHO and National standards, serious measures should be taken by the government to prevent people from exposure of these chemicals.

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