Chapter 27
Water Quality and Human Health

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Abstract Availability of fresh water has always been an important factor impacting human population and civilizations. However, with the growth of population and economy, the pollution from anthropogenic activities is degrading the quality of water. The degradation in water quality is affecting the health of mankind and ecosystem. It is benign to understand the water quality parameters impacting the human health for judicious management of water quality. This chapter discusses about the significance of water quality parameter impacting the drinking water from aesthetic, health, and operational point of view, methods of analysis, and treatment techniques for reducing the contaminants.

27.1 Introduction

"Water, water, everywhere, Nor any drop to drink", the lines from "the Rime of the ancient Mariner" written by Samuel Taylor Coleridge, has very well illustrated the importance of water quality long back in 1798, when the inland waters were not contaminated. Even the ancient literature, Rig Veda, talks about the quality of water for the well-being of mankind and the measures for improvising the quality of water in the verse 83.4

प्र वाता वन्ति पतयन्ति विद्‌युत उदोषधीर्जिहते पिंवते स्वः।
इरा विश्वम्भै भुवनाय जायते यत्पर्जन्यः पृश्वी रेतसावति ।।

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The change in hydromorphology, rise in emerging pollutants, and spread of invasive species resulted in loss of pristine quality water bodies, due to which the water quality problems persist in developed and developing countries alike (WWAP 2019). Poor water quality increases water-related health risks. In developing countries, where only a small fraction of the wastewater is treated prior to release in the environment, several water-related diseases, including cholera and schistosomiasis prevail. WHO (2016) reported 4% of the population in low income economies suffered from diarrhea in 2015, among whom 60% were children below age of five. Access to potable water is essential for the development of a nation, since it improves human health, reduces health care costs, reduces mortality, and increases the working days, thereby increasing the wealth index of the citizens (WHO 2011a).

Approximately 820 million Indian people are facing high to extreme water stress situation (NITI 2019). Further, India's 70% water resources are contaminated with excess iron, fluoride, salinity, nitrate and arsenic, ranking it at 120th position out of 122 countries based on Water Quality Index (WQI). Therefore, National Institute for Transforming India (NITI) Aayog has framed a Composite Water Management Index for assessing and improving the efficient management of water resources of the country. In developing countries, consumption of unsafe water results in one of the highest disease burdens in form of water borne diseases (NITI 2018). Unsafe drinking water and poor sanitation results in approximately 10 million cases of diarrhea, more than 7.2 lakh typhoid cases, and 1.5 lakh viral hepatitis cases every year in India (BIS 2012). Accordingly, to eliminate the impact of deteriorated water quality on human health, Bureau of Indian Standards (BIS) has prescribed the limits for water quality parameters in light of World Health Organization (WHO) guidelines. The parameters, which are missing from WHO guidelines and crucial for Indian conditions, have been incorporated from the standards of other countries. This chapter describes the health effect of the water quality parameters, their prescribed limits, and options for their treatment.

27.2 Organoleptic/Physical Parameters

Organoleptic or physical parameters are those parameters which can be detected by the senses. BIS (2012) has prescribed limits for six physical parameters, namely color, odor, pH, taste, turbidity, and total dissolved solids, which can be judged by the sensory organs (Table 27.1). The drinking water supplied to the citizens should not exceed the values mentioned under 'Acceptable limit', however, in absence of alternate source, this may be relaxed to the values mentioned under 'Permissible limit'. However, water sources with values exceeding the 'Permissible limit', will have to be rejected.

Table 27.1 BIS limits for organoleptic parameters (BIS 2012)

Sr. No.	Characteristic	Acceptable limit	Permissible limit
1	Color, Hazen units, Max	5	15
2	Odor	Agreeable	Agreeable
3	pH	6.5–8.5	No relaxation
4	Taste	Agreeable	Agreeable
5	Turbidity, NTU, Max	1	5
6	Total dissolved solids, mg/L, Max	500	2000

27.2.1 Color

Drinking water should ideally be colorless. Color in water may be due dissolved or suspended colloidal particles and indicates the presence of iron, manganese, or organic matter. Iron salts impart brown/red; manganese salts impart black, chromium salts impart yellow, and decaying leaves and macroscopic plants impart brownish-yellow hue to the water (Nathanson 1986). Color is also introduced in the water through mixing of the industrial effluents.

Color is expressed in Pt–Co or Hazen units, and the units are interchangeable. Color is measured by visual comparison of the sample with known concentrations of colored solutions or by spectrophotometer, after adjusting the pH to around 7.6 followed by centrifugation for 1 h to remove turbidity (APHA 2017).

Presence of color in drinking water is undesirable from the aesthetic point of view and is generally not harmful to human health, but indicator of a hazardous situation. A substantial change in color of water should be investigated for the harmful content.

27.2.2 Odor and Taste

These are indicators of the presence of undesirable impurities such as hydrogen sulfide, sewage contamination, excess dissolved solids, corrosion byproducts, disinfection byproducts, petroleum products, etc. A change in the normal appearance, taste, or odor of a drinking-water supply indicates change in the quality of the raw water source or deficiency in the treatment process, demanding immediate curative measures. The limits prescribed for odor and taste are related to consumer acceptability, are of great significance for consumer confidence, and are not directly related to human health (WHO 2017).

Odor and taste are analyzed by the threshold odor test and the flavor profile analysis. Both the tests are subjective tests since both depends on the human perception of the odor and taste in water (APHA 2017).

The tastes and odors can be removed by coagulation-flocculation, aeration, ozonation, or activated carbon. The selection of the method will depend on the taste and odor causing components in the water.

27.2.3 pH

pH is defined as negative logarithm of hydrogen ion concentration. The pH of pure water is 7 at 25 °C because hydrogen and hydroxyl ion concentrations are equal, however, natural waters usually have pH values in the range of 4–9, and most are slightly alkaline. Waters in humid areas with highly leached soils in general have lower pH than waters in areas with limestone formations or those in semi-arid or arid regions. Waters originating from forested areas also tend to have a low pH due to presence of high concentrations of humic substances. Although, pH has no direct impact on human health, the prescribed standard is operational parameter.

The pH of water is generally measured electrometrically using pH meter consisting of potentiometer, a glass electrode, a reference electrode, and a temperature compensating device.

If pH deviates from the operational range, acid or alkali dosing is used. The pH is generally reduced by aerating with CO_2.

27.2.4 Turbidity

Turbidity in water is due to the presence of suspended and colloidal matter, such as silt, clay, tiny fragments of organic/inorganic matter, and microscopic plants and organisms. These suspended matter scatter and adsorb light rays, reducing the clarity of water and giving it murky or turbid appearance. Turbidity in water is due to the poor source, poor treatment, and disturbance of sediments / biofilms in the distribution system, and ingress of dirty water through the supply line breaks and other faults. High turbidity, generally more than 5 NTU, leads to staining of materials, fittings, and clothes, and also reduces the acceptability of drinking water. Although, most particles that contribute to turbidity have no health significance, their presence may provide a shield to pathogenic micro-organisms during the disinfection process and can lead to waterborne diseases.

Turbidity is measured by nephelometer. A ray of light is passed through the water sample and the scattered light is measured by detectors at 90° to the incident light in comparison to standard suspension in nephelometric turbidity units (NTU).

Turbidity in water is generally removed by coagulation, flocculation and clarification followed by filtration. The water with low turbidity can be treated through slow sand filter, microfiltration, or ultrafiltration membrane for removal of suspended solids.

27.2.5 *Total Dissolved Solids*

Total dissolved solids (TDS) in water includes all dissolved material in solution, whether ionized or not. TDS is numerical sum of all mineral constituents dissolved in water and is expressed in mg/L. TDS in drinking water is contributed from natural sources, sewage, urban runoff and industrial wastewater. Due to the difference in the solubility of minerals in different geological regions, the dissolved solids in water vary from one place to another. Based on TDS contents, water can be classified in to four categories as fresh, brackish, saline and brine water (Table 27.2).

No health-based guideline value for TDS has been proposed due to unavailability of reliable data on possible health effects due to consumption of TDS in drinking water (WHO 2011a). However, the water suppliers should keep in mind that drinking water is palatable up to 600 mg/L, and significantly unpalatable at TDS levels greater than 1000 mg/L. TDS associated with high concentrations of carbonates of Ca and Mg results in scale formation and bitter test, however, TDS associated with high concentration of chlorides and sulfates of cations, particularly Na & K, leads to salty/brackish taste and increased corrosivity.

It is estimated by filtering a known volume of water sample through 2.0 μm (or smaller) nominal pore size filter, evaporating the filtrate to dryness at 180 ± 2 °C, and reporting the weight of solids remaining after evaporation in mg/L.

Dissolved solids in water can be removed by precipitation, ion exchange processes, nanofiltration membranes, reverse osmosis membranes, and thermal distillation processes.

27.3 General Inorganic Parameters

BIS (2012) has prescribed limits for 13 general inorganic parameters, namely ammonia, barium, calcium, magnesium, total hardness, chloride, fluoride, nitrate, sulfate, sulfide, total alkalinity, chloramines, and free residual chlorine which are undesirable in excessive amounts, and 1 inorganic parameter, cyanide, which is toxic (Table 27.3).

Table 27.2 Classification of water based on total dissolved solids

Sr. No.	TDS (mg/L)	Water quality
1	0–1,000	Fresh water
2	1000–10,000	Brackish water
3	10,000–100,000	Saline water
4	>100,000	Brine

Table 27.3 BIS limits for general inorganic parameters (BIS 2012)

Sr. No.	Characteristic	Acceptable limit	Permissible limit
1	Ammonia (as NH_4-N), mg/L, *Max*	0.5	No relaxation
2	Barium (as Ba), mg/L, *Max*	0.7	No relaxation
3	Calcium (as Ca), mg/L, *Max*	75	200
4	Magnesium (as Mg), mg/L, *Max*	30	100
5	Total hardness (as CaCO3), mg/L, *Max*	200	600
6	Total alkalinity (as CaCO3), mg/L, *Max*	200	600
7	Chloride (as Cl), mg/L, *Max*	250	1000
8	Fluoride (as F), mg/L, *Max*	1.0	1.5
9	Nitrate (as NO_3), mg/L, *Max*	45	No relaxation
10	Sulfate (as SO_4), mg/L, *Max*	200	400
11	Sulfide (as H_2S), mg/L, *Max*	0.05	No relaxation
12	Chloramines (as Cl_2), mg/L, *Max*	4.0	No relaxation
13	Free residual chlorine (as Cl_2), mg/L, *Min*	0.2	1.0
14	Cyanide (as CN), mg/L, *Max*	0.05	No relaxation

27.3.1 Ammonia

Ammonia in water comprises of non-ionized (NH_3) and ionized form (NH_4^+), originating from mammalian metabolism, agricultural runoff, and industrial effluents. Less than 0.2 mg/L ammonia is encountered in oxic water, whereas anaerobic water resources may contain upto 3 mg/L NH_3. Presence of ammonia in drinking water indicates possible bacterial, sewage, and animal waste pollution.

The guideline value prescribed by BIS for ammonia is aesthetic based and not health-based, as the toxicological effects are about 200 mg/kg body weight. WHO has not prescribed any guideline value for ammonia. The threshold odor and taste concentration is approximately 1.5 mg/L and 35 mg/L respectively (WHO 2017).

Ammonia is estimated in drinking water by ammonia selective electrode method or phenate method. Ammonia selective electrode uses a hydrophobic gas permeable membrane that separate the sample from the electrode internal solution of ammonium chloride. The ammonium present in the water is converted to ammonia gas by raising the pH above 11, which diffuses through the membrane, resulting in a change in the pH of the internal solution, which is sensed by a pH electrode. The phenate method is a colorimetric method, in which ammonia in water reacts with phenol to form an intense blue compound, indophenol, in the presence of hypochlorite, and sodium nitroprusside as a catalyst.

Ammonia in drinking water can be removed by ion-exchange resin, biological filter (nitrification), air stripping, and reverse osmosis membrane.

27.3.2 Barium

Barium (Ba) compounds are present in igneous and sedimentary rocks, and their average abundance in the earth's crust is 390 mg/kg and in soils it is 63 to 810 mg/kg. It is found primarily in barite ($BaSO_4$) or in witherite ($BaCO_3$). They are used in drilling fluid additive, X-ray diagnostic tests, plastics, rubbers, paint, glass, carpets, ceramics, sealants, furniture, fertilizers and pesticides. The average concentration of Ba in streams is 10 mg/L and in groundwaters 0.05–1 mg/L (APHA 2017). Barium in water comes primarily from natural sources as well as industrial emissions and anthropogenic uses, and the concentration is controlled by the solubility of $BaSO_4$, and to some extent by adsorption on hydroxides.

The health effects of the different barium compounds depend on their solubility and the insoluble compounds are not generally harmful. Ingestion of Ba laden water may cause difficulties in breathing, increased blood pressure, changes in heart rhythm, stomach irritation, brain swelling, muscle weakness, and damage to the liver, kidney, heart, and spleen, in people, but are not carcinogen (WQA 2013a; WHO 2017). The U.S. EPA and WHO recommends guideline value of 1 mg/L and 1.3 mg/L, respectively.

Barium concentration in drinking water can be estimated by iodometric titration, atomic absorption spectrometer, and inductively coupled plasma mass spectrometer.

Barium in drinking water can be removed by ion exchange, lime softening, reverse osmosis, and distillation to below 1 mg/L.

27.3.3 Total Hardness, Calcium, and Magnesium

Hardness in drinking water is due to dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, and is expressed as milligrams of calcium carbonate per litre. The hardness of drinking-water is important for aesthetic acceptability and it does not pose a health hazard. Hardness in water prevents the lather (foam) formation with the soap, and is important for economic and operational considerations. It is classified as soft water, hard water, moderately hard water and very hard water (Table 27.4).

Drinking-water can be an important contributor of calcium and magnesium to those who are marginal for calcium and magnesium. Typical recommended dietary

Table 27.4 Classification of drinking water based in hardness (WHO 2011a, b)

Sr. No.	Total hardness (mg/L)	Water type
1	<60	Soft water
2	60–120	Moderately hard water
3	120–180	Hard water
4	>180	Very hard water

intake for Ca & Mg is 1000 mg/day and 200–400 mg/day respectively (WHO b), and a glass of milk (200 mL) can met ≈30% Ca and ≈15% Mg requirement (Brink et al. 1992; Gaucheron 2005). The recommended upper intake level for Ca is 2500 mg/day, and the individuals exposed to high concentration are protected by a tightly regulated intestinal absorption and elimination mechanism through the action of 1,25-dihydroxyvitamin D. The excess absorbed calcium is excreted by the kidney in healthy people who do not have renal impairment. Drinking water with both magnesium and sulfate, above 250 mg/L each, can have a laxative effect, although the effect recedes as exposure continues.

The taste threshold for the calcium ion is in the range of 100–300 mg/L, however, some consumers can tolerate water hardness in excess of 500 mg/L. WHO has not established any guideline value considering the fact that the levels found in drinking water does not pose a health hazard to humans (WHO 2011a, b).

Total hardness, calcium and magnesium in drinking water is analyzed by EDTA titrimetric method. These parameters can also be analyzed by Ion Chromatograph.

The removal of hardness from drinking water depends on type of hardness and extent of hardness removal. Lime soda softening, ion exchange resins, nanofiltration membranes, and reverse osmosis membranes are capable of reducing hardness of water.

27.3.4 *Total Alkalinity*

Alkalinity is the buffering capacity of the water to neutralize acids and bases, and is dependent on the presence of certain chemicals in the water like bicarbonate, carbonate, and hydroxides. The alkalinity in the water comes mostly from the rocks and land of the catchment area of the water body. Water with alkalinity levels less than 150 mg/L is more likely to be corrosive, and alkalinity levels greater than 150 may contribute to scaling. The alkalinity of water affects the amount of chemicals required to accomplish effective coagulation and softening during treatment. Alkalinity in drinking water, due to naturally occurring materials such as carbonate and bicarbonate up to approximately 400 mg/L as calcium carbonate, is not a health hazard (USEPA 1976), therefore, WHO has not prescribed any guideline value for alkalinity.

Alkalinity in water is determined by titration with standard sulfuric acid using pH sensitive indicators or pH meter.

Alkalinity in water can be removed by acidification of water and can be added by passing the low alkaline water through calcite filter.

27.3.5 *Chloride*

Chloride ions come into water either from geogenic or anthropogenic sources. The geogenic sources includes chloride bearing minerals like halite, potassium chloride, calcium chloride, limestone, sandstone, shale, etc. Anthropogenic sources of chloride are human sewage, livestock waste, synthetic fertilizer, etc. Chloride is a conservative anion in most aqueous environments and its movement is not retarded by the interaction of water with soils, sediments, and rocks. Further, it is not affected by the microbial action or redox chemistry in environment. Hence, it can be used as an indicator of other type of contamination. High concentration of chloride in water gives a salty taste. Concentration of chloride associated with calcium, sodium and potassium in excess of 250 mg/L is detected by taste, however, no side effects on human health has been observed at the levels found in drinking water, due to which WHO has not proposed any guideline value. Excessive chloride concentration in water makes it corrosive and is important from operational point of view.

Chloride concentration in drinking water can be determined with argentometric titration using potassium chromate indicator or potentiometer. It can also be analyzed by ion chromatograph.

Chloride in drinking water can be removed by reverse osmosis or distillation.

27.3.6 Fluoride

The average abundance of fluoride in earth's crust is 300 mg/kg, and is found at significant levels in a wide variety of minerals, including fluorspar, rock phosphate, cryolite, apatite, mica, hornblende and others. It is found in all-natural waters at some concentration; in seawater, it is about 1 mg/L; in rivers and lakes, it is less than 0.5 mg/L; and in groundwater, its concentration varies depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. Fluoride concentration in water is limited by fluorite solubility, means, the presence of 40 mg/L calcium will limit fluoride concentration to 3.1 mg/L (Hem 1989). Therefore, high fluoride concentrations are expected in groundwaters from calcium poor aquifers and in areas where fluoride-bearing minerals are common (Nanyaro et al. 1984; Gaciri and Davis 1993; Kundu et al. 2001). The highest natural level reported is 2800 mg/L (WHO 2004).

Fluoride in drinking water has a narrow range between intakes that cause beneficial (0.5–1.0 mg/L) and detrimental health effects (>1.0 mg/L), primarily dental and skeletal fluorosis. WHO (2011a) and BIS (2012) have prescribed the maximum allowable limit for fluoride uptake to human's in drinking water as 1.5 mg/L. However, the national standard should be based on the average water intake and intake from other sources.

Fluoride in drinking water can be estimated by fluoride selective electrode, spectrophotometer (SPADNS method), or ion chromatograph.

Fluoride in drinking water can be removed by precipitation, adsorption with aluminum based media, evaporation, or reverse osmosis membrane. Use of reverse osmosis membrane should be avoided for water having Ca and F ions as CaF_2 will lead to precipitation fouling of the membrane.

27.3.7 Nitrate

Nitrate (NO_3^-) concentration in both surface water and groundwater is due to agricultural activities, natural vegetation, wastewater, and human and animal excreta waste. Nitrate concentration in drinking water is a potential health hazard, when present in large quantities. Nitrites are formed by reduction of nitrate in the human body, which combines with hemoglobin in the blood to form methemoglobin that leads to methaemoglobinaemia (blue baby syndrome) in infants. The combination of nitrates with amines, amides, or other nitrogenous compounds through the action of bacteria in the digestive tract results in the formation of nitrosamines, which are potentially carcinogenic. The guideline values prescribed by WHO (2017) for nitrate in drinking water is 50 mg/L as NO_3 considering the fact that no adverse health effects has been observed below this concentration in epidemiological studies.

Nitrate in the drinking water can be estimated by electrometric (nitrate selective electrode), colorimetric (Cd reduction method), or ion chromatographic methods.

Nitrate in drinking water can be removed by biological denitrification, reverse osmosis, or distillation.

27.3.8 Sulfate

Sulfates (SO_4^{-2}) occur naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). Other sources of sulfur in water includes decomposition of organic, plant and animal, matter. Sulfate in drinking-water can cause taste impairment depending on associated cation, ranging from 250 mg/L for sodium sulfate to 1000 mg/L for calcium sulfate. Very high levels of sulfate may cause a laxative effect in unaccustomed consumers, and therefore, the health authorities should be notified of sources of drinking water that contain sulfate concentrations in excess of 500 mg/L (WHO 2011a). Adults generally adapt to high sulfate concentrations within 1 or 2 weeks, however, infants may be more sensitive (USEPA 2003).

The concentration of sulfate found in natural waters is generally not at levels to cause adverse health effects and the existing data do not identify a level of sulfate that is likely to impact the human health, due to which WHO has not proposed any health based guideline (WHO 2017).

Sulfate in the drinking water can be estimated by gravimetric, turbidimetric, or ion chromatographic methods.

Sulfate concentration in drinking water can be reduced by reverse osmosis, ion exchange, or distillation.

27.3.9 Sulfide

Hydrogen sulfide (H_2S) gas produces an offensive "rotten egg" odor and unpleasant taste in the water. Its concentration in groundwater and surface water depends on the rock mineralogy, microorganisms present, and influx of effluents. The sulfur/sulfate reducing bacteria uses sulfate and sulfur compounds in decaying plant material, rocks or soil, as an electron acceptor for the degradation of organic compounds, resulting in the production of S^{-2}, CO_2, and CH_4 in anaerobic environment (Muyzer and Stams 2008). In water, H_2S dissociates into monohydrogensulfide (HS^-) and sulfide (S^{2-}) ions, and the concentration of these species depends on pH of water, with hydrogen sulfide concentrations increasing with decreasing pH. H_2S gets rapidly oxidized to SO_4^{-2} in well aerated or chlorinated waters. Further, the taste and odor threshold of H_2S in water is between 0.05 and 0.1 mg/L respectively, due to which the chances of a person consuming a harmful dose of H_2S from drinking water becomes very thin and is the basis for WHO not proposing a health based guideline value. The oral dose of sodium sulfide fatal to humans is around 10–15 g, leading to irritation of mucous membranes, nausea, vomiting, and epigastric pain (WHO 2003a).

Sulfide in drinking water can be estimated by titrimetric iodometric method or spectrophotometric methylene blue method (BIS 1987).

Trace amount of sulfide (0.05–0.3 mg/L) in water can be removed by adsorption on activated carbon and more than 0.3 mg/L by oxidation to sulfate by aeration (<2 mg/L), manganese greensand filter (<10 mg/L), and chlorination (<75 mg/L).

27.3.10 Chloramines

Chloramines are a group of compounds (monochloramine, dichloramine and trichloramine) formed from the reaction of chlorine with ammonia. Among the group, monochloramine is the only useful disinfectant and other chloramines are formed occasionally, therefore, WHO has proposed the health based guideline value only for monochloramine. Chloramine is preferred by water treatment operators in place of chlorine, as it is more stable and reduces the formation of Trihalomethanes (THMs). Monochloramine is weaker oxidant than free chlorine and are not very effective in getting rid of taste and odor already present. Higher chloramines, particularly trichloramine, give rise to taste and odor complaints, however, they are little unstable and escapes from the water before reaching the taps. WHO (2017) has prescribed 3 mg/L as the guideline value for monochloramine. IARC has classified chloramine in Group 3 (not classifiable as to its carcinogenicity to humans).

Chloramines in drinking water can be estimated by amperometric titration, *N,N*-diethyl-*p*-phenylenediamine (DPD) ferrous titration, or DPD colorimetric method (APHA 2017).

Chloramines in water can be removed by activated carbon filter with 10 min empty bed contact time. Since chloramines are small, stable molecules with no net charge; distillation, reverse osmosis, and ion exchange resins are not efficient technologies for their removal (WQA 2013b).

27.3.11 Free Residual Chlorine

Chlorine (Cl_2) is the most widely used disinfectant and oxidant in drinking water treatment for killing pathogens and reducing disagreeable tastes and odors in water. Chlorine dissolves rapidly in water to establish an equilibrium with hypochlorous acid (HOCl) and hydrochloric acid (HC1). In dilute solution with pH levels above 4.0, molecular chlorine cease to exist and HOCl becomes the dominant species. Between pH 6.0 and 8.5, hypochlorous acid dissociates to form hypochlorite ion (OCl^-), which becomes dominant above 9.0 pH. The total concentration of Cl_2, HOCl, and OCl^- in water is defined as 'free available chlorine', and the concentration of these species left after reaction with microorganisms, organics, and metals is termed as 'free residual chlorine' (IARC 1991).

Chlorine in drinking water is sensed by most of the consumers at concentrations well below 5 mg/L, and some may even sense as low as 0.3 mg/L. WHO (2017) has prescribed the health-based guideline value of 5 mg/L for chlorine. Ingestion of a small amount of bleach results in the irritation of the esophagus, a burning sensation in the mouth and throat, and spontaneous vomiting, however, specific adverse health related effects have not been observed in humans and animals exposed to chlorine in drinking-water. IARC has concluded that hypochlorites are not classifiable as to their carcinogenicity to humans (Group 3).

Free residual chlorine in water can be estimated by iodometric titration, amperometric titration, DPD ferrous titrimetric method, DPD colorimetric method, or syringaldazine (FACTS) method.

Chlorine in drinking water can be removed by activated carbon filter or by reducing with sodium metabisulfite.

27.3.12 Cyanide

Cyanides (CN^-) compounds are powerful and rapid-acting poisons, can both occur naturally or anthropogenically in drinking waters. Natural sources of CN are certain species of bacteria, fungi, and algae, and a number of food and plant products like almonds, millet sprouts, lima beans, soy, spinach, bamboo shoots, and cassava roots. The anthropogenic sources are discharges from some metal mining and processing industries, some organic chemical industries, vehicle exhaust, burning of municipal waste, landfill leachates, and cyanide-containing pesticides. Cyanides are generally absent in drinking-water and can occur occasionally at very low concentrations. Although, at few occasions spills of cyanide from industries may give rise to concentrations of concern in drinking waters, particularly surface waters.

Cyanide is a well-established toxin, however, the actual dose resulting in acute fatal intoxication to humans has not been established due to the lack of well-conducted studies on sub-lethal toxicity. The lowest recorded lethal dose for humans is 0.56 mg/kg bodyweight. Low exposures to cyanides are not fatal to humans with efficient detoxification system. The major pathway for conversion of cyanide to much less toxic thiocyanate ion is via the intramitochnodrial enzyme rhodanease, a liver enzyme that catalyzes the transfer of sulfur from a donor to cyanide. Urine is the major route of excretion of thiocyanate, normally ranging between 0.85 and 14 mg over a 24 h period (Health Canada 1991). USEPA has allowed 0.2 mg CN per L in the drinking water as the maximum limit. WHO has not established a guideline value for cyanide in drinking water as cyanide concentration in water resources has been observed to be well below the health concern.

Cyanide in drinking water can be estimated by titration with $AgNO_3$, colorimetric method, or CN selective electrode method.

Cyanide in drinking water is reduced adsorption on activated carbon, oxidation by 2-step chlorination, hydrogen peroxide, or persulfate, or reverse osmosis.

27.4 Organic Parameters

BIS (2012) has prescribed limits for 3 organic parameters, namely anionic detergents, mineral oil, and phenolic compounds, which are undesirable in excessive amounts, and 24 parameters, namely polychlorinated biphenyls, polynuclear aromatic hydrocarbons, trihalomethanes (bromoform, bromomonochloromethane, and bromodichloromethane), and pesticides (alachlor, atrazine, Aldrin/dieldrin, alpha HCH, beta HCH, Butachlor, chlorpyriphos, delta HCH, 2,4-dichlorophenoxyacetic acid, DDT, endosulfan, ethion, gamma HCH, isoproturon, malathion, methyl parathion, monocrotophos, and phorate), which are toxic substances (Table 27.5).

27.4.1 Anionic Detergents

Anionic detergents are surface active compounds (fatty acid soaps, linear alkyl benzene sulfonates, alkyl ether sulfates, and alkyl sulfates) consisting of a hydrophobic alkyl chain and a hydrophilic negatively charged head group such as carboxylate, sulfate, phosphate or sulfonate. These are used in consumer products like laundries, car washing, dry cleaning, soaps, dishwashing, and personal care products, and are released to the environment after use, causing pollution of water resources (Brook et al. 2013). High concentration of detergents in drinking-water results in foaming, taste problems, and indicator of wastewater ingress, requiring attention of water treatment operators.

Anionic detergents are not able to penetration through intact skin, however, orally ingested detergents are readily absorbed from the gastrointestinal tract. The adsorbed detergents are metabolized in the liver, and the surfactants along with their metabolites are mostly eliminated through urine and only minor amounts are eliminated with feces. The detergents on contact with the human body may cause swelling and

Table 27.5 BIS limits for organic parameters (BIS 2012)

Sr. No.	Characteristic	Acceptable limit	Permissible limit
1	Anionic detergents (as MBAS), mg/L, *Max*	0.2	1.0
2	Mineral oil, mg/L, *Max*	0.5	No relaxation
3	Phenolic compounds (as C_6H_5OH), mg/L, Max	0.001	0.002
4	Polychlorinated biphenyls, mg/L, *Max*	0.0005	No relaxation
5	Polynuclear aromatic hydrocarbons (as PAH), mg/L, *Max*	0.0001	No relaxation
6	Trihalomethanes, mg/L, *Max*		
6a	Bromoform	0.1	No relaxation
6b	Dibromochloromethane	0.1	No relaxation
6c	Bromodichloromethane	0.06	No relaxation
6d	Chloroform	0.2	No relaxation
7	Pesticides, µg/L, Max		
7a	Alachlor	20.0	No relaxation
7b	Atrazine	2.0	No relaxation
7c	Aldrin/ Dieldrin	0.03	No relaxation
7d	Alpha HCH	0.01	No relaxation
7e	Beta HCH	0.04	No relaxation
7f	Delta HCH	0.04	No relaxation
7 g	Gamma HCH (Lindane)	2.0	No relaxation
7 h	Butachlor	125.0	No relaxation
7i	Chlorpyriphos	30.0	No relaxation
7j	2,4-Dichlorophenoxyacetic acid	30.0	No relaxation
7 k	DDT (o,p & p,p – DDT, DDE, DDD)	1.0	No relaxation
7 l	Endosulfan (alpha, beta, and sulfate)	0.4	No relaxation
7 m	Ethion	3.0	No relaxation
7n	Isoproturon	9.0	No relaxation
7o	Malathion	190.0	No relaxation
7p	Methyl parathion	0.3	No relaxation
7q	Monocrotophos	1.0	No relaxation
7r	Phorate	2.0	No relaxation

irritation of the eyes, skin, and mucous membranes (Madsen et al. 2001). WHO has not prescribed any guideline value for anionic detergents.

Anionic detergents in water samples can be determined spectrophotometrically by reacting the anionic detergents with methylene blue in basic medium, extracting the excess methylene blue into chloroform, and measurement of blue color in $CHCl_3$ at 652 nm.

Anionic detergents in drinking water can be removed by $FeCl_3$ and cationic polyelectrolyte assisted precipitation (Aboulhassan et al. 2006; Kaleta and Elektorowicz 2013), adsorption (Tripathi et al. 2013), electrochemical oxidation (Rabbani et al. 2017), and constructed wetlands (Kruszelnicka et al. 2019). Narkis and Weinber (1989) observed that coagulation-flocculation-sedimentation, followed by sand filtration and adsorption through granular activated carbon is most effective means for removal of detergents.

27.4.2 Mineral Oil

Mineral oil (also known as base oil, mineral base oil or lubricant base oil) are highly purified chemical substances prepared from crude petroleum oil. It is used in baby lotions, cold creams, ointments and many other cosmetic and personal care products, due to its ability to reduce water loss from skin. The extent of refining/purification is determined by the Modified Ames test (ASTM 1996) and the IP346 assay (Institute for Petroleum 1985; CONCAWE 1994). Untreated and mildly treated mineral oils are carcinogenic to humans (Group 1) (IARC 2012; WHO 2005a).

Mineral oil in drinking water is analyzed by partition gravimetric method, partition infra-red method, or soxhlet extraction method. BIS prefer partition infra-red method involving acidification and extraction, followed by measuring the absorbance at 2980 cm^{-1} against reference standards.

Mineral oil in drinking water can be removed be adsorption on aluminum hydroxide precipitates, granular activated carbon filters, and ceramic membranes. PVDF UF membranes can also be employed for mineral oil removal from water.

27.4.3 Phenolic Compounds

Phenolic compounds are defined as hydroxyl derivatives of benzene and its condensed nuclei. These compounds may enter into the water resources from natural, industrial, domestic and agricultural activities. Alkylphenols may be derived from lignin transformation and tannins. Phenol derivatives are present in coal tar, synthetic resins, plastics, rubber proofing, and dye manufacturing. In agricultural activities, phenolic compounds are employed as herbicides and insecticides. These chemicals, after entering into the water resources, may undergo transformation into other moieties which may be more harmful than the original compound (Davi and Gnudi 1999; Anku et al. 2017). The carcinogenic and mutagenic properties of phenolic compounds makes them a threat to human beings. WHO has prescribed health based guideline value of 0.2 and 0.009 mg/L for 2,4,6-trichlorophenol and pentachlorophenol respectively. IARC has classified both these compounds in Group 2B (possibly carcinogenic to humans).

Phenolic compounds in water samples can be analyzed by distilling the sample, followed by treating the distillate with 4-aminoantipyrine at pH 8.0 in the presence of potassium ferricyanide to form a colored antipyrene dye, extracting the dye with chloroform, and measuring the absorbance at 460 nm (BIS 2003).

Phenolic compounds present in the drinking water can be removed by activated carbon adsorption, electro-fenton oxidation, photocatalysis, and reverse osmosis membrane.

27.4.4 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are chlorinated hydrocarbon compounds comprising of two benzene rings linked by a single carbon–carbon bond. As the amount of chlorine in these compound increases, the product becomes progressively thicker, up to a solid wax. PCBs are a concern due to their persistence, long range transport ability, bioaccumulation, and negative impact on humans and environment (Huang et al. 2014). They have been used in plasticizers, surface coatings, inks, adhesives, flame retardants, pesticide extenders, paints, and dielectric fluids in transformers and capacitors. Most of the countries have banned production and use of PCBs. PCBs were never manufactured in India and their import was banned in 1998. Indian government has also decided to completely prohibit the use of PCBs in any form by December 2025 (UNIDO 2015).

The orally ingested PCBs are rapidly absorbed from the gastrointestinal tract and accumulate in the liver and adipose tissue. They also cross the placenta, are excreted in milk, and accumulate in the fetus/infant. PCBs in human tissue are believed to be associated with an elevated risk of cancer of the digestive system, particularly the liver, and of malignant melanoma. PCBs exposure is also associated with reduced growth rates, retarded development, neurological effects, and immunological changes (WHO 2003b).

Analysis of PCBs in drinking water involves extraction at neutral pH with methylene chloride using separatory funnel, continuous liquid–liquid extractor, or solid phase extraction, followed by sequential sulfuric acid/potassium permanganate cleanup and extract analysis using gas chromatograph equipped with electron capture detector (ECD), electrolytic conductivity detector (ELCD), or mass detector (MS).

PCBs in drinking water can be removed by phytoremediation, microbial degradation, activated carbon, and biofilm covered activated carbon (Jing et al. 2018).

27.4.5 Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) contain two or more fused aromatic rings of carbon and hydrogen atoms. Most of the PAHs in the environment originates from the incomplete combustion of fossil fuels, road runoff, industrial wastewater, leaching from creosote-impregnated wood, and petroleum spills, and only a small fraction of PAHs are produced commercially. PAHs have very low solubility in water and high affinity for particulate matter, due to which they are not found in notable concentrations (WHO 2003c; Karyab et al. 2013). Concentrations of individual PAHs in surface and coastal waters are generally around 50 µg/L, in uncontaminated groundwater usually in the range of 0–5 µg/L, and at heavily contaminated sites upto 10 µg/L (Environment Canada 1994).

The major concern regarding PAHs is the potential carcinogenicity related to lung, bladder, as well as skin cancer (IPCS 1998). Since the concentration of all the PAHs except benzo(a)pyrene are at level well below those of health concern, WHO has proposed a drinking-water guideline value of 0.7 µg/L for benzo(a)pyrene.

PAHs in drinking water can be analyzed by extracting with methylene chloride, followed by analysis with HPLC equipped with UV and fluorescence detector or GC equipped with FID/MS.

PAHs in drinking water can be removed by adsorption on activated carbon, biodegradation under aerobic conditions, phytoremediation, advanced oxidation processes, and membrane processes (Mojiri et al. 2019).

27.4.6 Trihalomethanes

Trihalomethanes (THMs) are generated in drinking water as a byproduct of disinfection. Chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and bromoform ($CHBr_3$) are the most commonly occurring and regulated THMs. The concentration of THMs in drinking water is directly proportional to chlorine dose, organic matter/humic acid concentration, bromide ion concentration, temperature, and pH (Bond et al. 2012). Chloroform is the principal disinfection by-product in chlorinated drinking water, however, the presence of bromide results in preferential formation of brominated THMs and proportional decrease in chloroform concentrations. The exposure to THMs are primarily from inhalation of indoor air and ingestion of tap water, and may lead to cancer of bladder and colon, and reproductive and developmental toxicity (Krasner et al. 1989; Golfinopoulos et al. 2003; WHO b). IARC has classified chloroform and bromodichloromethane as possible carcinogen to humans (Group 2B), and bromoform and dibromochloromethane not classifiable as to its carcinogenicity to humans (Group 3). The guideline value prescribed by WHO for chloroform, Bromoform, dibromochloromethane, and bromodichloromethane are 0.3 mg/L, 0.1 mg/L, 0.1 mg/L and 0.06 mg/L respectively.

THMs in drinking water can be analyzed by employing liquid/liquid extraction using isooctane/pentane for at least five fold concentration enhancement, followed by analyzing the extract in a gas chromatograph equipped with electron capture detector or mass spectrometer.

THMs in the drinking water can be reduced by removing the precursors through enhanced coagulation and dosing chlorine after filtration. In case some oxidation is required before filtration, an alternative to chlorine like potassium permanganate, peroxide, or ozone may be dosed. THMs can be removed by degassing, adsorption on activated carbon or by reverse osmosis membranes.

27.4.7 Pesticides

Pesticide is a composite term that encompasses all chemicals that are used to kill or control insects, weeds, fungi and other pests, to protect the crops. They are divided into herbicides (protection against weeds), insecticides (against insects), and fungicides (against fungi) based on their usage. Although the use of pesticides has improved the agricultural yield and ensured food security, the quality of yield has significantly affected. Most of the pesticides are inherently toxic, not only to the pests, against which they are used, but also to other organisms. Damage to non-target organisms, perturbation of structure and function of environment, and toxic contamination of environment are few consequences of pesticide use. Long term and rampant use of pesticides resulted in persistence, bio-accumulation and long range transport of these hazardous chemicals. The toxicants affect entire ecological balance and result in severe health hazards to human beings. These changes occur at a very slow pace and the adverse impacts become visible at a stage where it is almost impossible to reverse the trend.

The health effects of pesticides depend on the type of pesticide, concentration in water, duration of exposure, and individual health status. Humans and animals can be exposed to pesticides through contact with the skin, ingestion, or inhalation. Within a human or animal body, pesticides may be metabolized, excreted, stored, or bio-accumulated in body fat. The negative health effects associated with chemical pesticides are dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive, and endocrine effects (Nicolopoulou-Stamati et al. 2016; Sabarwal et al. 2018).

The pesticides in the water samples can be analyzed by extraction of pesticides from water samples with organic solvents, followed by analysis with GC equipped suitable detectors (Electron capture detector for chlorinated pesticides, Nitrogen phosphorus detector for nitrogen or phosphorus containing pesticides, Flame ionization detectors, or Mass spectrometer). Identification of compounds is done by comparing the retention times with those of standard pesticides and the qualitative determination is carried out by comparing the retention time and peak area of the pesticides (EPA 2007; APHA 2017).

Pesticides in drinking water can be reduced by adsorption, oxidation, microbial degradation, membrane processes, or combination of these (Baldauf 1993; Ormad et al. 2008; Ahmad et al. 2010; Marican and Duran-Lara 2017). However, the most efficient process seems to be oxidation before coagulation-flocculation-sedimentation followed by adsorption on activated carbon. Nanofiltration has also emerged as a good alternative for removal of pesticides without removing all the dissolved solids.

27.4.7.1 Alachlor

Alachlor is a chloroacetanilide herbicide. It is used to control the annual grasses and broad leaved weeds in corn, peanuts, soybeans, and other crops. The research data indicates that the groundwater contamination due to alachlor usage takes place after a gap of considerable time. Alachlor and its metabolite 2,6-diethylanilchlor has shown to be mutagenic. IARC has not evaluated alachlor and has recommended for identification of carcinogenic hazards in medium priority (IARC 2019a). The guideline value prescribed by WHO for Alachlor in drinking water is 0.02 mg/L.

27.4.7.2 Atrazine

Atrazine is a chlorotriazine herbicide. It is used to selectively control the annual broadleaf and grassy weeds in fruit orchards, coffee plantation, grasslands, cereal crops, sugar cane, roses and vines. Along with atrazine, the metabolite hydroxyatrazine is found in water contaminated with atrazine. IARC has concluded that atrazine is not classifiable as to its carcinogenicity in humans (Group 3) and the 2019 Priorities Advisory Group assigned atrazine a medium priority (IARC 2019a). WHO (2017) has prescribed the guideline value of 0.1 and 0.2 mg/L for atrazine and hydroxyatrazine respectively.

27.4.7.3 Aldrin/Dieldrin

Aldrin and Dieldrin are synthetic organochlorine insecticides. They were used to control broad spectrum of soil-dwelling pests, for seed dressings, and for wood protection. Aldrin is rapidly converted to dieldrin under most environmental conditions. The use of both compounds for use in agricultural practices were banned by most of the countries since the early 1970s. These are highly persistent with high affinity for soil and sediments, due to which most dieldrin in the environment is found in the bottom sediments of the water bodies. Further, the solubility of dieldrin in water is very low ($\approx$27 μg/L), and therefore, the concentrations are not high in natural waters. Plants grown on dieldrin contaminated soil, store it in their leaves and roots. Similarly, fish, animals, or humans feeding dieldrin-contaminated materials store it in their fat (WHO 2017; IARC 2019b), and the bio-accumulated dieldrin is typically measured in blood or body tissues. The target organs by dieldrin are the central nervous system and liver. It is excreted in the bile, feces, and breast milk, and can cross the placenta (ASTDR 2002; IARC 2019b). IARC has classified dieldrin in Group 3 (not classifiable as to its carcinogenicity to humans). WHO (2017) has prescribed guideline value of 0.03 μg/L for drinking and other domestic usage for combined concentration of aldrin and dieldrin.

27.4.7.4 Hexachlorocyclohexane (HCH)

HCH consists of eight isomers, but only α-HCH, β-HCH, γ-HCH, and δ-HCH are of commercial significance. All of the isomers are toxic to animals to varying degrees and are persistent in the environment, with only γ-HCH (Lindane) has an appreciable insecticidal activity. Lindane is used as an insecticide on fruit and vegetable crops, for seed treatment, and in forestry. Technical BHC is a mixture of a number of stereoisomers, principally alpha-BHC, beta-BHC, gamma-BHC and delta-BHC, and the proportion of these isomers can vary in different technical mixtures. The Stockholm Convention held in 2009 accepted inclusion of γ-, α-, and β-HCH in Persistent Organic Pollutants (POPs) list requiring the address to these chemicals at global level (Vijgen et al. 2010). However, the convention exempted the use of lindane as human health pharmaceutical. Several countries have already restricted the use of lindane. Lindane is not likely to pose a carcinogenic risk to humans, which was further confirmed by the epidemiological study designed to assess the potential association between breast cancer and exposure to chlorinated pesticides (WHO 2011a). WHO (2017) has prescribed the guideline value 0.002 mg/L for γ-BHC.

27.4.7.5 Butachlor

Butachlor is a chloroacetanilide herbicide for the pre-emergent control of grass and broadleaf weeds in rice and barley. Butachlor is non-irritating to the skin and moderately irritating to the eyes, and almost non-toxic. Further, it has been shown that butachlor is not genotoxic and is not oncogenic (Heydens et al. 2010; Furukawa et al. 2014). WHO has not prescribed any guideline value for butachlor.

27.4.7.6 Chlorpyriphos

Chlorpyriphos is a broad-spectrum organophosphorus insecticide, used for soil treatment (pre-plat and at planting), seed treatment, and foliar spray. They are used to control mosquitoes, flies, various crop pests in soil and on foliage. It is used as an insecticide on grain, cotton, corn, almonds, vegetable crops, ornamental plants and fruit trees (Femia et al. 2013). WHO Pesticide Evaluation Scheme (WHOPES) does not recommend the addition of chlorpyriphos to water for public health purposes, however, its use as an aquatic larvicide for the control of mosquito larvae in some countries can’t be ruled out. Chlorpyriphos has low solubility in water. Further, the chlorpyriphos attached to the soil is not leached out because of the strong ionic interaction between the two, however, it gets degraded by microbial action at a slow rate. Chlorpyriphos exposure can result in neurological disorder, persistent developmental disorders and autoimmune disorders. Exposure during pregnancy retards the mental development of children. Chlorpyriphos is not genotoxic and do not pose carcinogenic risk to humans. WHO (2017) has prescribed the guideline value of 0.03 mg/L for drinking and other domestic usage, considering the fact that it is used as a mosquito larvicide in water bodies.

27.4.8 2,4-Dichlorophenoxyacetic Acid (2,4-D)

2,4-D is a systemic herbicide for control of broad-leaved weeds, including aquatic weeds. 2,4-D is easily biodegradable in the environment and its residues rarely exceed a few tens of micrograms per kilogram in food (Trivedi and Mandavgane 2018). Few epidemiological studies indicated 2,4-D promoting two forms of cancer in humans: soft tissue sarcomas and non-Hodgkin lymphoma, however, the results were inconsistent and therefore, Joint FAO/WHO Meeting on Pesticide Residues (JMPR) concluded that 2,4-D is neither genotoxic nor carcinogenic. A guideline value of 0.03 mg/L has been proposed for 2,4-D by WHO (2017).

27.4.8.1 DDT and Metabolites

DDT (1,1,1-trichloro-II,2-bis(p-chlorophenyl)ethane) is an organochlorine insecticide. It was widely used across the globe to control insects on agricultural crops and vectors. Nowadays, it is used only in a few countries for controlling vectors transmitting diseases like malaria, typhus, yellow fever, and sleeping sickness. Technical-grade DDT is a mixture of three forms, p,p′-DDT (85%), o,p′-DDT (15%), and o,o′-DDT (trace amounts), and may also contain DDE (1,1-dichloro-II,2-bis(p-chlorophenyl)ethylene) and DDD (1,1-dichloro-II,2-bis(p-chlorophenyl)ethane) as contaminants. DDD was also used to kill pests, and one form, o, p′-DDD, has been used to treat cancer of the adrenal gland. DDT and its metabolites, DDE and DDD, are persistent in the environment for a very long time, potentially for hundreds of years. Most of the DDT in the soil breaks down to DDD and DDE through microbial degradation and therefore, the metabolites should be analyzed instead of DDT. Further, these metabolites may evaporate into the air and deposited in other places. DDT and its metabolites get strongly adsorbed to the soil, and therefore generally remain in the surface layers of soil. Part of DDT and its metabolites may reach the surface water resources along with the soil particles, and only a very small fraction may seep into the groundwater.

IARC (1991) has concluded that there is insufficient evidence in humans and sufficient evidence in experimental animals for the carcinogenicity of DDT (Group 2B). WHO (2017) prescribes a guideline value of 0.001 mg/L for DDT and its metabolites in drinking water to protect the human health, however, it further states that the benefits of DDT use in malaria and other vector control programmes outweigh any health risk from the presence of DDT in drinking-water.

27.4.8.2 Endosulfan

Endosulfan, an organochlorine insecticide, is a mixture of two isomers, α-endosulfan (70%) and β-endosulfan (30%). It is used to control pests on fruit, vegetables, tea, and non-food crops. It is also used to control the tsetse fly and home garden pest, and as a wood preservative. WHO classifies endosulfan in Category 2 (moderately hazardous) and United States Environmental Protection Agency (USEPA) classifies endosulfan as Category 1b (highly hazardous). WHO (2017) has not established any guideline value for endosulfan citing the reason that the concentration of endosulfan encountered in drinking water is well below those of health concern.

27.4.8.3 Ethion

Ethion is an organophosphate pesticide. It used to kill aphids, mites, scales, thrips, leafhoppers, maggots and foliar feeding larvae, on a wide variety of food, fiber and ornamental crops, orchids, lawns and turf. It is also used as a cattle dip for ticks and for buffalo flies. Ethion is absorbed by the skin, as well as by the respiratory and gastrointestinal tracts. Short term exposure symptoms include nausea, vomiting, abdominal cramps, diarrhea, excessive salivation, headache, giddiness, weakness, muscle twitching, difficult breathing, blurring or dimness of vision, and loss of muscle coordination. Ethion is very toxic for humans at a probable oral dose of 50–500 mg/kg, and may lead to death from failure of the respiratory center, paralysis of the respiratory muscles, intense bronchoconstriction, or all three. Long term exposure may damage the nervous system (Pohanish 2015). WHO (2017) has not recommend any guideline value for ethion.

27.4.8.4 Isoproturon

Isoproturon (3-(4-isopropylphenyl)-1,1-dimethylurea) is a selective, systemic phenylurease class herbicide used to control annual grasses and broad-leaved weeds in cereals. It is mobile in soil, however, it gets photodegraded, hydrolyzed and biodegraded. It does not possess significant genotoxic activity, but it causes marked enzyme induction and liver enlargement (EC 2002; WHO 2003). Its use has been banned in EU after 2007 considering potential groundwater contamination and risk to aquatic life. WHO (2017) recommends guideline value 0.009 mg/L for Isoproturon.

27.4.8.5 Malathion

Malathion is an organophosphorus insecticide to control mosquitoes and a variety of insects that attack fruits, vegetables, landscaping plants and shrubs, by acetylcholinesterase inhibition. It is also used to control ticks and insects on pets and lice on human body. Under least favorable conditions (i.e. low pH and little organic content), Malathion in low pH water, with little organics, may persist for years, however, in normal conditions, the half-life is roughly 7–14 days. Malathion travels to the liver and kidneys and affects the nervous system. Generally, the body can break down Malathion and removes it quickly. The health based value for malathion is 0.9 mg/L, and the values encountered in drinking water resources are much lower than this values and hence WHO (2017) considered unnecessary to derive a formal guideline value for malathion in drinking water.

27.4.8.6 Methyl parathion

Methyl parathion is an organophosphorus insecticide and acaricide for use on many crops, in particular cotton. It derives its insecticidal properties from acetylcholinesterase inhibition, and this inhibition is responsible for the toxicity in humans. After application, part of methyl parathion get adsorbed on soil particles and part of it volatilizes to air. Methyl parathion and its breakdown products, generally does not move through soil, and hence their chances of reaching groundwater is minimal. Methyl parathion in environment is degraded by microbes. Half-life of methyl parathion in water ranges from weeks to months. Poisoning with methyl parathion leads sweating, dizziness, vomiting, diarrhea, convulsions, cardiac arrest, respiratory arrest, and, in extreme cases, death, due to cholinergic crisis. The health based value for methyl parathion is 9 μg/L, and the values encountered in drinking water resources are much lower than this values and hence, WHO (2017) considered unnecessary to derive a formal guideline value for malathion in drinking water.

27.4.8.7 Monocrotophos

Monocrotophos is an organophosphate insecticide and acaricide used to protect crops from mites, ticks, leaf hoppers, aphids and other insects (Singh and Walker 2006). Monocrotophos is highly soluble in water because of its hydrophilic nature, and is weakly sorbed by soil particles. Monocrotophos poisoning in humans is characterized by blurred vision, muscular weakness, profuse perspiration, confusion, vomiting, small pupils and even death due to respiratory failure. It also leads to genotoxic, cardiotoxicity, hyperglycaemic and stressogenic effects to non-target living organisms (Kaur and Goyal 2019). Use of monocrotophos has been banned in most of the countries and is unlikely to occur in drinking-water (WHO 2017).

27.4.8.8 Phorate

Phorate is an organophosphate insecticide/nematocide used for the control of sucking, biting, and chewing insects, mites and certain nematodes. Phorate is a restricted use pesticide with no residential application and is among the most poisonous chemicals commonly used for pest control. Phorate can cause cholinesterase inhibition in humans causing nausea, dizziness, confusion, and at very high exposures, respiratory paralysis and death.

Phorate applied to soil is rapidly degraded by microorganisms and interaction with water. It's half-life in field study was observed to be 7.5 days and in aqueous solution, it is two hours at pH 8 and 70 °C (Health Canada 1986), due to which phorate is unlikely to occur in drinking water (WHO 2017).

27.5 Trace Toxic Metal and Metalloid

BIS (2012) has prescribed limits for 8 metal/metalloid, namely aluminum, boron, copper, iron, manganese, selenium, silver, and zinc, which are undesirable in excessive amounts, and 7 metal/metalloid, namely cadmium, lead, mercury, molybdenum, nickel, arsenic and chromium, which are toxic substances (Table 27.6).

Trace metals in the water samples can be analyzed by atomic absorption spectrometer (AAS), inductively coupled plasma optical emission spectrometry (ICP-OES), or inductively coupled plasma mass spectrometer (ICP-MS). For analysis of trace metals by these techniques, the samples are digested in nitric acid and hydrogen peroxide for oxidation/removal of organics in microwave reaction system and centrifuged before injecting in AAS, ICP-OES, or ICP-MS.

Table 27.6 BIS limits for trace toxic metal/metalloid (BIS 2012)

Sr. No.	Characteristic	Acceptable limit	Permissible limit
1	Aluminum (as Al), mg/L, *Max*	0.03	0.2
2	Boron (as B), mg/L, *Max*	0.5	1.0
3	Copper (as Cu), mg/L, Max	0.05	1.5
4	Iron (as Fe), mg/L, *Max*	0.3	No relaxation
5	Manganese (as Mn), mg/L, *Max*	0.1	0.3
6	Selenium (as Se), mg/L, *Max*	0.01	No relaxation
7	Silver (as Ag), mg/L, *Max*	0.1	No relaxation
8	Zinc (as Zn), mg/L, *Max*	5.0	15.0
9	Cadmium (as Cd), mg/L, *Max*	0.003	No relaxation
10	Lead (as Pb), mg/L, *Max*	0.01	No relaxation
11	Mercury (as Hg), mg/L, *Max*	0.001	
12	Molybdenum (as Mo), mg/L, *Max*	0.07	No relaxation
13	Nickel (as Ni), mg/L, *Max*	0.02	No relaxation
14	Total arsenic (as As), mg/L, *Max*	0.01	0.05
15	Total chromium (as Cr), mg/L, *Max*	0.05	No relaxation

27.5.1 Aluminum

Aluminum (Al) is the most abundant metallic element and constitutes about 8% of Earth's crust. High Al concentration in drinking water results in undesirable color and turbidity. The orally ingested aluminum is not acutely toxic to humans, however, it has been hypothesized that aluminum exposure is a risk factor for the development or acceleration of onset of Alzheimer disease in humans. WHO (2017) recommends the guideline value of 0.9 mg/L for aluminum in drinking water.

Aluminum in drinking water can be reduced to around 0.1 mg/L by optimizing pH in the coagulation process, use of polyelectrolyte, and media filtration.

27.5.2 Boron

Boron (B) is a naturally occurring element and is used in many consumer products like fiberglass, borosilicate glass, soaps and detergents, flame retardants, neutron absorbers for nuclear installations, mild antiseptics, cosmetics, pharmaceuticals (as pH buffers), boron neutron capture therapy (for cancer treatment), pesticides, and fertilizers. The concentration of boron in the earth's crust has been estimated to be <10 mg/kg, but in boron-rich areas, boron concentrations may be as high as 100 mg/kg. Boron enters in the environment mainly through the weathering of rocks, boric acid volatilization from seawater, and volcanic activity. Boron concentration in groundwater and surface water is generally small, however, the concentration can be significantly increased depending on the anthropogenic activities and surrounding geology. Boron toxicity results in gastrointestinal tract distress, vomiting, abdominal pain, diarrhea, and nausea (Simonnot et al. 2000; Yazbeck et al. 2005; Health Canada 2020). The guideline value of 2.4 mg/L has been prescribed by WHO (2017) for boron in drinking water.

Boron in drinking water can be removed by reverse osmosis membranes up to some extent but effective removal is achieved by boron specific ion exchange resins like Amberlite PWA10, Purolite S108, Diaion CRB 02 (Simonnot et al. 2000; Kabay et al. 2007).

27.5.3 Copper

Copper (Cu) is an essential nutrient as well as a drinking water contaminant. It is used to make pipes, valves and fittings, and is present in alloys and coatings. Copper concentration above 1 mg/L results in staining of laundry and sanitary ware, and beyond 5 mg/L, copper imparts astringent taste and cause discoloration. The epidemiological studies have not been able to establish the relationship between ingestion of copper in drinking water on the gastrointestinal tract, carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis (NRC 2000). US EPA (1991) classifies copper as Group D, not classifiable as to human carcinogenicity. The guideline value of 2 mg/L prescribed by WHO (2017) is to protect against gastric irritation.

Copper from drinking water can be removed by lime soda softening process, adsorption on activated carbon, reverse osmosis, electrodialysis, and distillation.

27.5.4 Iron

Iron (Fe) is one of the most abundant metals in Earth's crust, and in fresh waters, it ranges from <0.001 to 90 mg/L (Health Canada 1978). Fe in trace amount is essential for nutrition, however, higher concentrations impart inky flavor, bitter, and astringent taste to water. Taste and odor problems may be caused by filamentous organisms that prey on iron compounds (frenothrix, gallionella and leptothrix). In addition, these bacterial may clog the well screens or may develop in the distribution system. Fe in water also stains the laundry and plumbing fixtures. So, the presence of Fe is unacceptable in drinking water, not due to health reasons but due to aesthetic/operational reasons. No guideline value for iron in drinking-water is proposed by WHO (2017) citing the reason that concentrations found in drinking water do not pose any health effect.

Iron in drinking water can be removed by aeration-flocculation-sedimentation followed by media filtration, manganese greensand filter, iron specific ion exchange resins, calcium carbonate based minerals, constructed soil filter, electrocoagulation, UF membrane, and nanomaterials (Khadse et al. 2015; Khatri et al. 2017).

27.5.5 Manganese

Manganese is one of the most abundant metals in Earth's crust and generally coexist with iron. It is used in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate), and as an octane enhancer (as methyl-cyclo-pentadienyl manganese tri-carbonyl) in petrol. Manganese occurs in surface water sources which are anaerobic or anoxic. At levels exceeding 0.1 mg/L, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry, and at levels exceeding 0.2 mg/L, manganese will often form a coating on pipes which may slough off as a black precipitate.

Manganese is an essential element for humans, however, consuming drinking water with concentration more than 0.4 mg/L is expected to be associated with adverse effect on learning in children. WHO (2017) has not established a guideline value for manganese, as the health based value (0.4 mg/L) is well above concentrations of manganese, 0.1 mg/L, normally causing acceptability problems in drinking water.

Manganese in drinking water can be removed by chemical precipitation, coagulation, flotation, ion-exchange, oxidation/filtration, electrochemical treatment, adsorption, and membrane filtration (Health Canada 2016; Alvarez-Bastida et al. 2018). Oxidation by $KMnO_4$, followed by precipitation and filtration can achieve a manganese concentration of 0.05 mg/L in drinking water.

27.5.6 Selenium

Selenium (Se), a metalloid, is a member of group VIA and generally present in elemental form or ionic [selenide (Se^{-2}), selenate ($SeO_4{}^{-2}$), or selenite ($SeO_3{}^{-2}$)]. It is widely distributed in the Earth's crust, in association with sulfur containing minerals, at a concentration of 50–90 μg/kg. Its concentration in groundwater and surface water ranges from 0.06 to 400 μg/L. It is an essential element and FAO/WHO recommends daily intake of 6–21, 26, and 30 μg/L Se for infants/children, females, and males respectively. Most water soluble inorganic and organic selenium are efficiently absorbed across the gastrointestinal tract, which is cleared by the liver, transported to peripheral tissues, and distributed to all organs, with highest concentration in kidney, liver, spleen, testes, and skeletal muscle. High intake of Se results in gastrointestinal disturbances, discoloration of the skin, decayed teeth, hair or nail loss, nail abnormalities, changes in peripheral nerves, and several type of cancer (WHO 2011c; Health Canada 2014). A provisional guideline value of 0.04 mg/L has been recommended by WHO (2017).

Se in drinking water can be removed by adsorption on iron/aluminum coated adsorbents, zerovalent iron/iron oxides, ion-exchange resins, and reverse osmosis (Kapoor et al. 1995; Sharma et al. 2019).

27.5.7 Silver

Silver (Ag) is a member of group XI, occurring primarily in the form of the sulfide (argentite Ag_2S) or intimately associated with other metal sulfides, and gold. Its abundance in earth's crust is 0.08 mg/kg. Ag is used in electroplating, as a conductor, in dental alloys, paints, jewelry, silverware, coinage, mirror production, and disinfectant. The average Ag concentration in natural water are 0.2–0.3 μg/L and occasionally above 5 μg/L. Levels in drinking-water treated with silver for disinfection may be above 50 μg/L.

The excess Ag intake results in heavy discoloration of skin and hair and the condition is known as argyria. The estimated acute lethal dose of $AgNO_3$ for humans is minimum 10 g. There are no adequate data to derive a health-based guideline value for silver in drinking-water. WHO (2017) does not specify any guideline value for Ag in drinking water.

Silver present in drinking water can be reduced by reverse osmosis membranes, distillation, and ion exchange resins.

27.5.8 Zinc

Zinc (Zn), a member of group XII, is an essential trace element found in virtually all food and potable water. The concentration of Zn in surface water and groundwater normally does not exceed 0.01 and 0.05 mg/L respectively. Zn concentrations in excess of 3–5 mg/L impart an undesirable astringent taste to water and develop a greasy film on boiling, although, drinking water rarely contains Zn concentration above 0.1 mg/L. The daily requirement of Zn for adult humans is 15–22 mg. Drinking water usually makes a negligible contribution to zinc intake and is not of health concern at levels found in drinking water, therefore, WHO (2017) has not established any guideline value.

Zn present in drinking water can be removed by coagulation, ion exchange, adsorption, and evaporation. Reverse osmosis membranes could also be effective in zinc removal although Zn precipitates may foul the membranes (Alswata et al. 2017; Khulbe and Matsuura 2018).

27.5.9 Cadmium

Cadmium (Cd), a group XII element, and its compounds are widely used in batteries, pigments, electronic components, and nuclear reactors. It is released to the environment through wastewater, leaching of solid waste, and diffuse pollution from fertilizers and local air pollution. Cadmium concentration in natural waters is usually below 1 μg/L and can go up to 100 μg/L. Cadmium accumulates primarily in the kidneys, has a long biological half-life in humans of 10–35 years, and adversely affects the kidney. The absorption of cadmium compounds is dependent on the solubility of the compounds. The epidemiological studies had established the Cd induced carcinogenicity by the inhalation route, and IARC has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans), however, evidence of carcinogenicity by the oral route is lacking (WHO 2011d; Health Canada 2019; Idrees et al. 2018). WHO (2017) has prescribed a guideline value of 0.003 mg/L for Cd in drinking water.

Cadmium in drinking water can be removed by coagulation/filtration, electrocoagulation, ion exchange, adsorption, distillation, or reverse osmosis (Zhao et al. 2002; Yaacoubi et al. 2014; Heffron et al. 2016, 2019).

27.5.10 Lead

Lead (Pb), a group X element, accounts for 13 mg/kg of Earth's crust, and is used principally in the production of lead-acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors, ammunition, glazes, and plastic stabilizers. The organic lead compounds tetraethyl and tetra methyl lead has also been used extensively as antiknock and lubricating agents in petrol, although their use in many countries including India has largely been phased out. Exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. The evidence for the carcinogenicity of lead in humans is inconclusive because of the limited number of studies, and therefore, Pb has been placed in Group 2B (possible human carcinogen) of the IARC classification, however, inorganic lead compounds have been placed in Group 2A (namely probable human carcinogen). The provisional guideline value for lead in drinking water prescribed by WHO (2017) is 0.01 mg/L.

Pb in drinking water can be removed by coagulation and filtration, lime softening, electrocoagulation, ion-exchange resins, or reverse osmosis (Heffron et al. 2016; Health Canada 2017).

27.5.11 Mercury

Mercury (Hg), a group XII element, is a toxic element. It is present in Earth's crust at an average concentration of 0.08 mg/kg and cinnabar (HgS) is the most common ore. Mercury and its compounds are used in dental preparations, thermometers, fluorescent and ultraviolet lamps, and pharmaceuticals, fungicides, and chlor-alkali industry. In oxic waters, Hg exists as $Hg(OH)_2$ and $HgCl_2$, and in anoxic sediments, it is immobilized as the sulfide. Mercury content in the surface and groundwater is generally less than 0.5 μg/L, however, concentration up to 5.5 μg/L has been reported in the wells in Izu Oshima Island (Japan). Mercury poisoning results in neurological and renal disturbances. Neurological disturbances is due to organic mercury ingestion and renal disturbance is due inorganic mercury. The guideline value for mercury prescribed by WHO (2017) is 0.006 mg/L.

The treatment technologies that are effective in removing Hg from drinking water are $FeCl_3$ assisted co-precipitation at pH 8, lime softening, adsorption on granular activated carbon, ion-exchange resins, or reverse osmosis.

27.5.12 Molybdenum

Molybdenum (Mo), a group VI element, is an essential trace element for human, animal, and plant health, and exposure to high doses can be detrimental. Its abundance in Earth crust is around 1.5 mg/kg. Mo is present in special steels, electric contacts, filaments, X-ray tubes, spark plugs, induction heating elements, lubricants, fertilizer, and treatment of seeds. The estimated daily requirement of Mo for adults is 0.1–0.3 mg, however, Mo content in the drinking water usually do not exceed 10 μg/L (WHO 2011a, e; Smedly and Kinniburgh 2017). Therefore, WHO (2017) did not recommend any guideline value.

Molybdenum in drinking water can be removed by co-precipitation with ferric iron, adsorption on modified biochar and activated carbon, or ion-exchange resins (LeGendre and Runnells 1975; Verbinnen et al. 2012; Zhang et al. 2015; Lian et al. 2018).

27.5.13 Nickel

Nickel (Ni), a group X element, is an essential metal for several animal species, micro-organisms and plants, and toxicity symptoms can occur when too little or too much nickel is taken up. The average abundance of nickel in the earth's crust is 1.2 mg/L, in soils it is 2.5 mg/L, in streams it is 1 μg/L and in groundwater it is <0.1 mg/L. Nickel is obtained chiefly from pyrrhotite and garnierite. Nickel is released to the environment from the burning of fossil fuels and waste discharge from electroplating industries. In general concentration of nickel in water resources is generally below 0.02 mg/L. IARC has included inhaled nickel compounds in Group 1 (carcinogenic to humans) and metallic nickel in Group B (possibly carcinogenic), however, there is a lack of evidence of a carcinogenic risk from oral exposure to nickel. The guideline value for nickel prescribed by WHO (2017) is 0.07 mg/L.

Nickel in drinking water can be removed by chemical coagulation-sedimentation-filtration, adsorption, or electrocoagulation (WHO 2005c; Kalkan et al. 2012; Heffron et al. 2016; Thanh et al. 2018).

27.5.14 Arsenic

Arsenic (As), a group XV metalloid, is usually present in natural waters at concentrations of less than 1–2 μg/L. However, in groundwaters, the concentrations can be significantly elevated depending on the aquifer geology. Arsenic can exist in four valences –3, 0, +3, and +5, out of which arsenite (As^{+3}) is dominant in reducing conditions and arsenate (As^{+5}) is dominant in oxic environment. The acute toxicity of arsenic compounds in humans is predominantly a function of their rate of removal from the body. Arsine is considered to be the most toxic form, followed by the arsenites, the arsenates and organic arsenic compounds. Signs of chronic arsenicism, including dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular disease, have been observed in populations ingesting arsenic-contaminated drinking-water. WHO (2017) has recommended 0.010 mg/L as the provisional guideline value for drinking water.

As in drinking water can be removed by oxidation followed by adsorption, coagulation-flocculation, electrocoagulation, nanomaterials, or reverse osmosis (Ng et al. 2004; Thirunavukkarasu et al. 2005; Nicomel et al. 2015; Heffron et al. 2016; Hao et al. 2018).

27.5.15 Chromium

Chromium (Cr), a group VI element, is widely distributed in Earth crust with an average concentration of 100 mg/kg. In water, chromium occurs in two oxidation states, Cr (III) and Cr (VI). Chromium (III) is an essential human dietary element and is found in many vegetables, fruits, meats, grains, and yeast. Cr enters the environment by industrial processes discharge. Further, chromium enters the environment by leakage, poor storage, or inadequate industrial waste disposal practices. IARC has classified chromium (VI) in Group 1 (human carcinogen) and chromium (III) in Group 3 (not classifiable as to its carcinogenicity to humans). WHO (2017) prescribes provisional guideline value of 0.05 mg/L for Cr.

Cr in drinking water can be removed by adsorption, ion exchange, electrocoagulation, biosorption, nanomaterial, or reverse osmosis membranes (Rengraj et al. 2001; Shah et al. 2011; Heffron et al. 2016; Mitra et al. 2017; Chen et al. 2018; Liu et al. 2018).

27.6 Bacteriological Quality

The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant. Infectious diseases caused by pathogenic bacteria, viruses and parasites are the most common and widespread health risk associated with drinking-water. Microbiological contamination is most likely to arise from the entry of fecal matter to waters. Specific waterborne disease outbreaks attributed to contaminated groundwater include cholera, salmonellosis, shigellosis, infectious hepatitis, gastroenteritis, and amoebic dysentery.

Microbiological examination of water samples is conducted to determine the sanitary quality and degree of contamination with wastes. The examination involves

Table 27.7 BIS limits for bacteriological parameters (BIS 2012)

Sr. No.	Characteristic	Requirement
1	Total coliform bacteria	Shall not be detectable in any 100 mL sample
2	*E. coli* or thermotolerant coliform bacteria	Shall not be detectable in any 100 mL sample

detection and enumeration of indicator organisms, rather than pathogens. The coliform group of bacteria is the principal indicator of suitability of a water for domestic, industrial, or other uses. Escherichia coli (*E. coli*) is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens. Fecal coliforms may enter surface water by a number of ways, from contaminated soil runoff from storm water, from vegetation and insects, wash from cities, or from direct sewage pollution by man or animals. BIS (2012) has prescribed absence of total coliform and *E. coli* bacteria in the drinking water (Table 27.7). WHO (2017) also recommends that total coliforms and *E. coli* (or, alternatively, thermotolerant coliforms) should be absent in the drinking water and their presence indicate inadequate treatment or breaches in distribution system integrity.

Coliforms in the drinking water can be eliminated by disinfection with chlorine, chloramine, chlorine dioxide, hydrogen peroxide, ozone, silver nanoparticles, and ultraviolet radiation (EPA 2011; Percival et al. 2014; Nguyen et al. 2017).

27.7 Radioactive Substances

Water used for drinking may contain radioactive substances and are harmful to human health. Minute traces of radioactivity are normally found in all drinking water, which may vary from place to place depending on the radiochemical composition of the soil and rock strata through which the raw water has passed. Several naturally occurring and human made sources present throughout the environment results in radioactivity of water, and it is quite expensive as well as time consuming to identify individual radionuclides. Therefore, measurement of total radioactivity in the form of alpha and beta emitters is conducted, followed by investigation of the concentration of individual radionuclides, in case the alpha and beta emissions exceed the guideline value. The acceptable limits prescribed by BIS (2012) for radioactive substances in drinking water is provided in Table 27.8.

WHO (2017) recommends guideline levels of 0.5 Bq/L for gross alpha activity and 1.0 Bq/L for gross beta activity.

The alpha radioactivity in water sample is measured by alpha counter having ZnS-Ag scintillation counter after evaporating the sample to near dryness. Similarly,

Table 27.8 BIS limits for parameters concerning radioactive substances (BIS 2012)

Sr. No.	Characteristic	Acceptable limit	Permissible limit
1	Alpha emitters, Bq/L, *Max*	0.1	No relaxation
2	Beta emitters, Bq/L, *Max*	1.0	No relaxation

beta radioactivity in the water sample is measured by Geiger Muller counting system after evaporating the sample to near dryness.

The radioactive material in the drinking water can be removed by aeration, adsorption, and membrane processes (RO/NF) (Huikuri et al. 1998; Montana et al. 2013; Baeza et al. 2017; Khulbe and Matsuura 2018).

27.8 Summary and Conclusion

The quality of water is very important and a determining factor of its usefulness. Significance of water quality parameters can be judged from the fact that unsafe water is responsible for around 88% of the deaths from diarrheal diseases. Accordingly, BIS has prescribed the limiting values for 66 drinking water quality parameters important from human health, aesthetic reasons, and operational issues. The water supply departments should prioritize microbial safety of drinking water on the top, followed by chemical constituents causing adverse health effects, organoleptic parameters, and operational parameters at the end. The aesthetic or organoleptic parameters, although do not impact human health, and are significant in the sense that they decide the acceptability of water for drinking. The contribution of drinking water to the total exposure of radioactivity is very small, however, in certain areas with prominent radioisotopes in their geological formations, radiological parameters become important.

All the prescribed BIS parameters should be analyzed at least once when the treatment system is initially operationalized. During continuous operation, it is recommended to analyze the microbial parameters every day, the operational and organoleptic parameters weekly, and other parameters annually. However, depending upon the geology and source, the critical parameters should be analyzed more frequently.

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