WATER RESOURCES AND HYDROLOGICAL CYCLE:

Water is one of the most abundant compounds found in nature, covering approximately three-fourths of the surface of the earth. In spite of this apparent abundance, several factors serve to limit the amount of water available for human use. As shown in Fig. 1, over 98 percent of the total water is contained in the oceans and other saline bodies of water and is not readily usable for most of the purposes. Of the remaining 2 percent, 87 percent is tied up in ice caps and glaciers and 12 percent in groundwater. Thus, for general livelihood and for the support of varied technical and agricultural activities, humans must depend upon the remaining 1 percent water found in freshwater lakes and rivers (instantaneous volume).

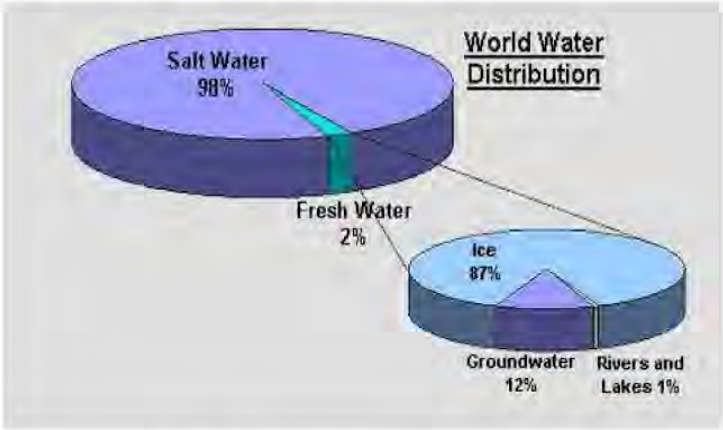


Fig. 1: World water distribution

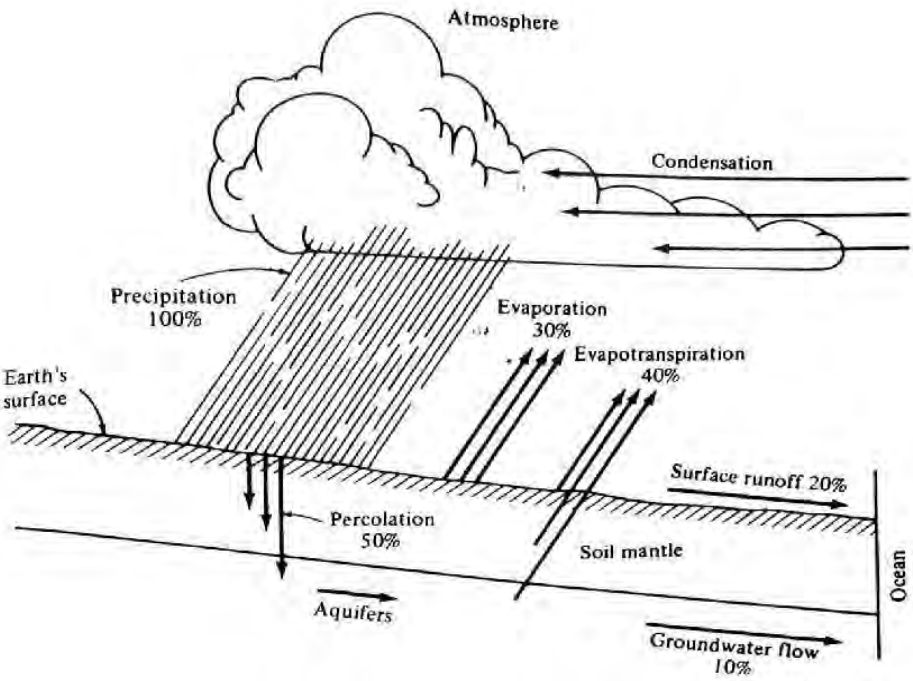


Fig. 2: The hydrological cycle

Table 1: Class of Water

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfections	A	Total coliform organisms MPN/100ml shall be 50 or less.
		pH between 6.5 and 8.5
		Dissolved oxygen 6 mg/l or more
		Biochemical oxygen demand 2 mg/l or less
Outdoor bathing (organized)	B	Total coliform organisms MPN/100ml shall be 500 or less
		pH between 6.5 and 8.5
		Dissolved oxygen 5 mg/l or more
		Biochemical oxygen demand 3 mg/l or less
Drinking water source with conventional treatment followed by disinfection	C	Total coliform organisms MPN/ 100ml shall be 5000 or less
		pH between 6 and 9
		Dissolved oxygen 4 mg/l or more
		Biochemical oxygen demand 3 mg/l or less
Propagation of wildlife, fisheries	D	pH between 6.5 and 8.5
		Dissolved oxygen 4 mg/l or more
		Free ammonia (as N) 1.2 mg/l or less
Irrigation, industrial cooling, controlled waste disposal	E	pH between 6.0 and 8.5
		Electrical conductivity less than 2250 micromhos/cm
		Sodium absorption ratio less than 26
		Boron less than 2mg/l

WATER SUPPLY SOURCES:

There are two major sources of water supply: Surface water sources and Groundwater sources

Surface water sources: Surface water sources are those sources of water in which water flows over the surface of the earth and is thus directly available for water supplies. For example, Natural ponds, lakes, streams, rivers, and impounding reservoirs.

Groundwater source: Groundwater sources are those sources of water in which water is found below the surface of the earth. For example, Infiltration galleries, Infiltration wells, Springs, Wells, etc.

Factors governing the selection of a particular source of water

The following important factors are generally considered in selecting a particular source of water for a population.

(i) **Quantity of available water:** The quantity of water available at the source must be sufficient to meet the various demands during the entire design period of the scheme. Sometimes the water sources may be mobilised for the present-day demand, and extra units added over time. If a sufficient quantity of water is not available in the vicinity of the area, we may have to think of bringing water from distant sources.

(ii) **Quality of available water**: The water available at the source must not contain any toxic, poisonous, elements which may become fatal for the consuming population. The impurities present in the water should be as less as possible and should be such as to be removed easily and economically by conventional treatment methods.

(iii) **Distance of the source of supply:** The source of water must be situated as near as possible to the city. Because when the distance between the source and the city is less, lesser length of pipe conduits and fewer number of associated appurtenances are required, thereby reducing the cost of the project.

(iv) **General topography of the intervening area**: The area between the source and the city should not be highly uneven. It should not contain deep valleys or high mountains and ridges. In such uneven topographies, the cost of trestles for carrying water pipes in valleys and that of constructing tunnels in mountains shall be enormous.

(v) **Elevation of the source of supply**: The source of water must be on a high contour, lying sufficiently higher than the city or town to be supplied with water, to make the gravity flow possible. When the water is available at lower levels than the average city level, pumping has to be resorted to, which involves huge operational costs and frequent possible breakdowns.

WATER POLLUTION:

Water pollution may be defined as the presence of impurities in water in such quantity and of such nature as to impair the use of the water for a stated purpose. Thus, the definition of water quality is predicted on the intended use of the water, and a gross determination of the quantity of suspended and dissolved impurities, while useful in some cases, is not sufficient to completely define water quality. Many parameters have evolved that qualitatively reflect the impact that various impurities may have on selected water uses.

Water pollutants

Water that has been withdrawn, used for some purpose, and then returned will be polluted in one way or another. Agricultural return water contains pesticides, fertilizers, and salts; municipal return water carries human sewage, pharmaceuticals, and surfactants; power plants discharge water that is elevated in temperature, and industry contributes a wide range of chemical pollutants and organic wastes. To aggravate the problem, pollutants also enter the water from natural sources and from human sources via nonaqueous routes. Arsenic, antimony, and fluoride often come from natural mineral deposits through which groundwater flows.

The list of pollutants that contaminate water is lengthy, so it helps to organize the list into a smaller number of major categories, as has been done in the following sections.

Pathogens: Pathogens are disease-causing organisms that grow and multiply within the host. The resulting growth of microorganisms in a host is called contamination. Examples of pathogens associated with water include bacteria responsible for cholera, bacillary dysentery (shigellosis), typhoid, and paratyphoid fever; viruses responsible for infectious hepatitis and poliomyelitis; protozoa which cause amoebic dysentery, giardiasis, and cryptosporidiosis; and helminths or parasitic worms that cause diseases such as schistosomiasis and dracunculiasis (guinea-worm disease).

Although it is not the only source of pathogens in water, contamination by human faeces is the most important. Table 2 provides a more complete list of pathogens and the diseases caused by them.

Table 2: Typical pathogens and associated diseases

Organism	Disease
Bacteria	
Francisella tularensis	Tularemia (deer fly fever)
Leptospirae	Leptospirosis (Weil's disease, swineherd's disease, hemorrhagic jaundice)
Salmonella paratyphi (A, B, C)	Paratyphoid (enteric fever)
Salmonella typhi	Typhoid fever, enteric fever

Shigella (S. flexneri, S. sonnei, S. dysenteriae, S. boydii)	Shigellosis (bacillary dysentery)
Vibrio comma (Vibrio cholerae)	Cholera (Asiatic, Indian, El Tor)
Viruses	
Enteric cytopathogenic human orphan (ECHO) (ECHO)	Aseptic meningitis, epidemic exanthem. infantile diarrhea
Poliomyelitis (3 types)	Acute anterior poliomyelitis, infantile paralysis
Unknown viruses	Infectious hepatitis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery, amebic enteritis, amebic colitis)
Giardia lamblia	Giardiasis (Giardia enteritis, lambliasis)
Helminths (parasitic worms)	
Dracunculus medinensis	Dracontiasis (dracunculiasis; dracunculosis; medina; serpent, dragon, or guinea-worm infection)
Echinococcus	Echinococcosis (hydatidosis; granulosus; dog tapeworm)
Schistosoma (S. mansoni, S. japonicum, S. haematobium)	Schistosomiasis (bilharziasis or "Bill Harris" or "blood fluke" disease)

Oxygen-demanding waste: One of the most important measures of the quality of a water source is the amount of dissolved oxygen (DO) present. The saturated value of DO in water is modest in the order of 8 to 15 mg/L of oxygen, depending on temperature and salinity. The minimum recommended amount of DO for a healthy fish population has often been set at 5 mg/L, but a more careful analysis of the needs of different fish species at different times in their lifecycle yields a range of oxygen requirements.

Oxygen-demanding wastes are substances that oxidize in the receiving body of water. As bacteria decompose these wastes, they utilize oxygen dissolved in the water, which reduces the remaining amount of DO. As DO drops, fish and other aquatic lives are threatened and in the extreme case, killed. In addition, as dissolved oxygen levels fall, undesirable odours, tastes, and colours reduce the acceptability of that water as a domestic supply and reduce its attractiveness for recreational uses.

Nutrients: Nutrients are chemicals, such as nitrogen, phosphorus, carbon, sulphur, calcium, potassium, iron, manganese, boron, and cobalt that are essential to the growth of living things. In terms of water quality, nutrients can be considered as pollutants when their concentrations are sufficient to allow excessive growth of aquatic plants, particularly algae.

Nutrient enrichment can lead to algae blooms, which eventually die and decompose. Their decomposition decreases dissolved oxygen from the water, potentially leading to levels of DO that are insufficient to sustain normal aquatic life forms. Algae and decaying organic matter add colour, turbidity, odours, and objectionable tastes to water that are difficult to remove and that may greatly reduce its acceptability as a domestic water source.

Salts: Water naturally accumulates a variety of dissolved solids, or salts, as it passes through soils and rocks on its way to the sea. These salts typically include such as cations of sodium, calcium, magnesium, and potassium, and anions such as chloride, sulphate, and bicarbonate. A careful analysis of salinity would result in a list of the concentrations of the primary cations and anions, but a simpler, more commonly used measure of salinity is the concentration of total dissolved solids (TDS). As a rough approximation, fresh water can be considered to be water with less than 1,500 mg/L TDS; brackish waters may have TDS values up to 5,000 mg/L, and

saline waters are those with concentrations above 5,000 mg/L. Seawater contains 30,000 to 34,000 mg/L TDS.

Heavy metals: In some contexts, the definition of a metal is based on physical properties. Metals are characterized by high thermal and electrical conductivity, high reflectivity and metallic lustre, strength, and ductility. From a chemical perspective, however, it is more common to use a broader definition that says a metal is an element that will give up one or more electrons to form a cation in an aqueous solution. These definitions are imprecise, as there are some elements that exhibit both metallic and non-metallic characteristics and form anions in an aqueous solution. These elements are sometimes referred to as metalloids and include selenium, arsenic, phosphorus, silicon, and boron. Including the metalloids, about 80 elements can be called metals. The term heavy metal is less precisely defined. It is often used to refer to metals with specific gravity greater than about 4 or 5. In terms of their environmental impacts, the most important heavy metals are mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As).

PHYSICAL WATER-QUALITY PARAMETERS:

COLOUR

Pure water is colourless, but water in nature is often coloured by foreign substances. Water whose colour is partly due to suspended matter is said to have apparent colour. Colour contributed by dissolved solids that remain after the removal of suspended matter is known as true colour.

Sources

After contact with organic debris such as leaves, weeds, or wood, water picks up tannins, humic acid, and humates and takes on yellowish-brown hues. Iron oxides cause reddish water, and manganese oxides cause brown or blackish water. Industrial wastes from textile and dyeing operations, pulp and paper production, food processing, chemical production, mining, refining, and slaughterhouse operations may add substantial coloration to water in receiving streams.

Impacts

Coloured water is not aesthetically acceptable to the general public. In fact, given a choice, consumers tend to choose clear, non-coloured water over poorer quality treated potable water supplies with an objectionable colour. Highly coloured water is unsuitable for laundering, dyeing, papermaking, beverage manufacturing, dairy production and other food processing, textile and plastic production. Thus, the colour of water affects its marketability for both domestic and industrial use.

While true colour is not usually considered unsanitary or unsafe, the organic compounds causing true colour may exert a chlorine demand and thereby seriously reduce the effectiveness of chlorine as a disinfectant. Perhaps more important are the products formed by the combination of chlorine with some colour-producing organics.

Measurement

For precise determination of small colour intensities, compact instrument properly lighted from inside, called a tintometer, is generally used. The instrument contains an eye piece with two holes. A slide of standard coloured water is seen through one hole, and the slide of water to be tested is seen from the other hole. The standard coloured slide is replaced by another, till a

matching is obtained, as is done in a turbidimeter. The standard colour intensity corresponding to this matching will represent the intensity of colour of the water sample.

In fieldwork, instruments employing coloured glass disks that are calibrated to the colour standards are often used. Because biological and physical changes occurring during storage may affect colour, samples should be tested within 72 h of collection.

TASTE AND ODOUR

The terms taste and odour are themselves definitive of this parameter. Because the sensations of taste and smell are closely related and often confused, a wide variety of tastes and odours may be attributed to water by consumers. Substances that produce an odour in water will almost invariably impart a taste as well. The converse is not true, as there are many mineral substances that produce taste but no odour.

Sources

Many substances with which water comes into contact in nature or during human use may impart perceptible taste and odour. These include minerals, metals, and salts from the soil, end products from biological reactions, and wastewater constituents. Inorganic substances are more likely to produce tastes unaccompanied by odour. Alkaline material imparts a bitter taste to water, while metallic salts may give a salty or bitter taste.

Organic material, on the other hand, is likely to produce both taste and odour. A multitude of organic chemicals may cause taste and odour problems in the water, with petroleum-based products being prime offenders. The biological decomposition of organics may also result in taste- and odour-producing liquids and gases in water. Principal among these are the reduced products of sulphur that impart a "rotten egg" taste and odour. Also, certain species of algae secrete an oily substance that may result in both taste and odour. The combination of two or more substances, neither of which would produce taste or odour by itself, may sometimes result in taste and odour problems. This synergistic effect was noted earlier in the case of organics and chlorine.

Impacts

Consumers find taste and odour aesthetically displeasing for obvious reasons. Because water is thought of as tasteless and odourless, the consumer associates taste and odour with contamination and may prefer to use a tasteless, odourless water that might actually pose more of a health threat. Odours produced by organic substances may pose more than a problem of simple aesthetics, since some of those substances may be carcinogenic.

Measurement

Direct measurement of materials that produce tastes and odours can be made if the causative agents are known. Several types of analyses are available for measuring taste-producing inorganics. Measurement of taste- and odour-causing organics can be made using gas or liquid chromatography. Because chromatographic analysis is time-consuming and requires expensive equipment, it is not routinely performed on water samples, but should be done if problem organics are suspected.

SUSPENDED SOLIDS

As noted earlier, solids can be dispersed in water in both suspended and dissolved forms. Although some dissolved solids may be perceived by the physical senses, they fall more appropriately under the category of chemical parameters and will be discussed more fully in a later section.

Sources

Solids suspended in water may consist of inorganic or organic particles or of immiscible liquids. Inorganic solids such as clay, silt, and other soil constituents are common in surface water. Organic materials such as plant fibres and biological solids (algal cells, bacteria, etc.) are also common constituents of surface waters. These materials are often natural contaminants resulting from the erosive action of water flowing over surfaces. Because of the filtering capacity of the soil, suspended material is seldom a constituent of groundwater.

Other suspended materials may result from human use of the water. Domestic wastewater usually contains large quantities of suspended solids that are mostly organic in nature. Industrial use of water may result in a wide variety of suspended impurities of either organic or inorganic nature. Immiscible liquids such as oils and greases are often constituents of wastewater.

Impacts

Suspended material may be objectionable in water for several reasons. It is aesthetically displeasing and provides adsorption sites for chemical and biological agents. Suspended organic solids may be degraded biologically, resulting in objectionable by-products. Biologically active (live) suspended solids may include disease-causing organisms and toxin-producing strains of algae.

Measurement

There are several tests available for measuring solids. Most of them are gravimetric tests involving the mass of residues. The total solids test quantifies all the solids in the water, suspended and dissolved, organic and inorganic. This parameter is measured by evaporating a sample to dryness and weighing the residue. The total quantity of residue is expressed as milligrams per litre (mg/L) on a dry-mass-of-solids basis. A drying temperature slightly above boiling (104 °C) is sufficient to drive off the liquid and the water adsorbed to the surface of the particles, while a temperature of about 180°C is necessary to evaporate the occluded water.

TURBIDITY

Direct measurement of suspended solids is not usually performed on samples from natural bodies of water or on potable (drinkable) water supplies. The nature of the solids in these waters and the secondary effects they produce are more important than the actual quantity. For such waters, a test for turbidity is commonly used.

Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended material in water. Because absorption and scattering are influenced by both size and surface characteristics of the suspended material, turbidity is not a direct quantitative measurement of suspended solids. For example, one small pebble in a glass of water would produce virtually no turbidity. If this pebble were crushed into thousands of particles of colloidal size, a measurable turbidity would result, even though the mass of solids had not changed.

Sources
Most turbidity in surface waters results from the erosion of colloidal material such as clay, silt, rock fragments, and metal oxides from the soil. Vegetable fibres and microorganisms may also contribute to turbidity. Household and industrial wastewater may contain a wide variety of turbidity-producing materials. Soaps, detergents, and emulsifying agents produce stable colloids that result in turbidity. Although turbidity measurements are not commonly run-on wastewater, discharges of wastewater may increase the turbidity of natural bodies of water.

Impacts
When turbid water in a small, transparent container, such as a drinking glass, is held up to the light, an aesthetically displeasing opaqueness or "milky" coloration is apparent. The colloidal material associated with turbidity provides adsorption sites for chemicals that may be harmful or cause undesirable tastes and odours and for biological organisms that may be harmful. Disinfection of turbid waters is difficult because of the adsorptive characteristics of some colloids and because the solids may partially shield organisms from the disinfectant.

In natural water bodies, turbidity may impart a brown or other colour to the water. Depending on the light-absorbing properties of the solids, it may interfere with light penetration and photosynthetic reactions in streams and lakes. Accumulation of turbidity-causing particles in porous streambeds results in sediment deposits that can adversely affect the flora and fauna of the stream.

Measurement
Turbidity is measured photometrically by determining the percentage of light of given intensity that is either absorbed or scattered. The original measuring apparatus, called a Jackson turbidimeter, was based on light absorption and employed a long tube and standardized candle. In recent years this awkward apparatus has been replaced by a turbidity meter in which a standardized electric bulb produces a light that is then directed through a small sample container. In the absorption mode, a photometer measures the light intensity on the side of the vial opposite from the light source, while in the scattering mode, a photometer measures the light intensity at a 90° angle from the light source. Turbidity meter readings are now expressed as formazin turbidity units, or FTUs. The term nephelometry turbidity unit (NTU) is often used to indicate that the test was run according to the scattering principle.

TEMPERATURE
Temperature is not used to evaluate directly either potable water or wastewater. It is, however, one of the most important parameters in natural surface water systems. The temperature of surface waters governs to a large extent the biological species present and their rates of activity. Temperature has an effect on most chemical reactions that occur in natural water systems. Temperature also has a pronounced effect on the solubilities of gases in water.

Sources
The use of water for dissipation of waste heat in industry and the subsequent discharge of the heated water may result in dramatic, though perhaps localized, temperature changes in receiving streams. Removal of forest canopies and irrigation return flows can also result in increased stream temperature.

Impacts

Cooler waters usually have a wider diversity of biological species. At lower temperatures, the rate of biological activity, i.e., utilization of food supplies, growth, reproduction, etc., is slower. If the temperature is increased, biological activity increases. An increase of 10 °C is usually sufficient to double the biological activity, if essential nutrients are present. At elevated temperatures and increased metabolic rates, organisms that are more efficient at food utilization and reproduction flourish, while other species decline and are perhaps eliminated altogether. Accelerated growth of algae often occurs in warm water and can become a problem when cells cluster into algae mats. Natural secretion of oils by algae in the mats and the decay products of dead algae cells can result in taste and odour problems. Higher-order species, such as fish, are affected dramatically by temperature and by dissolved oxygen levels, which are a function of temperature. Game fish generally require cooler temperatures and higher dissolved-oxygen levels.

Temperature changes affect the reaction rates and solubility levels of chemicals. Most chemical reactions involving dissolution of solids are accelerated by increased temperatures. The solubility of gases on the other hand, decreases at elevated temperatures.

CHEMICAL WATER-QUALITY PARAMETERS:

pH

The pH value of water indicates the logarithm of reciprocal of hydrogen ion concentration present in water. It is thus an indicator of the acidity or the alkalinity of water. Since the pH is the log of reciprocal of H^+, the higher values of pH mean lower hydrogen ion concentrations, and thus represent alkaline solutions; whereas, the lower values of pH means higher hydrogen ion concentrations representing acidic solutions.

Pure water is a balanced combination of positively charged hydrogen ions (i.e., H^+) and negatively charged hydroxyl ions (i.e., OH^-). In pure or neutral waters, their number is equal. Further, it has been found that the product of concentration of H ions and concentration of OH ions in a water solution, is constant. This constant has been found to be equal to 10^{-14} moles/litre. Therefore, if H ion and OH ion concentrations are equal, virtually each will have a concentration equal to $\sqrt{10^{-14}} = 10^{-7}$ moles per litre. A neutral water will, therefore, have a pH equal to

$$\log_{10}\left(\frac{1}{H^+}\right) = \log_{10}\left(\frac{1}{10^{-7}}\right) = \log_{10} 10^7 = 7$$

Example: Find the pH of a solution of 0.002 M of HCl.

Solution: The equation for pH is $-\log [H^+]$

$$[H] = 2.0 \times 10^{-3} \text{ M}$$
$$pH = -\log [2.0 \times 10^{-3}]$$
$$= 2.70$$

ELECTRICAL CONDUCTIVITY

Electrical conductivity of water is a measure of the ability of water to conduct electricity. Pure water is a poor conductor of electricity, but it shows significant conductivity when ions of

dissolved salts are present in it. The elements whose ionic forms contribute to these measures include Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Bicarbonate (HCO_3^-), Sulphate (SO_4^{2-}), and Chloride (Cl^-), etc. The higher the concentration of such ionic (dissolved) constituents, the higher will be the conductivity. It measures as to how much electricity is being conducted through a centimetre of water. It is hence expressed in units of mhos per centimetre (mhos is the unit of conductivity and equals 1 ampere/1 volt). This unit has been renamed by ISO (International Standards Organization) as Siemen (1 mho = 1 Siemen).

ACIDITY

Acidity of water is its quantitative capacity to neutralise a strong base to a designated pH. Strong mineral acids, weak acids such as carbonic & acetic and hydrolysing salts such as ferric and aluminium sulphates may contribute to the measured acidity. Dissolved carbon dioxide (CO_2) is the main source of acidity in unpolluted waters. According to the method of determination, acidity is important because acid contributes to corrosiveness and influences certain chemical and biological processes. It measures the amount of base required to neutralise a given sample to the specific pH. It is expressed as mg/L in terms of calcium carbonate.

ALKALINITY

Alkalinity is defined as the quantity of ions in water that will react to neutralize hydrogen ions. Alkalinity is thus a measure of the ability of water to neutralize acids.

Sources

Constituents of alkalinity in natural water systems include CO_3^{2-}, HCO_3^-, OH^-, $HSiO_3^-$, $H_2BO_3^-$ HPO_4^-, $H_2PO_4^-$, HS^-, and NH_3^0. These compounds result from the dissolution of mineral substances in the soil and atmosphere. Phosphates may also originate from detergents in wastewater discharges and from fertilizers and insecticides from agricultural land. Hydrogen sulphide and ammonia may be the products of microbial decomposition of organic material. By far the most common constituents of alkalinity are bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and hydroxide (OH^-). In addition to their mineral origin, these substances can originate from carbon dioxide, a constituent of the atmosphere and a product of microbial decomposition of organic material. These reactions are as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3^* \quad \textbf{(Dissolved } CO_2 \textbf{ and carbonic acid)}$$
$$H_2CO_3^* \rightleftharpoons H^+ + HCO_3^- \quad \textbf{(bicarbonate)}$$
$$CO_3^- \rightleftharpoons H^+ + CO_3^{2-} \quad \textbf{(carbonate)}$$
$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^- \quad \textbf{(hydroxide)}$$

Hydroxide reaction is a weak reaction chemically. However, utilization of the bicarbonate ion as a carbon source by algae can drive the reaction to the right and result in substantial accumulation of OH^- Water with heavy algal growths often has pH values as high as 9 to 10. Because the reactions represented by the above equations involve hydrogen or hydroxide ions, the relative quantities of the alkalinity species are pH dependent.

Impacts

In large quantities, alkalinity imparts a bitter taste to water. The principal objection to alkaline water, however, is the reactions that can occur between alkalinity and certain cations in the water. The resultant precipitate can foul pipes and other water-systems appurtenances.

Measurement
Alkalinity measurements are made by titrating the water with an acid and determining the hydrogen equivalent. Alkalinity is then expressed as milligrams per litre of $CaCO_3$.

HARDNESS
Hardness is defined as the concentration of multivalent metallic cations in solution. At supersaturated conditions, the hardness cations will react with anions in the water to form a solid precipitate. Hardness is classified as carbonate hardness and noncarbonate hardness, depending upon the anion with which it associates. The hardness that is equivalent to the alkalinity is termed carbonate hardness, with any remaining hardness being called non-carbonate hardness. Carbonate hardness is sensitive to heat and precipitates readily at high temperatures.

$$\boldsymbol{Ca(HCO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O}$$
$$\boldsymbol{Mg(HCO_3)_2 \rightarrow Mg(OH)_2 + 2CO_2}$$

Sources
The multivalent metallic ions most abundant in natural waters are calcium and magnesium. Others may include iron and manganese in their reduced states (Fe^{2+}, Mn^{2+}), strontium (Sr^{2+}), and aluminium (Al^{3+}). The latter are usually found in much smaller quantities than calcium and magnesium, and for all practical purposes, hardness may be represented by the sum of the calcium and magnesium ions.

Impacts
Soap consumption by hard waters represents an economic loss to the water user. Sodium soaps react with multivalent metallic cations to form a precipitate, thereby losing their surfactant properties. A typical divalent cation reaction is:

$$\underbrace{\boldsymbol{2NaCO_2C_{17}H_{33}}}_{\textbf{Soap}} \boldsymbol{+ Cation^{2^+} \rightarrow} \underbrace{\boldsymbol{Cation^{2^+}(CO_2C_{17}H_{33})_2}}_{\textbf{Precipitate}} \boldsymbol{+ 2Na^+}$$

Lathering does not occur until all of the hardness ions are precipitated, at which point the water has been "softened" by the soap. The precipitate formed by hardness and soap adheres to surfaces of tubs, sinks, and dishwashers and may stain clothing, dishes, and other items. Residues of the hardness-soap precipitate may remain in the pores, so that skin may feel rough and uncomfortable. In recent years these problems have been largely alleviated by the development of soaps and detergents that do not react with hardness.

Boiler scale, the result of the carbonate hardness precipitate may cause considerable economic loss through fouling of water heaters and hot-water pipes. Changes in pH in the water distribution systems may also result in deposits of precipitates. Bicarbonates begin to convert to the less soluble carbonates at pH values above 9.0.

Magnesium hardness, particularly associated with the sulphate ion, has a laxative effect on persons unaccustomed to it. Magnesium concentrations of less than 50 mg/L are desirable in potable waters, although many public water supplies exceed this amount. Calcium hardness presents no public health problem. In fact, hard water is apparently beneficial to the human cardiovascular system.

Measurement

Hardness can be measured by using spectrophotometric techniques or chemical titration to determine the quantity of calcium and magnesium ions in a given sample. Hardness can be measured directly by titration with ethylenediamine tetraacetic acid (EDTA) using eriochrome black T (EBT) as an indicator. The EBT reacts with the divalent metallic cations, forming a complex that is red in colour. The EDTA replaces the EBT in the complex, and when the replacement is complete, the solution changes from red to blue. If 0.01 M EDTA is used, 1.0 mL of the titrant measures 1.0 mg of hardness as $CaCO_3$.

Use

Analysis for hardness is commonly made on natural waters and on waters intended for potable supplies and for certain industrial uses. Hardness may range from practically zero to several hundred, or even several thousand, parts per million. Although acceptability levels vary according to a consumer's acclimation to hardness, a generally accepted classification is as follows:

Soft	< 50 mg/L as $CaCO_3$
Moderately hard	50-150 mg/L as $CaCO_3$
Hard	150-300 mg/L as $CaCO_3$
Very hard	> 300 mg/L as $CaCO_3$

The Public Health Service standards recommend a maximum of 500 mg/L of hardness in drinking water. A maximum limit is not set by the EPA standards.

DISSOLVED OXYGEN

Dissolved oxygen (DO) is the amount of oxygen that is present in water. Water bodies receive oxygen from the atmosphere and from aquatic plants. Running water, such as that of a swift moving stream, dissolves more oxygen than the still water of a pond or lake. The dissolved oxygen (DO) levels in natural and waste waters depend on the physical, chemical, and biochemical activities in a waterbody. DO analysis is a key test in water pollution and waste treatment process control.

There are three methods for DO analysis: the iodometric (Winkler) method and its modifications, the membrane-electrode method, and the optical-probe method. The iodometric method is a titrimetric procedure based on DO's oxidizing property. The membrane-electrode method is based on molecular oxygen's diffusion rate across a membrane. The optical-probe method uses luminescence-based oxygen sensors to measure light emissions that correlate to the DO concentration. The choice of procedure depends on the interferences present, the accuracy desired, and, in some cases, convenience or expedience.

METALS

All metals are soluble to some extent in water. While excessive amounts of any metal may present health hazards, only those metals that are harmful in relatively small amounts are commonly labelled as toxic; other metals fall into the nontoxic group. Sources of metals in natural waters include dissolution from natural deposits and discharges of domestic, industrial, or agricultural wastewater. Measurement of metals in water is usually made by atomic absorption spectrophotometry.

Non-toxic Metals

In addition to the hardness ions, calcium and magnesium, other non-toxic metals commonly found in water include sodium, iron, manganese, aluminium, copper, and zinc. Sodium, by far the most common nontoxic metal found in natural waters, is abundant in the earth's crust and is highly reactive with other elements. The salts of sodium are very soluble in water. Excessive concentrations cause a bitter taste in water and cause health hazard to cardiac and kidney patients. Sodium is also corrosive to metal surfaces and, in large concentrations, is toxic to plants.

Iron and manganese quite frequently occur together and present no health hazards at concentrations normally found in natural waters. Iron and manganese in very small quantities may cause colour problems. Iron concentrations of 0.3 mg/L and manganese concentrations as low as 0.05 mg/L can cause colour problems. Additionally, some bacteria use iron and manganese compounds for an energy source, and the resulting slime growth may produce taste and odour problems.

When significant quantities of iron are encountered in natural water systems, it is usually associated with chloride ($FeCl_2$), bicarbonate [$Fe(HCO_3)_2$], or sulfate [$Fe(SO_4)$] anions and exist in a reduced state. In the presence of oxygen, the ferrous (Fe^{2+}) ion is oxidized to the ferric (Fe^{3+}) ion and forms an insoluble compound with hydroxide [$Fe(OH)_3$]. Thus, significant quantities of iron will usually be found only in systems devoid of oxygen such as groundwaters or perhaps the bottom layers of stratified lakes. Similarly, manganese ions (Mn^{2+} and Mn^{4+}) associated with chloride, nitrates, and sulphates are soluble, while oxidized compounds (Mn^{3+} and Mn^{5+}) are virtually insoluble. It is possible, however, for organic acids derived from decomposing vegetation to chelate iron and manganese and prevent their oxidation and subsequent precipitation in natural waters.

The other nontoxic metals are generally found in very small quantities in natural water systems, and most would cause taste problems long before toxic levels were reached. However, copper and zinc are synergetic and when both are present, even in small quantities, may be toxic to many biological species.

Toxic Metals

As noted earlier, toxic metals are harmful to humans and other organisms in small quantities. Toxic metals that may be dissolved in water include arsenic, barium, cadmium, chromium, lead, mercury, and silver. Cumulative toxins such as arsenic, cadmium, lead, and mercury are particularly hazardous. These metals are concentrated by the food chain, thereby posing the greatest danger to organisms near the top of the chain. Fortunately, toxic metals are present in only minute quantities in most natural water systems. Although natural sources of all the toxic metals exist, significant concentration in water can usually be traced to mining, industrial, or agricultural sources.

BIODEGRADABLE ORGANICS

Biodegradable material consists of organic that can be utilized for food by naturally occurring microorganisms within a reasonable length of time. In dissolved form, these materials usually consist of starches, fats, proteins, alcohols, acids, aldehydes, and esters. They may be the end product of the initial microbial decomposition of plant or animal tissue, or they may result from domestic or industrial wastewater discharges. Although some of these materials can cause

colour, taste, and odour problems, the principal problem associated with biodegradable organics is a secondary effect resulting from the action of microorganisms on these substances.

Microbial utilization of dissolved organic can be accompanied by oxidation (addition of oxygen to, or the deletion of hydrogen from, elements of the organic molecule) or by reduction (addition of hydrogen to, or deletion of oxygen from, elements of the organic molecule. Although it is possible for the two processes to occur simultaneously, the oxidation process is by far more efficient and is predominant when oxygen is available. In aerobic (oxygen-present) environments, the end products of microbial decomposition of organics are stable and acceptable compounds. Anaerobic (oxygen-absent) decomposition results in unstable and objectionable end products. Should oxygen later become available, anaerobic end products will be oxidized to aerobic end products.

The amount of oxygen consumed during microbial utilization of organics is called the biochemical oxygen demand (BOD). The BOD is measured by determining the oxygen consumed from a sample placed in an air-tight container and kept in a controlled environment for a preselected period of time. In the standard test, a 300 mL BOD bottle is used and the sample is incubated at 20°C for 5 days. Light must be excluded from the incubator to prevent algal growth that may produce oxygen in the bottle. Because the saturation concentration for oxygen in water at 20°C is approximately 9 mg/L, dilution of the sample with BOD-free, oxygen-saturated water is necessary to measure BOD values greater than just a few milligrams per litre.

The BOD of a diluted sample is calculated by

$$\boldsymbol{BOD_5 = \frac{(DO_i - DO_f)}{P}}$$

Where, DO_i and DO_f are the initial and final dissolved-oxygen concentrations (mg/L) and P is the dilution factor of the sample in the 300 mL bottle.

Example: A wastewater sample of 30 ml is diluted up to 300 ml with distilled water. The initial DO of the diluted sample is 7.2 mg/L and 1.5 mg/L is found after 5day incubation. Find the BOD after 5 days?

Solution: $D_0 = 7.2$ mg/l

$D_F = 1.5$ mg/L

$$P = \frac{\text{Vol.of undilute sample}}{\text{Vol.of dilute sample}} = \frac{30}{300} = 0.1$$

$$BOD_5 = \frac{(DO_i - DO_f)}{P}$$

$$BOD_5 = \frac{7.2-1.5}{0.1} = \mathbf{57\ mg/L}$$

Most natural water and municipal wastewaters will have a population of microorganisms that will consume the organics. In sterile waters, microorganisms must be added and the BOD of the material containing the organisms must be determined and subtracted from the total BOD of the mixture. The presence of toxic materials in the water will invalidate the BOD results.

The BODs only represent the oxygen consumed in 5 days. The total BOD, or BOD for any other time period, can be determined provided additional information is known or obtained.

The rate at which organics are utilized by microorganisms is assumed to be a first-order reaction; that is, the rate at which organics utilized is proportional to the amount available. Mathematically, this can be expressed as follows:

$$\frac{dL_t}{dt} = -kL_t \qquad \text{..... (1)}$$

Where, L_t is the oxygen equivalent of the organics at time t, and k is a reaction constant. The units of L_t are milligrams per liter, and the units of k are d^{-1}.

Equation (1) can be rearranged and integrated as follows:

$$\frac{dL_t}{L_t} = -k\,dt$$

$$\int_{L_0}^{Lt} \frac{dL_t}{L_t} = -k \int_0^t dt$$

$$ln\frac{L_t}{L_0} = -kt$$

$$L_t = L_0 e^{-kt} \qquad \text{..... (2)}$$

The term L_0 in this equation represents the total or ultimate biochemical oxygen demand at time 0, while L_t represents the amount remaining at time t, and decays exponentially with time, as shown in Fig. 3.

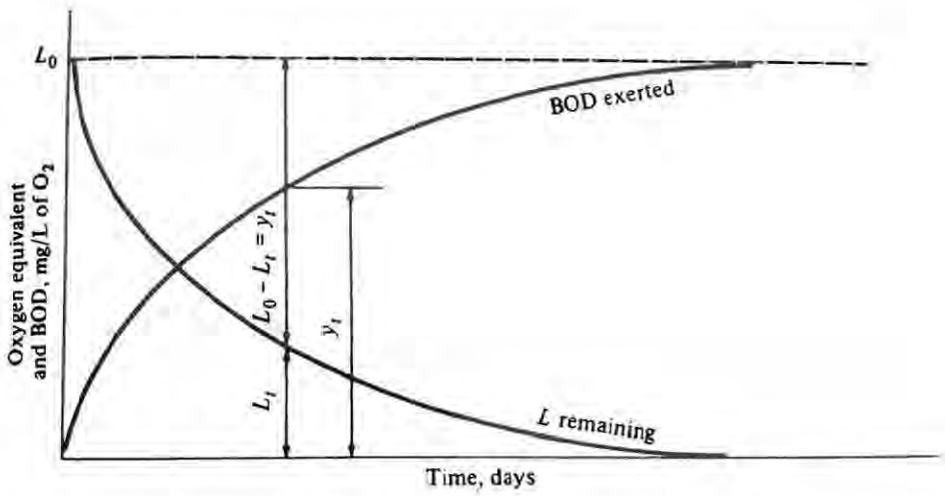


Fig. 3: BOD and oxygen-equivalent relationships

The oxygen equivalent remaining is not the parameter of primary importance. However, the amount of oxygen used in the consumption of the organics, the BOD_t can be found from the L_t

value. If L_0 is the oxygen equivalent of the total mass of organics, then the difference between the value L_0 and L_t is the oxygen equivalent consumed, or the BOD exerted. Mathematically

$$y_t = L_0 - L_t$$

$$y_t = L_0 - L_0 e^{-kt}$$

$$y_t = L_0(1 - e^{-kt}) \quad \text{.....} \quad (3)$$

Where, y_t represents the BOD_t exerted. L_0 indicating the total or ultimate BOD. These relationships are shown in Fig 3.

Equation (3) represents the BOD exerted by the carbon component of the organic compounds. Other components of organics, such as nitrogen and sulphur, may also be oxidized by microorganisms, resulting in an oxygen demand.

The value of k determines the speed of the BOD reaction without influencing the magnitude of the ultimate BOD. The value of k for any given organic compound is temperature-dependent. Because microorganisms are more active at higher temperatures, the value of k increases with increasing temperatures.

The change in k can be approximated by the van't Hoff-Arrhenius model:

$$k_T = k_{20}\theta^{T-20^\circ} \text{.....} \quad (4)$$

Where, K_T is rate constant at any temperature (d^{-1}).
K_{20} is rate constant at temperature 20°C (d^{-1}).
θ is temperature coefficient. A value of 1.047 for θ is often used.

Example: The BOD of a wastewater is determined to be 150 mg/L at 20°C. The k value is known to be 0.23 per day. What would the BOD_8 be if the test were run at 15°C?

Solution: Given, BOD_5 (y_t) = 150 mg/L, k =0.23 per day, T= 15°C, e = 2.718

1. Determine the ultimate BOD.

$$y_t = L_0(1 - e^{-kt})$$

$$L_0 = \frac{y_t}{1-e^{-kt}} = \frac{150}{1-e^{-0.23\ x\ 5}} = \mathbf{220\ mg/L}$$

2. The k value for 15°C.

$$k_T = k_{20}\theta^{T-20^\circ}$$

$K_{15} = 0.23\ (1.047^{15-20}) = \mathbf{0.18}$

3. Calculate BOD_8 (y_8)

$$y_8 = L_0(1 - e^{-kt}) = 220\ (1 - e^{-0.18 \times 8}) = \mathbf{168\ mg/L}$$

Downstream BOD:

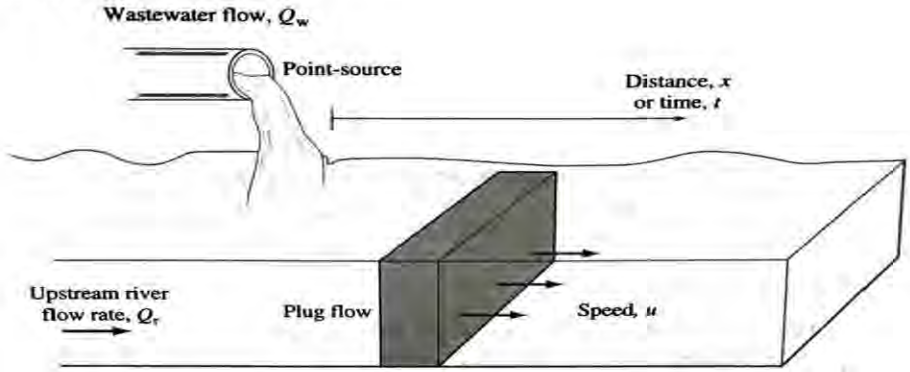


Fig. 4: The point-source, plug flow model for dissolved-oxygen calculations.

Where L_0 is the BOD of the mixture of stream water and wastewater at the point of discharge. Assuming complete and instantaneous mixing,

$$L_0 = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r}$$

Where
L_0 = Ultimate BOD of the mixture of stream water and wastewater (mg/L)
L_r = Ultimate BOD of the river just upstream of the point of discharge (mg/L.)
L_w = Ultimate BOD of the wastewater (mg/L.)
Q_r = Volumetric flow rate of the river just upstream of the discharge point (m^3/s)
Q_w = Volumetric flow rate of wastewater (m^3/s)

EXAMPLE: A wastewater treatment plant serving a city of 200,000 discharges 1.10 m^3/s of treated effluent having an ultimate BOD of 50.0 mg/L into a stream that has a flow of 8.70 m^3/s and a BOD of its own equal to 6.0 mg/L. Assuming complete and instantaneous mixing, estimate the ultimate BOD of the river just downstream from the outfall.

Solution: The BOD of the mixture of effluent and stream water:
L_0 = (1.10 m^3/s x 50.0 mg/L + 8.70 m^3/s x 6.0 mg/L) / (1.10 + 8.70) m^3/s
= 10.9 mg/L.

Table 3: Drinking Water Quality Standards as per BIS [IS: 10500, 2012, 1st amendment (2015)]

S. No.	Name of the Parameter	Acceptable Limit	Permissible Limit in the Absence of Alternate Source
Physical Parameters			
1.	Colour, Hazen units, *Max*	5	15
2.	Odour	Agreeable	Agreeable
3.	*p*H value	6.5-8.5	No relaxation
4.	Taste	Agreeable	Agreeable
5.	Turbidity, NTU, *Max*	1	5
6.	Total dissolved solids, mg/l,	500	2000
General Parameters Concerning Substances Undesirable in Excessive Amounts			
7.	Aluminium (as Al), mg/l, *Max*	0.03	0.2

8.	Ammonia (as total ammonia-N), mg/l *Max*	0.5	No relaxation
9.	Anionic detergents (as MBAS= Methylene Blue Active Substances Assay) mg/l *Max*	0.2	1.0
10.	Barium (as Ba), mg/l, *Max*	0.7	No relaxation
11.	Boron (as B), mg/l, *Max*	0.5	1.0
12.	Calcium (as Ca), mg/l, *Max*	75	200
13.	Chloramines (as Cl_2), mg/l, *Max*	4.0	No relaxation
14.	Chloride (as Cl), mg/l, *Max*	250	1 000
15.	Copper (as Cu), mg/l, *Max*	0.05	1.5
16.	Fluoride (as F) mg/l, *Max*	1.0	1.5
17.	Free residual chlorine, mg/l, *Min*	0.2	1
18.	Iron (as Fe), mg/l, *Max*	1.0	No relaxation
19.	Magnesium (as Mg), mg/l, *Max*	30	100
20.	Manganese (as Mn), mg/l, *Max*	0.1	0.3
21.	Mineral oil, mg/l, *Max*	0.5	No relaxation
22.	Nitrate (as NO_3), mg/l, *Max*	45	No relaxation
23.	Phenolic compounds (as C_6H_5OH), mg/l, *Max*	0.001	0.002
24.	Selenium (as Se), mg/l, *Max*	0.01	No relaxation
25.	Silver (as Ag), mg/l, *Max*	0.1	No relaxation
26.	Sulphate (as SO_4) mg/l, *Max*	200	400
27.	Sulphide (as H_2S), mg/l, *Max*	0.05	No relaxation
28.	Total alkalinity as calcium carbonate, mg/l, *Max*	200	600
29.	Total hardness (as $CaCO_3$), mg/l, *Max*	200	600
30.	Zinc (as Zn), mg/l, *Max*	5	15
Parameters Concerning Toxic Substances			
31.	Cadmium (as Cd), mg/l, *Max*	0.003	No relaxation
32.	Cyanide (as CN), mg/l, *Max*	0.05	No relaxation
33.	Lead (as Pb), mg/l, *Max*	0.01	No relaxation
34.	Mercury (as Hg), mg/l, *Max*	0.001	No relaxation
35.	Molybdenum (as Mo), mg/l, *Max*	0.07	No relaxation
36.	Nickel (as Ni), mg/l, *Max*	0.02	No relaxation
37.	Pesticides, µg/l		
	(a) Alachlor	20	No relaxation
	(b) Atrazine	2	No relaxation
	(c) Aldrin/ Dieldrin	0.03	No relaxation
	(d) Alpha HCH	0.01	No relaxation
	(e) Beta HCH	0.04	No relaxation
	(f) Butachlor	125	No relaxation
	(g) Chlorpyriphos	30	No relaxation
	(h) Delta HCH	0.04	No relaxation
	(i) 2,4- Dichlorophenoxyacetic acid	30	No relaxation
	(j) DDT (*o, p* and *p, p* – Isomers of DDT) (Dichlorodiphenyltrichloroethane)	1	No relaxation
	(k) Endosulfan (alpha, beta, and sulphate)	0.4	No relaxation
	(l) Ethion	3	No relaxation
	(m) Gamma — HCH (Lindane)	2	No relaxation
	(n) Isoproturon	9	No relaxation
	(o) Malathion	190	No relaxation
	(p) Methyl parathion	0.3	No relaxation
	(q) Monocrotophos	1	No relaxation
	(r) Phorate	2	No relaxation
38.	Polychlorinated biphenyls, mg/l, *Max*	0.0005	No relaxation
39.	Polynuclear aromatic hydrocarbons (as PAH), mg/l, *Max*	0.0001	No relaxation
40.	Total arsenic (as As), mg/l, *Max*	0.01	No relaxation

41.	Total chromium (as Cr), mg/l, *Max*	0.05	No relaxation
42.	Trihalomethanes:		
	(a) Bromoform, mg/l, *Max*	0.1	No relaxation
	(b) Dibromochloromethane, mg/l, *Max*	0.1	No relaxation
	(c) Bromodichloromethane, mg/l, *Max*	0.06	No relaxation
	(d) Chloroform, mg/l, *Max*	0.2	No relaxation
Parameters Concerning Radioactive Substances			
43.	Radioactive materials:		
	(a) Alpha emitters Bq/l, *Max* (One becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second)	0.1	No relaxation
	(b) Beta emitters Bq/l, *Max*	1.0	No relaxation
Bacteriological Quality			
44.	(i) All water intended for drinking:		
	(a) *E. coli* or thermotolerant coliform bacteria	Shall not be detectable in any 100 ml sample.	
ii)	Treated water entering the distribution system:		
	(a) *E. coli* or thermotolerant coliform bacteria	Shall not be detectable in any 100 ml sample	
	(b) Total coliform bacteria	Shall not be detectable in any 100 ml sample	

WATER PURIFICATION PROCESS IN NATURAL SURFACE STREAMS:

The self-purification mechanisms of natural water systems include physical, chemical, and biological processes. The speed and completeness with which these processes occur depend on many variables that are system-specific. Hydraulic characteristics such as volume, rate, and turbulence of flow, physical characteristics of bottom and bank material, variations in sunlight and temperature, as well as the chemical nature of the natural water, are all system variables that have an influence on the natural purification processes. In natural waters, these system variables are set by nature and can seldom be altered.

Physical Processes

The major physical processes involved in the self-purification of watercourses are dilution, sedimentation and resuspension, filtration, and gas transfer. These processes are not only important in and of themselves, but are also of significance in their relation to certain chemical and biochemical self-purification processes.

i. Dilution

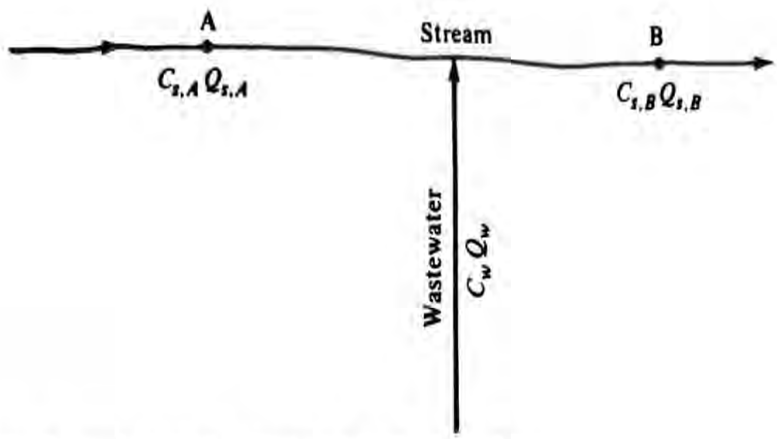
Dilution is a powerful adjunct to self-cleaning mechanisms of surface waters; its success depends upon discharging relatively small quantities of waste into large bodies of water. Growth in population and industrial activity, with attendant increases in water demand and wastewater quantities, precludes the use of many streams for the dilution of raw or poorly treated wastewater.

The dilution capacity of a stream can be calculated using the principles of mass balance. If the volumetric flow rate and the concentration of a given material are known in both the stream and waste discharge, the concentration after mixing can be calculated as follows.

$$C_s Q_s + C_w Q_w = Q_m C_m$$

Where, C represents the concentration (mass/volume) of the selected material, Q is the volumetric flow rate (volume/time), and the subscripts s, w, and m designate stream, waste, and mixture conditions.

Example: A treated wastewater enters a stream as shown in the accompanying figure. The concentration of sodium in the stream at point A is 10 mg/L, and the flow rate is 20 m^3/s. The concentration of sodium in the waste stream is 250 mg/L, and the flow rate is 1.5 m^3/s. Determine the concentration of sodium at point B assuming that complete mixing has occurred.



Solution: Mass balance between points A and B

Mass in = Mass out

$C_{S,B} Q_{S,B} = C_{S,A} Q_{S,A} + C_W Q_W$

Since $Q_{S,B}$ is the sum of the other two flows

$C_{S,B} = (C_{S,A} Q_{S,A} + C_W Q_W) / (Q_{S,A} + Q_W)$

$= (10 \times 20 + 250 \times 1.5) / (20 + 1.5)$

$=$ **26.7 mg/L**

ii. Sedimentation and Resuspension

Settling or sedimentation, is nature's method of removing suspended particles from a watercourse, and most large solids will settle down readily in quiescent water. Particles in the colloidal size range can stay in suspension for long periods of time, though eventually, most of these will also settle out. This natural sedimentation process is not without its drawbacks. Anaerobic conditions are likely to develop in sediment deposits, and any organics trapped in them will decompose, releasing soluble compounds into the stream above. Sediment deposits can also alter the streambed by filling up the pore space and creating unsuitable conditions for the reproduction of many aquatic organisms. The development of banks of silt and mud along the bottom of streams can alter its course or hamper navigation activities. Sediment accumulations reduce reservoir storage capacities and silt in harbours, and increase flooding.

Resuspension of solids is common in times of flooding or heavy runoff. In such cases, increased turbulence may resuspend solids formerly deposited along normally quiescent areas of a stream and carry them for considerable distances downstream. Eventually they will again settle down, but not before their presence has increased the turbidity of the waters into which they have been introduced.

iii. Filtration

As large bits of debris wash along a streambed, they often lodge on reeds or stones where they remain caught until high waters wash them into the mainstream again. Small bits of organic matter or inorganic clays and other sediments may be filtered out by pebbles or rocks along the

streambed. As water percolates from the surface downward into groundwater aquifers, filtration of a much more sophisticated type occurs, and, if the soil layers are deep enough and fine enough, removal of suspended material is essentially complete by the time water enters the aquifer. Many streams interchange freely with the alluvial aquifers underneath them, so the filtered water may renter the stream at some point downstream.

iv. Gas transfer

The transfer of gases into and out of water is an important part of the natural purification process. The replenishment of oxygen lost to bacterial degradation or organic waste is accomplished by the transfer of oxygen from the air into the water. Conversely, gases evolved in the water by chemical and biological processes may be transferred from the water to the atmosphere. A knowledge of the principles of gas transfer is essential to understanding these natural processes.

Zones of Self-purification process of polluted river or stream:

A polluted stream undergoing self-purification can be divided into four zones, i.e., zones of degradation, zone of active decomposition, zone of recovery, and zone of clean water. These zones are discussed below. The physical, chemical, and biological indices and characteristics of each zone are shown in fig. 5.

(i) **Zone of degradation**: This zone is found for a certain length just below the point where sewage is discharged into the river-stream. This zone is characterised by water becoming dark and turbid with formation of sludge deposits at the bottom. D.O. is reduced to about 40% of the saturation value. There is an increase in carbon dioxide content; reoxygenation (i.e., re-aeration) occurs but is slower than de-oxygenation. These conditions are unfavourable to the development of algae, but fish life may be present feeding on fresh organic matter. Moreover, certain typical bottom worms such as Limondrilus and Tubifex appear with sewage fungi, such as sphaerotilusnatans.

(ii) **Zone of active decomposition:** This zone is marked by heavy pollution. It is characterised by water becoming greyish and darker than in the previous zone. D.O. concentration falls down to zero, and anaerobic conditions may set in with the evolution of gases like methane, carbon dioxide, hydrogen sulphide, etc., bubbling to the surface, with masses of sludge forming an ugly scum layer at the surface. As the organic decomposition slackens due to stabilisation of organic matter, the re-aeration sets in and D.O. again rises to the original level (i.e., about 40%). In this zone, bacteria flora will flourish. At the upper end, anaerobic bacteria will replace aerobic bacteria, while at its lower end, the position will be reversed. Protozoa and fungi will first disappear and then reappear. Fish life will be absent. Algae and Tubifex will also mostly be absent. Maggots and Psychoda (sewage fly) larvae will, however, be present in all but the most septic sewage.

(iii) **Zone of recovery:** In this zone, the river or stream tries to recover from its degraded condition to its former appearance. The water becomes clearer, and so the algae reappear while fungi decrease. B.O.D. falls down and D.O. content rises above 40% of the saturation value. Protozoa, Rotifers, Crustaceans and large plants like Sponges, Bryozons, etc. also reappear. Bottom organisms will include: Tubifex, Mussels, Snails, etc. The organic material will be mineralised to form nitrates, sulphates, phosphates, carbonates, etc.

(iv) **Zone of cleaner water:** In this zone, the river attains its original conditions with D.O. rising up to the saturation value. Water becomes attractive in appearance, and Game fish (which requires

at least 4 to 5 mg/l of D.O.) and usual aquatic life prevails. Some pathogenic organisms may still, however, survive and remain present, which confirms the fact that "when once a river water has been polluted, it will not be safe to drink it, unless it is properly treated."

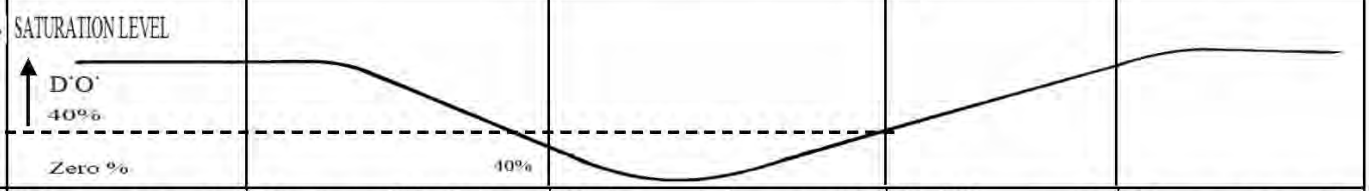
	Zones of Self-purification				
	Clear water	**Zone of Degradation**	**Zone of Active Decomposition**	**Zone of Recovery**	**Zone of Clearer Water**
Dissolved oxygen sag curve					
Physical indices	Clear water; No bottom sludge; No colour	Floating solids; Bottom sludge present, Colour getting turbid.	Darker and greyish colour; Evolution of gases like CH_4, CO_2, H_2S etc.; Lot of sludge coming to the surface forming an ugly scum layer at top.	Turbid with bottom sludge.	Clear water with no bottom sludge.
Fish presence	Ordinary fish like game, pan, food & forage, etc. present.	Tolerant fishes like carp, buffalo, gary, etc. present.	No fish present	Tolerant fish like carb buffalo, etc. are present.	Ordinary fish like game, pan, food, and forage, etc. present.
Bottom animals					
Algae & Protozoa etc. called Plankton					

Fig. 5: The physical, chemical, and biological indices and characteristics of each zone after waste discharge into the clean stream.

WATER TREATMENT PROCESS:

Surface waters often contain a wider variety of contaminants than ground water and treatment processes may be more complex. Most surface waters contain turbidity in excess of drinking-water standards. Although fast-moving streams may carry larger material in suspension, most of the solids will be colloidal in size and will require chemical coagulation for removal. Depending on the geology of the watershed, hardness may or may not be a problem in surface waters. If low levels of colour and other organic material are present, adsorption onto surface-active material, a process not significant in natural water systems, may be necessary. Treatment systems commonly used in treating surface waters are shown in Fig. 6.

The processes selected for the treatment of potable water depend on the quality of the raw water supply. Most groundwaters are clear and pathogen-free and do not contain significant amounts of organic materials. Such waters may often be used in potable systems with a minimal dose of chlorine to prevent contamination in the distribution system. Other groundwaters may contain large quantities of dissolved solids or gases. When these include excessive amounts of iron,

manganese, or hardness, chemical and physical treatment processes may be required. Treatment systems commonly used to prepare potable water from groundwater are shown in Fig. 7.

Process	Chemicals added	Waste streams
Presidimentation: May be necessary if water comes from fast-flowing streams. Removes larger suspended solids. Chemicals may be added to oxidize organics or to arrest their biological oxidation.	Chlorine, Ammonia	Sludge removed periodically and disposed of by spreading on land.
Mixing, flocculation, settling: Removes turbidity by coagulating colloids and settling them out; may also remove colour caused by large organic molecules.	Alum, Polymers	Sludge removed continuously; disposal by landfilling or other suitable means after dewatering.
Filtration: Polishes to remove remaining turbidity; disinfectant may be added to prevent biological growth on filter medium.	Chlorine	Backwash water decanted, and dewatered sludge disposed of with that from 2 above.
Adsorption: May be necessary if water contains dissolved organics; may consist of activated carbon columns or activated carbon may be added in powdered form in operation similar to 2 above.		Steam from cleaning cycle condensed and disposed of.
Disinfection: Destroys pathogens; enough added to provide residual in the distribution system.	Chlorine	
Storage: Provides contact time for disinfection and stores water for peak demand.		

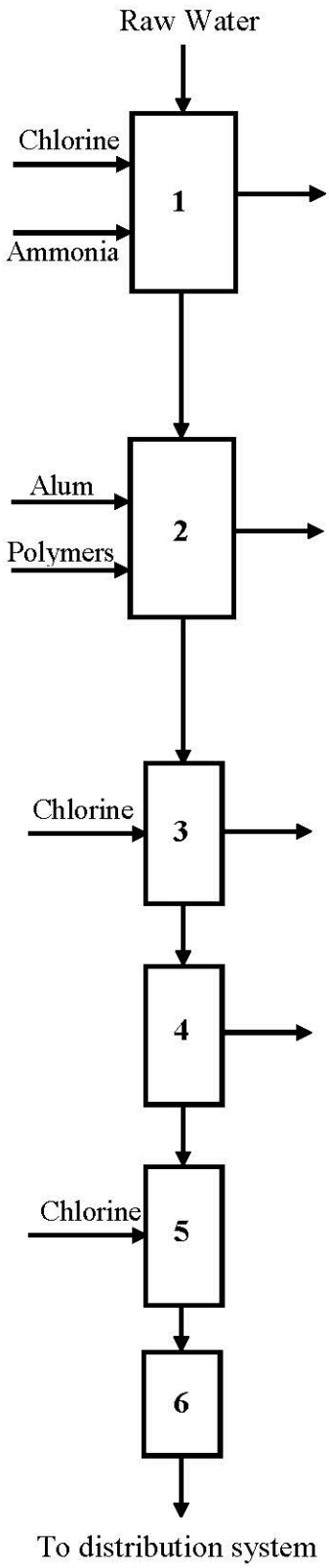


Fig. 6: Typical plant treating turbid surface water with organics.

Process	Chemicals added	Waste streams

Aeration: Removes undesirable gases and/or oxidation of iron and manganese.

Softening: Removes calcium and/or magnesium Soda hardness; may be done in one or two stages.

Filtration: Removes residual $CaCO_3$ crystals and $Mg(OH)_2$, floc left over from softening; disinfectant may be added to prevent biological growth on filter medium.

Disinfection: Destroys pathogens; enough added to provide residual in the distribution system.

Storage: Provides contact time for disinfection and stores water for peak demand.

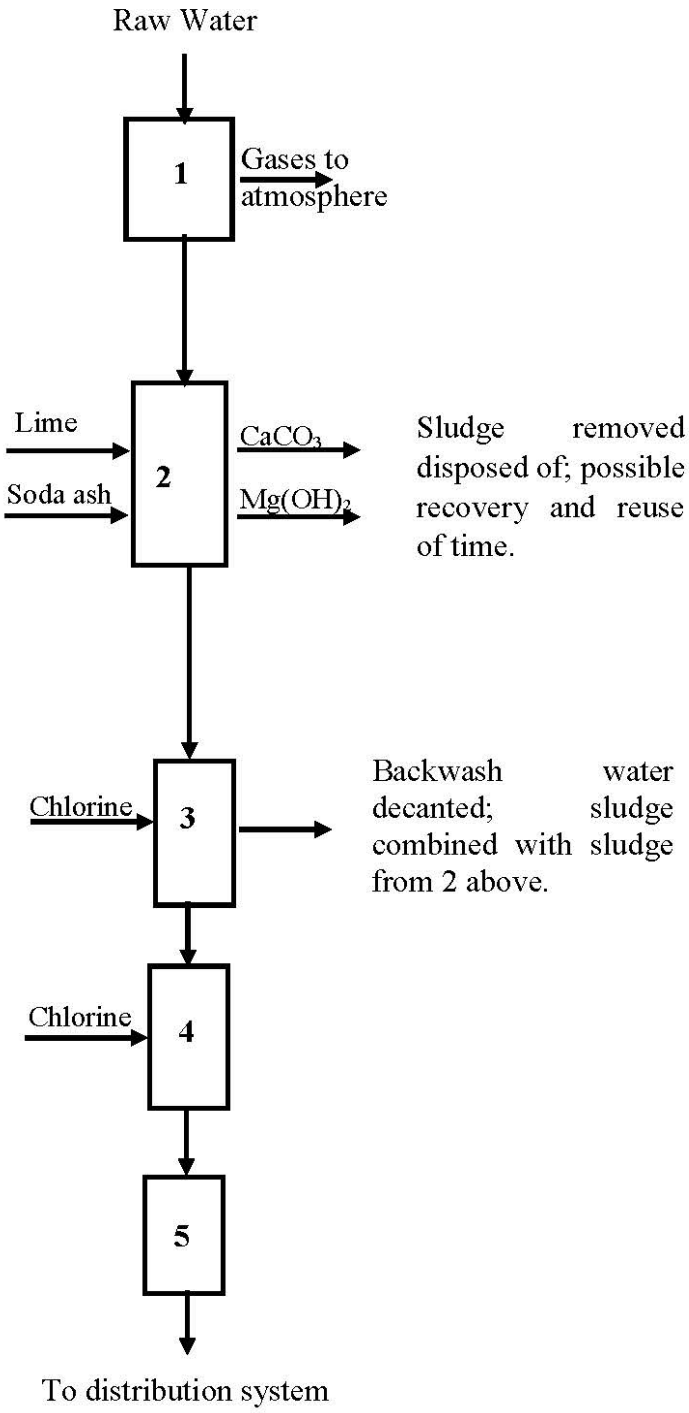


Fig. 7: Typical plant treating hard groundwater.