WATER CHEMISTRY & CHARACTERISTICS

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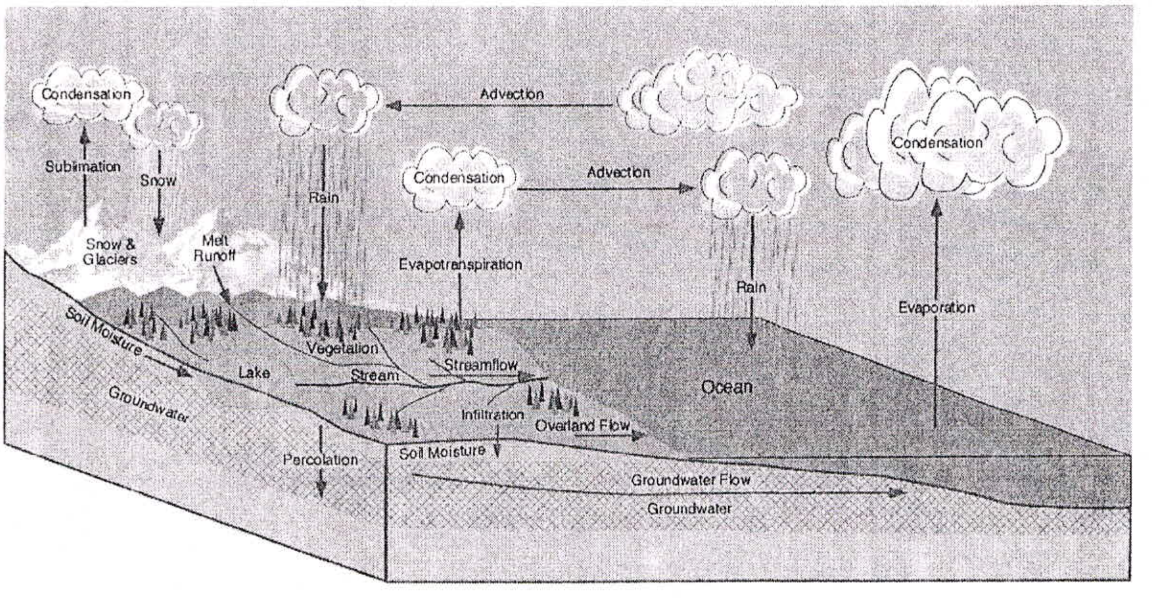
In its pure state, water is one of the most aggressive solvents (universal solvent) and to a certain degree, will dissolve virtually everything to which it is exposed. Pure water has a very high energy state and, like everything else in nature, seems to achieve energy equilibrium with its surroundings. It will dissolve the quantity of material available until the solution reaches saturation, the point at which no higher level of solids can be dissolved. Contaminants found in water include atmospheric gases, minerals, organic materials (some naturally occurring, others man-made) plus any materials used to transport or store water.

Source of Water – Natural Contamination & Purification

Water evaporates from surface supplies and transpires from vegetation directly into the atmosphere. The evaporated water then condenses in the cooler air on nuclei such as dust particles and eventually returns to the earth's surface as rain, snow, sleet, or other precipitation. It dissolves gases such as carbon dioxide, oxygen, and natural and industrial emissions such as nitric and sulfuric oxides, as well as carbon monoxide. Typical rain water has a pH of 5 to 6. The result of contact with higher levels of these dissolved gases is usually a mildly acidic condition called "acid" rain – that may have a pH as low as 4.0.



As the precipitation nears the ground, it picks up many additional contaminants - airborne particulates, spores, bacteria, and emissions from countless other sources. Most precipitation falls into the ocean, and some evaporates before reaching the earth's surface. The precipitation that reaches land replenishes groundwater aquifers and surface water supplies. The water that percolates down through the porous upper crust of the earth is substantially "filtered" by that process. Most of the particulate matter is removed, much of the organic contamination is consumed by bacterial activity in the soil, and a relatively clean, mildly acidic solution results. This acidic condition allows the water to dissolve many minerals, especially limestone, which contributes calcium. Other geologic formations contribute minerals, such as magnesium, iron, sulfates and chlorides. The addition of these minerals usually raises groundwater pH to a range of 7 to 8.5. This mineral-bearing water is stored in natural underground formations called aquifers. These are the source of the well water used by homes, industries and municipalities. Surface waters such as rivers, lakes and reservoirs typically contain less mineral contamination because that water did not pass through the earth's soils. Surface waters will, however, hold higher levels of organics and undissolved particles because the water has contacted vegetation and caused runoff to pick up surface debris.

Impurities in Water

Water

Physical

- Colour
- Odour & taste
- Turbidity
- Suspended solids

Chemical

- pH
- Total Solids
- Alkalinity
- Organic matter
- Dissolved gases

Biological

- Bacteria
- Virus
- Fungi
- Algae
- Protozoa

Physical Impurities

a) **Colour** - Drinking water should ideally have no visible colour. Colour iin drinking water is due to organic material, although some metal ions may also tint water. Though it is not a health concern but indicates a certain level of contamination, and can be an aesthetic concern. The source of colour in a drinking water supply should be investigated, particularly if a substantial change has taken place.

Colour is measured with spectrophotometer by using platinum cobalt method. "True colour" refers to the colour of a sample with its turbidity removed and "apparent" colour includes not only colour due to substances in solution, but also due to suspended matter.

High colour from natural organic carbon could also indicate a high propensity to produce disinfection by-products.

Indian standard for drinking water (IS 10500:1991) recommends 5 PtCo unit as desirable and 25 PtCo unit as permissible limit for colour.

b) **Odour & Taste** - The human nose and tongue are the most sensitive detectors. In its pure form water cannot produce odour or taste sensation. Odour and taste are useful parameters as they provide an early indication of contamination which could be hazardous or at least reduce the aesthetic quality of water. These parameters are an indication of harmful contamination in drinking water but certainly can't be relied on to detect harmful contaminants.

c) **Turbidity** - Turbidity consists of suspended material in water, causing a cloudy appearance. This cloudy appearance is caused by the scattering and absorption of light by these particles. The suspended matter may be inorganic or organic. Microorganisms (bacteria, viruses and protozoa) are typically attached to particulates, and removal of turbidity by filtration will significantly reduce microbial contamination in treated water. Turbidity in some groundwater sources is a consequence of inert clay or chalk particles or the precipitation of non soluble reduced iron and other oxides when water is pumped from anaerobic waters, whereas turbidity in surface waters may be the result of particulate matter of many types and is more likely to include attached microorganisms that are a threat to health. Turbidity in distribution systems can occur as a result of the disturbance of sediments and bio films but is also from the ingress of dirty water from outside the system.

Turbidity can seriously interfere with the efficiency of disinfection by providing protection for organisms, and much of water treatment is directed at removal of particulate matter before disinfection. Removal of particulate matter by coagulation and sedimentation and by filtration is an important barrier in achieving safe drinking-water. Achieving low turbidity by filtration (before disinfection) of water from surface sources and groundwater where raised turbidity occurs—for instance, where these are under the influence of surface waters—is strongly recommended to ensure microbially safe water.

Turbidity can also have a negative impact on consumer acceptability of water as a result of visible cloudiness. it is an important indicator of the possible presence of contaminants that would be of concern for health, especially from inadequately treated or unfiltered surface water. Data are emerging that show an increasing risk of gastro intestinal infections that correlates with high turbidity and turbidity events in distribution. This may be because turbidity is acting as an indicator of possible sources of microbial contamination. Therefore, turbidity events should be investigated and the causes corrected.

Turbidity is measured by nephelometric turbidity units (NTU) and can be initially noticed by the naked eye above approximately 4.0 NTU. However, to ensure effectiveness of disinfection, turbidity should be no more than 1 NTU and preferably much lower. Large, well-run municipal supplies should be able to achieve less than 0.5 NTU before disinfection at all times and should be able to average 0.2 NTU or less. Of particular importance is the fact that this will be a good indicator that they are removing chlorine-resistant pathogens such as *Cryptosporidium*.

Indian standard for drinking water (IS 10500:1991) recommends 5 NTU as desirable and 10 NTU as permissible limit for turbidity.

Chemical Impurities

a) **pH** - The pH value of a water source is a measure of its acidity or alkalinity. Surface water typically has a pH value between 6.5 and 8.5 and groundwater tends to have a pH between 6.0 and 8.5. The pH of a water source can vary naturally. Some types of rock and soil, such as limestone, can neutralize acid more effectively than other types of rock and soil, such as granite. When there are a large number of plants growing in a lake or river, they release carbon dioxide when they die and decompose. This carbon dioxide mixes with the water and gets converted into weak carbonic acid which reduces the pH.

   Although pH usually has no direct impact on consumers, it is one of the operational water quality parameters. The Indian guidelines for drinking water quality (IS 10500:1991) suggest that the pH of drinking water should be between 6.5 and 8.5.

b) **Total Dissolved Solids** - Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originates from natural sources, sewage, urban runoff and industrial wastewater. The presence of dissolved solids in water may affect its taste. In a study by the World Health Organization, a panel of tasters came to the following conclusions about the preferable level of TDS in water.

Sr. No.	Level of TDS (mg/L)	Rating
1	Less than 300	Excellent
2	300-600	Good
3	600-900	Fair
4	900-1200	Poor
5	Above 1200	Unacceptable

Water with extremely low TDS concentrations may also be unacceptable because of its flat, insipid taste.

Indian standard for drinking water (IS 10500:1991) recommends 500 mg/L as desirable and 2000 mg/L as permissible limit for dissolved solids.

c) **Alkalinity** - Alkalinity of the water is its acid neutralizing capacity. Alkalinity measurement indicates the quantities of bicarbonate, carbonate and hydroxide in water. It is significant in interpretation and control of water treatment processes.

If the alkalinity is too low, the ability of water to resist pH changes decreases. This means that the pH will go up and down, changing from acidic to basic fairly rapidly. Water with low alkalinity can also be corrosive which can result in copper and lead leaching out of household plumbing. It can also irritate the eyes. Water with high alkalinity has a soda-like taste, can dry out skin and can cause scaling on fixtures and throughout water distribution systems. This scaling is undesirable because it begins to decrease the efficiency of plumbing systems, which results in greater power consumption and increased costs.

Alkalinity is determined by titrating the solution with acid using phenolphthalein (P-alkalinity) and methyl orange (M alkalinity) indicator. Bicarbonate, carbonate, and hydroxide are determined from the P value and M value by alkalinity relationship-

Sr. No.	Values	Bicarbonate	Carbonate	Hydroxide
1	P = 0	M	0	0
2	P < M/2	M – 2P	2P	0
3	P = M/2	0	M	0
4	P > M/2	0	2 (M – P)	2P – M
5	P = M	0	0	M

Indian standard for drinking water (IS 10500:1991) recommends 200 mg/L as desirable and 600 mg/L as permissible limit for total (M) alkalinity.

d) **Total Hardness** - Hardness in water is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium ions. It is usually expressed as milligrams of calcium carbonate per litre. Hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce lather. The degree of hardness of drinking-water is important for aesthetic acceptability by consumers and for economic and operational considerations. Many hard waters are softened for those reasons using several applicable technologies. The choice of the most appropriate conditioning technology will depend on local circumstances (e.g.

water quality issues, piping materials, corrosion) and will be applied either centrally or in individual homes as a consumer preference.

The following table classifies the degree of hardness-

Sr. No.	Hardness Level (mg/L)	Hardness Level
1	0-17	Soft water
2	17-60	Slightly hard water
3	60-120	Moderately hard water
4	120-180	Hard water
5	>180	Very hard water

Drinking-water can be a contributor to calcium and magnesium intake and could be important for those who are marginal for calcium and magnesium. Where drinking water supplies are supplemented with or replaced by demineralized water that requires conditioning, consideration should be given to adding calcium and magnesium salts to achieve concentrations similar to those that the population received from the original supply.

Indian standard for drinking water (IS 10500:1991) limits calcium and magnesium content of water to 75 mg/L and 30 mg/L respectively as desirable limit.

e) **Iron** - Iron is a common water contaminant. Iron exists in two valence states -- water-soluble ferrous state (Fe^{+2}) and insoluble ferric state (Fe^{+3}). When oxygen or an oxidizing agent is introduced, ferrous iron becomes ferric which is insoluble and precipitates, leading to a rusty (red-brown) appearance in water. This change can occur when deep well water is pumped into a distribution system where it adsorbs oxygen. Ferric iron can create havoc with valves, piping, water treatment equipment, and water-using devices. Certain bacteria can further complicate iron problems. Organisms such as *Crenothrix*, *Sphaerotilus* and *Gallionella* use iron as an energy source. These iron-reducing bacteria eventually form a rusty, gelatinous sludge that can plug a water pipe. When diagnosing an iron problem, it is very important to determine whether or not such bacteria are present.

Iron is an essential element in human nutrition, particularly in the iron (II) oxidation state. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day.

Indian standard for drinking water (IS 10500:1991) recommends 0.3 mg/L as desirable and 1.0 mg/L as permissible limit for iron.

f) **Manganese** - Manganese occurs naturally in water sources particularly in anaerobic or low oxidation conditions. Manganese forms a dark, almost black, precipitate leading to black stains on clothes.

Indian standard for drinking water (IS 10500:1991) recommends 0.1 mg/L as desirable and 0.3 mg/L as permissible limit for Manganese.

g) **Sulfate** - Sulfates occur naturally in numerous minerals and are used commercially, principally in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however, the highest levels usually occur in groundwater and are from natural sources.

Drinking water with high sulfate levels (>500 mg/L) leads to gastrointestinal effects. The presence of sulfate in drinking-water may also cause noticeable taste and may contribute to the corrosion of distribution systems. Indian standard for drinking water (IS 10500:1991) recommends 200 mg/L as desirable and 400 mg/L as permissible limit for Sulfate.

h) **Nitrate – Nitrite** - Nitrate (NO_3^-) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrite (NO_2^-) is not usually present in significant concentrations except in a reducing environment, as nitrate is the more stable oxidation state. It can be formed by the microbial reduction of nitrate and in vivo by reduction from ingested nitrate. Nitrite can also be formed chemically in distribution pipes by *Nitrosomonas* bacteria during stagnation of nitrate containing and oxygen-poor drinking water in galvanized steel pipes or if chloramination is used to provide a residual disinfectant.

Nitrate can reach both surface water and groundwater as a consequence of agricultural activity, from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes. Some groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation.

Nitrite reacts with haemoglobin in the red blood cells to form methaeglobin, which binds oxygen tightly and does not release it, thus blocking oxygen transport leading to methaemoglobinaemia (blue baby syndrome). Nitrite can also react with nitrostable compounds, primarily secondary amines, in the body to form N-nitroso compounds which are considered carcinogenic to humans.

Indian standard for drinking water (IS 10500:1991) limits NO_3^- concentration to 45 mg/L.

i) **Organic Matter** - Tannins, humic acid and fulvic acids are common natural contaminants. They cause colour in the water and detract from the aesthetics of water but, unless they react with certain halogens, they have no known health consequences in normal concentrations. In the presence of free halogen compounds (principally chlorine or bromine), they form chlorinated hydrocarbons and trihalomethanes (THM's), which are suspected carcinogens.

A wide variety of synthetic compounds which are potential health hazards are present in water systems due to the use of industrial and agricultural chemicals. These compounds are not readily biodegradable and leach from soil or are carried by runoff into water sources.

Organic matter can be measured as Total organic carbon (TOC), Biochemical oxygen demand (BOD), or Chemical oxygen demand (COD). Measurement of these three parameters requires basic laboratory facilities and adequately trained personnel. Data on the level of organic matter in the treated water provide an indication on the potential for the regrowth of heterotrophic bacteria.

Biological Impurities

The waterborne microorganisms potentially causing illness include bacteria, viruses, protozoa and helminths. The human health effects caused by waterborne transmission vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis and typhoid fever. Contaminated water can be the source of large outbreaks of disease, including cholera, dysentery and cryptosporidiosis. Most waterborne pathogens are introduced into drinking water supplies by human or animal faeces, do not grow in water and initiate infection in the gastrointestinal tract following ingestion. The pathogens that are relevance for drinking water supply management are-

Pathogen [a]	Health significance [b]	Persistence in water supplies [c]	Resistance to chlorine [d]	Relative infectivity [e]	Important animal source
Bacteria					
Burkholderia pseudomallei	High	May multiply	Low	Low	No
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Escherichia coli – Pathogenic [f]	High	Moderate	Low	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	Low	High	Yes
Francisella tularensis	High	Long	Moderate	High	Yes
Legionella spp.	High	May multiply	Low	Moderate	No
Leptospira	High	Long	Low	High	Yes
Mycobacteria (non-tuberculous)	Low	May multiply	High	Low	No
Salmonella Typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long [g]	Low	Low	No
Viruses					
Adenoviruses	Moderate	Long	Moderate	High	No
Astroviruses	Moderate	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A virus	High	Long	Moderate	High	No
Hepatitis E virus	High	Long	Moderate	High	Potentially
Noroviruses	High	Long	Moderate	High	Potentially
Rotaviruses	High	Long	Moderate	High	No
Sapoviruses	High	Long	Moderate	High	Potentially
Protozoa					
Acanthamoeba spp.	High	May multiply	High	High	No
Cryptosporidium hominis/parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply [h]	Low	Moderate	No
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

[a] This table contains pathogens for which there is some evidence of health significance related to their occurrence in drinking-water supplies.

[b] Health significance relates to the incidence and severity of disease, including association with outbreaks.

[c] Detection period for infective stage in water at 20 °C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month.

[d] When the infective stage is freely suspended in water treated at conventional doses and contact times and pH between 7 and 8. Low means 99% inactivation at 20 °C generally in < 1 min, moderate 1–30 min and high > 30 min. It should be noted that organisms that survive and grow in biofilms, such as *Legionella* and mycobacteria, will be protected from chlorination.

[e] From experiments with human volunteers, from epidemiological evidence and from experimental animal studies. High means infective doses can be $1-10^2$ organisms or particles, moderate 10^2-10^4 and low $> 10^4$.

[f] Includes enteropathogenic, enterotoxigenic, enteroinvasive, diffusely adherent and enteroaggregative.

[g] *Vibrio cholerae* may persist for long periods in association with copepods and other aquatic organisms.

[h] In warm water.

a) **Bacteria** - Bacteria are generally the group of pathogens that is most sensitive to inactivation by disinfection. Some free-living pathogens, such as *Legionella* and non-tuberculous mycobacteria, can grow in water environments, but enteric bacteria typically do not grow in water and survive for shorter periods than viruses or protozoa. Many bacterial species that are infective to humans are carried by animals. There are a number of potentially waterborne bacterial pathogens like *Vibrio*, *Campylobacter*, *E. coli* O157, *Salmonella* and *Shigella.* Toxigenic *Vibrio cholerae* can cause watery diarrhoea. When it is left untreated, as may be the case when people are displaced by conflict and natural disaster, case fatality rates are very high. *Campylobacter* is an important cause of diarrhoea worldwide. Illness can produce a wide range of symptoms, but mortality is low. It is relatively common in the environment, and waterborne outbreaks have been recorded. Waterborne infection by *E. coli* O157 and other entero haemorrhagic strains of *E. coli* is far less common than infection by *Campylobacter*, but the symptoms of infection are more severe, including haemolytic uraemic syndrome and death.

b) **Viruses** - Viruses are the smallest pathogens and hence are more difficult to remove by physical processes such as filtration. Specific viruses may be less sensitive to disinfection than bacteria and parasites (e.g. adenovirus is less sensitive to UV light). Viruses can persist for long periods in water. Infective doses are typically low. Viruses typically have a limited host range, and many are species specific. Most human enteric viruses are not carried by animals, although there are some exceptions, including specific strains of hepatitis E virus. Rotaviruses, enteroviruses and noroviruses have been identified as potential reference pathogens.

Rotaviruses are the most important cause of gastrointestinal infection in children and can have severe consequences, including hospitalization and death, with the latter being far more frequent in low-income regions. In low-income countries, sources other than water are likely to dominate.

Enteroviruses, including polioviruses and the more recently recognized parechoviruses, can cause mild febrile illness, but are also important causative agents of severe diseases, such as paralysis, meningitis and encephalitis, in children.

Rotavirus and enteroviruses are excreted in very large numbers by infected patients, and waters contaminated by human waste could contain high concentrations.

Noroviruses are a major cause of acute gastroenteritis in all age groups. Symptoms of illness are generally mild and rarely last longer than 3 days; however, infection does not yield lasting protective immunity.

c) **Protozoa** - Protozoa are the group of pathogens that is least sensitive to inactivation by chemical disinfection. UV light irradiation is effective against *Cryptosporidium*, but *Cryptosporidium* is highly resistant to oxidizing disinfectants such as chlorine. Protozoa are of a moderate size (> 2 μm) and can be removed by physical processes. They can survive for long periods in water. They are moderately species specific. Livestock and humans can be sources of protozoa such as *Cryptosporidium* and *Balantidium*, whereas humans are the sole reservoirs of pathogenic *Cyclospora* and *Entamoeba*. *Giardia* infections are generally more common than *Cryptosporidium* infections, and symptoms can be longer lasting. However, *Cryptosporidium* is smaller than *Giardia* and hence more difficult to remove by physical processes; it is also more resistant to oxidizing disinfectants, and there is some evidence that it survives longer in water environments.

REFERENCES

1. Guidelines for Drinking Water Quality (2011) published by WHO
2. NALCO Water Handbook (1988) published by McGraw-Hill
3. Pure Water Handbook (1997) published by Osmonics Inc.
4. Standard Methods for the Examination of Water and Wastewater (1989) published by APHA and AWWA