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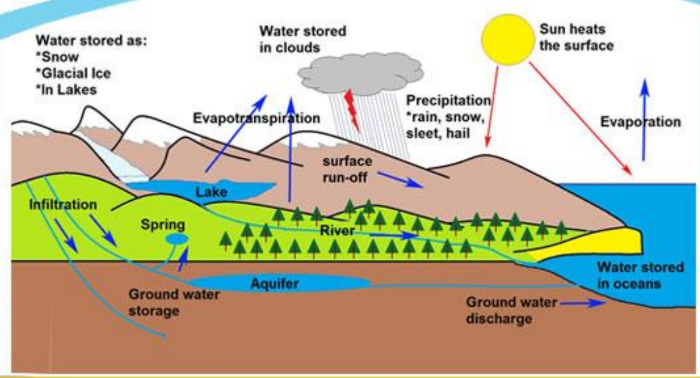

Production of Coursework

- Content for Post-Graduate Courses

Paper Name: 5 Water Resources and Management

Module: 26 Physical, Chemical and Biological Characteristics of Water

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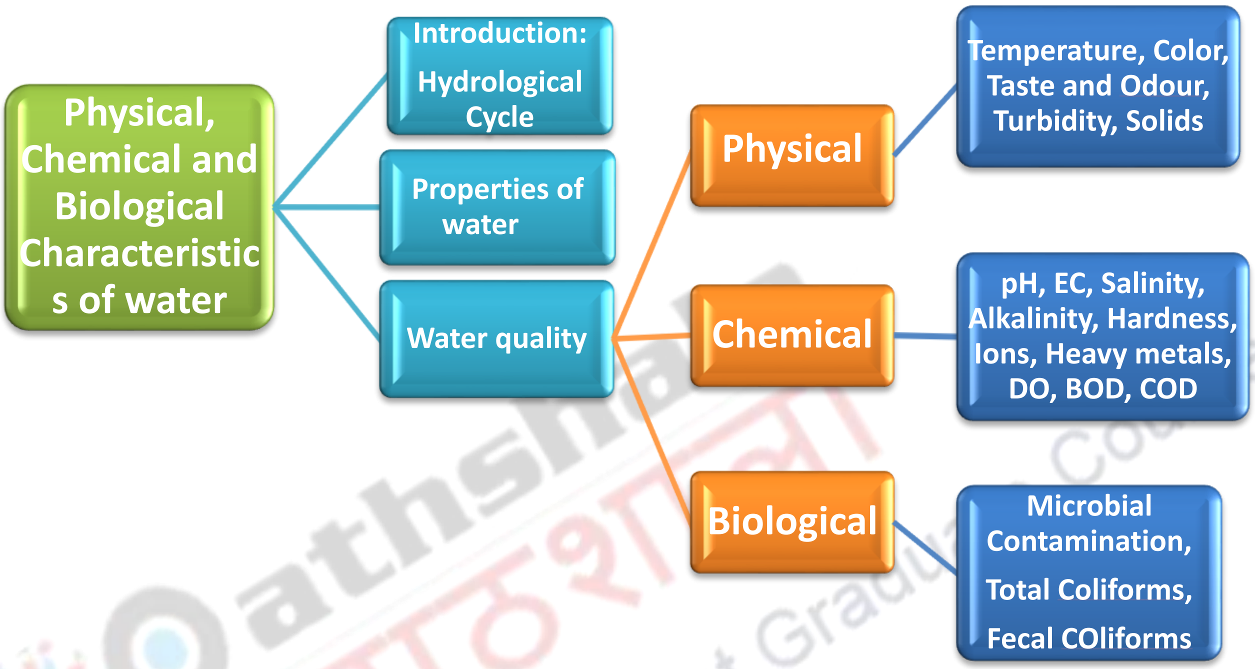
Description of Module	
Subject Name	**Environmental Sciences**
Paper Name	Water Resources and Management
Module Name/Title	Physical, Chemical and Biological Characteristics of Water
Module Id	EVS/WRM-V/26
Pre-requisites	
Objectives	The learner will be able to • Understand the essentiality and significance of water resources • Understand various unique properties of water molecule • .Differentiate between various physical, chemical and biological properties of water
Keywords	Water quality, Physical characteristics, chemical characteristics, biological characteristics, Permissible limit, Standards

Concept map


Physical, Chemical and Biological Characteristics of water
Introduction: Hydrological Cycle
Properties of water
Water quality
Physical
Chemical
Biological
Temperature, Color, Taste and Odour, Turbidity, Solids
pH, EC, Salinity, Alkalinity, Hardness, Ions, Heavy metals, DO, BOD, COD
Microbial Contamination, Total Coliforms, Fecal COliforms

PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF WATER

1. Introduction

Water is essential to life. Without it, the biosphere that exists on the surface of the earth would not be possible. It is also the only known chemical compound that occurs in all the three physical states viz., solid (snow, hail, sleet and ice), liquid (rain, water droplets) and gas(water vapors)within the relatively small range of air temperatures and pressures found at the Earth's surface and it can change between these phases in a fairly short period of time. The gaseous state of water regulates the atmospheric moisture dynamics. On an average, a molecule of water vapour in the atmosphere will exist in its gaseous phase for only a few days before condensing to liquid droplets or ice crystals to form clouds or fog. Similarly, clouds and fog have limited lifespan and often evaporate away or precipitate much of their moisture within a few hours of their formation. Most of the earth’s water sources get their water supplies from this precipitation. Thus, there is a continuous interchange of moisture between the earth and atmosphere, constituting the hydrological cycle (Fig 1).

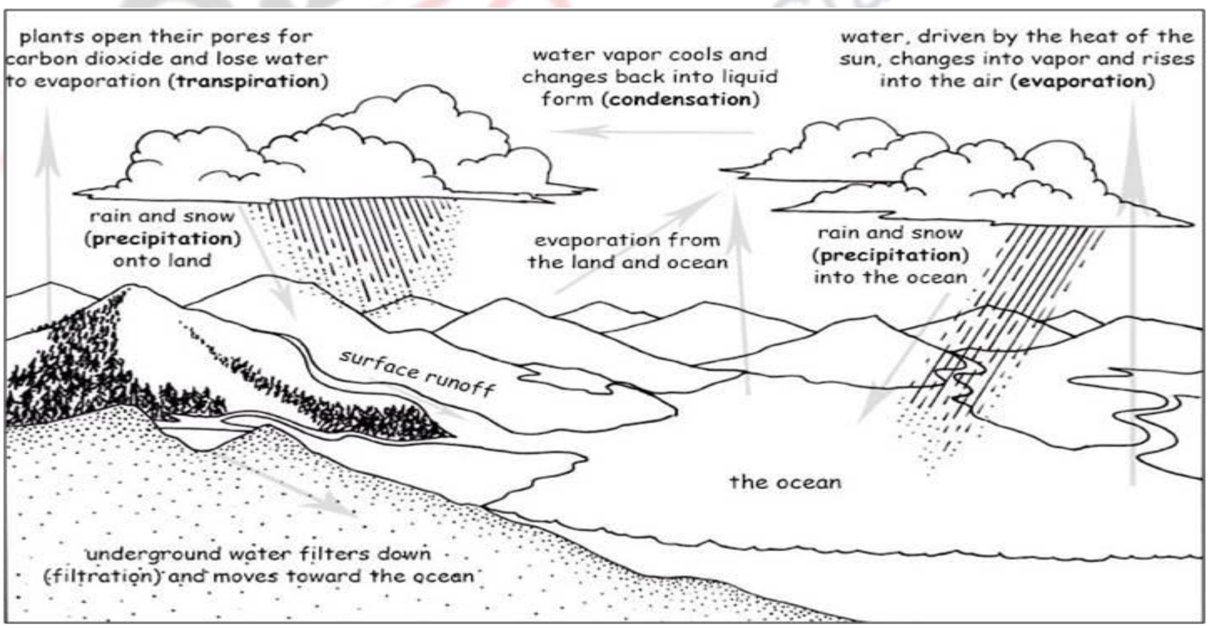


Fig 1: The Hydrological Cycle (www.exploringnature.org)

This cycle controls the temporal and spatial distribution of renewable fresh water in the form of evapotranspiration, precipitation and runoff. Climatic factors and changes in climate further complicate the predictability of this distribution. The total stock of ocean water and fresh water on this earth has been fairly constant throughout geological history but the ratio between ocean water and fresh water always changes according to climatic changes, mostly brought about by anthropogenic activities. Furthermore, the movement of water through hydrological cycle has a major influence on rainfall distribution and temperature modification. The cycle plays a vital role in creating habitable climate and moderating temperature.

Water covers more than 70 % of the earth's surface, of which 97% is in the ocean, which is unfit for human consumption and other uses because of its high salt content. Of the remaining three percent, 2% is locked in the polar ice caps and glaciers and only one percent is available as fresh water in rivers, lakes, streams, reservoirs, and ground water which is suitable for human consumption. A continuous and supply of clean water is essential for the survival and health of all living organisms.

The quality of water is of prime concern for mankind since it is directly linked with the human welfare. Water quality characteristics of aquatic environments arise from a multitude of physical, chemical and biological interactions. The water bodies such as rivers, lakes and estuaries are continuously in dynamic state of change with respect to their geological age and geochemical characteristics. This dynamic balance of the aquatic system is readily upset by human activities leading to pollution which is manifested dramatically as fish kill, offensive taste and odor. The physico-chemical characteristics of the water body have direct influence on the types and distribution of aquatic biota.

2. Properties of water

A water molecule (H_2O) is made up of three atoms, one oxygen and two hydrogen atoms. In each water molecule, the oxygen atom attracts more than its "fair share" of electrons. The oxygen end "acts" negative while the hydrogen end "acts" positive forming a single polar covalent bond which causes the water to be polar in nature (Fig 2a). However, water is neutral as it has equal number of electrons and protons giving it a Zero Net Charge.

The basic structure of a water molecule is well known with following dimensions:

O--H bond length = 95.7 picometers
H--O---H angle = 104.5°
O-H bond energy = 450 kJ/mol
Dipole moment = 1.83 debyes.

Water has a variety of unusual properties because of attractions between these polar molecules. The slightly negative regions of one molecule are attracted to the slightly positive regions of nearby molecules, forming a hydrogen bond. Each water molecule can form hydrogen bonds with up to four neighbors (Fig 2b). The key properties of water are dipole moment, dielectric constant, heat capacity, and its ability to both donate and accept protons. This imparts on water the ability to hydrogen bond with itself, to hydrogen bond with both proton donors and proton acceptors, to dissociate, to coordinate with ions and other dipoles, and to store and transport heat.

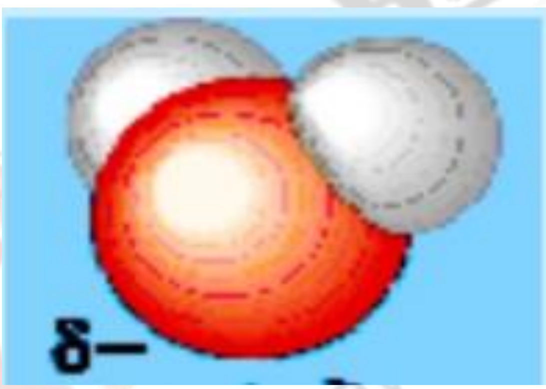


Fig 2a A single water molecule

Fig 2b. Hydrogen bonding in water molecules.

3. Water Quality

Clean, safe and sufficient freshwater is vital for the survival of all living organisms and smooth functioning of ecosystems, communities and economies. Water quality refers to the basic physical, chemical and biological characteristics of water that determine its suitability for life or for human uses. The acceptable quality of water varies with its intended use. The characteristics of water can be classified into three broad categories:

1. **Physical Characteristics**: temperature, color, odor, turbidity and solids

2. **Chemical Characteristics:** pH, conductivity, salinity, hardness, BOD,
3. **Biological Characteristics:** counts of specific organisms and groups of organisms

3.1 Physical Characteristics:

Physical characteristics of water (temperature, colour, taste, odour and etc.) are determined by senses of touch, sight, smell and taste. For example temperature by touch, colour, floating debris, turbidity and suspended solids by sight, and taste and odor by smell.

3.1.2 **Temperature**: Temperature is a measure of the average energy (kinetic) of water molecules. It is measured on a linear scale of degrees Celsius or degrees Fahrenheit. Temperature is a basic water quality variable. It determines the suitability of water for various forms of aquatic life. Depending on the geographic location the mean annual temperature varies in the range of 10 to 21^{o}C with an average of 16^{o}C. Temperature affects a number of water quality parameters such as dissolved oxygen which is a chemical characteristic. Oxygen solubility is less in warm water than cold water. Temperature also affects the aquatic life, for example, trout and salmon require cool temperature for survival and reproduction whereas bass and sunfish do better at warmer temperatures. Temperature in water bodies generally follows mean daily air temperature. It influences: amount of oxygen that can be dissolved in water, rate of photosynthesis by algae and other aquatic plants, metabolic rates of organisms, sensitivity of organisms to toxic wastes, parasites and diseases, and timing of reproduction, migration, and aestivation of aquatic organisms.

3.1.3 **Color:** Color in water is primarily a concern of water quality for aesthetic reason. Colored water give the appearance of being unfit to drink, even though the water may be perfectly safe for public use. Color of the water body can indicate the presence of organic substances, such as algae or humic compounds. In recent times, color has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water. Color is vital as most water users, be it domestic or industrial, usually prefer colorless water. Determination of color can help in estimating the costs related to discoloration of the water. Color is reduced or removed from water through the use of coagulation, settling and filtration techniques

3.1.4 **Taste and Odor:** Taste and odor are human perceptions of water quality. Human perception of taste includes sour (hydrochloric acid), salty (sodium chloride), sweet (sucrose) and bitter (caffeine). Relatively simple compounds produce sour and salty tastes. However, sweet and bitter tastes are produced by more complex organic compounds. Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater. Odor is measured by special instruments such as the Portable H_2S meter which is used for measuring the concentration of hydrogen sulfide. Some examples of odor producing substances are given in Table 1.

Table 1: Odor producing substances.

Compound	Chemical Formula	Odor Quality
Amines	CH_3NH_2, $(CH_3)_3H$	Fishy
Ammonia	NH_3	Ammoniacal
Diamines	$NH_2(CH_2)_4NH_2$, $(CH_2)_5NH_2H_{25}$	Rotten eggs
Mercaptans (E. g, methy1 and ethy1)	CH_3SH, $CH_3(CH_2)$ SH	Decayed cabbage
Organic sulfides		Rotten cabbage
Skatole		Fecal matter

3.1.5 **Turbidity:** Turbidity is a measure of the light-transmitting properties of water and is comprised of suspended and colloidal material. It is important for health and aesthetic reasons. Transparency of natural water bodies is affected by human activity, decaying plant matter, algal blooms, suspended sediments, and plant nutrients. Turbidity provides an inexpensive estimate of total suspende dsolids (TSS) concentration. It has little meaning except in relatively clear waters but is useful in defining drinking-water quality in water treatment.

3.1.6 **Solids:** Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions. The total solids content of water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103°C to 105°C.

Solids are classified as settle-able solids, suspended solids and filterable solids. Settle-able solids (silt and heavy organic solids) are the one that settle under the influence of gravity. Suspended solids and filterable solids are classified based on particle size and the retention of suspended solids on standard glass-fibre filters. The significance of suspended solids in water is great, on a number of grounds. The solids may in fact consist of algal growths leading to severe eutrophic conditions in any water body. They will reduce light penetration in surface waters and interfere with aquatic plant life. Deposition of these on the bed of rivers and lakes may give rise to septic and offensive conditions; and they may indicate the presence of unsatisfactory sewage effluent discharges.

3.2 Chemical Characteristics: The health concerns associated with chemical constituents of drinking-water arise mainly from the ability of chemical constituents to cause adverse health effects after extended exposure time. There are few chemical constituents of water that can lead to health problems resulting from even a single exposure. An appreciable number of serious health concerns may occur as a result of the chemical contamination of drinking-water. The major chemical properties of the water are discussed below:

3.2.1 pH: pH is a measure of how acidic or basic (alkaline) the water is. It is defined as the negative log of the hydrogen ion concentration. The pH scale is logarithmic and ranges from 0 (very acidic) to 14 (very alkaline). For each whole number increase (i.e. 1 to 2) the hydrogen ion concentration decreases tenfold and the water becomes less acidic. The range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae. However, the most frequently encountered range is 6.5-8.0. The range of pH apt for fisheries is considered to be 5.0-9.0, though 6.5-8.5 is preferable. At the extreme ends of the pH scale, (2 or 13) physical damage to gills, exoskeleton and fins occurs. Changes in pH may alter the concentrations of other substances in water to a more toxic form. Ammonia toxicity, chlorine disinfection efficiency, and metal solubility are all subjective to changes in pH value.

3.2.2 Electrical Conductivity: The conductivity of water is an expression of its ability to conduct an electric current as a result of breakdown of dissolved solids into positively and negatively charged ions. The major positively charged ions are sodium (Na^+), calcium (Ca^{+2}), potassium (K^+) and magnesium (Mg^{+2}). The major negatively charged ions in water include chloride (Cl^-), sulfate (SO_4^{-2}), carbonate (CO_3^{-2}), and bicarbonate (HCO_3^-). Nitrates (NO_3^{-2}) and phosphates (PO_4^{-3}) are minor contributors to conductivity, although they are very important biologically. Conductivity in itself is a property of little interest but it is an invaluable indicator of the range of hardness, alkalinity and the dissolved solids content of the water. Conductivity will vary with water source: ground water, water drained from agricultural fields, municipal waste water, rainfall. Therefore, conductivity can indicate groundwater seepage or a sewage leak.

3.2.3 Salinity: Salinity is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two measures are related. The salts in sea water are primarily sodium chloride (NaCl). However, other saline waters owe their high salinity to a combination of dissolved ions including sodium, chloride, carbonate and sulfate.

Salts and other substances affect the quality of water used for irrigation or drinking. They also have a critical influence on aquatic biota, and every kind of organism has a typical salinity range that it can tolerate. The presence of a high salt content may make water unsuitable for domestic, agricultural or industrial use. Moreover, the ionic composition of the water can be critical. For example, Cladocerans (water fleas) are far more sensitive to potassium chloride than sodium chloride at the same concentration.

3.2.4 Alkalinity: The alkalinity of natural water is generally due to the presence of bicarbonates formed in reactions in the soils through which the water percolates. It is a measure of the capacity of the water to neutralize acids and it reflects its *buffer capacity*. It may also be attributed to the presence of carbonates and hydroxides. Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes. Living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0. Higher alkalinity levels in surface waters can buffer the acid rain and other acid wastes. This inhibits harmful pH changes for the protection of aquatic life. Alkalinity in streams is influenced by rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges. Low nutrient (oligotrophic) lakes tend to have lower alkalinity while high nutrient (eutrophic) lakes have a tendency of higher alkalinity.

3.2.5 Hardness: Hardness is a natural characteristic of water which can enhance its palatability and consumer acceptability for drinking purposes. The hardness of water is due to the presence of calcium and magnesium minerals that are naturally present in the water. The common signs of a hard water supply are poor lathering of soaps and scum. The hardness is made up of two parts: temporary (carbonate) and permanent (non carbonate) hardness. The temporary hardness of water can easily be removed by boiling the water.

The following is a measure of hardness (expressed in mg/l as $CaCO_3$):

Soft: 0 - 100 mg/l as $CaCO_3$
Moderate: 100 - 200 mg/l as $CaCO_3$
Hard: 200 - 300 mg/l as $CaCO_3$
Very hard: 300 - 500 mg/l as $CaCO_3$
Extremely hard: 500 - 1,000 mg/l as $CaCO_3$

3.2.6 Major ions in Water: There are various kinds of trace ions in water supply that influence chemical nature and account for the bulk of natural water mineral content. Most of the dissolved, inorganic chemicals in freshwater occur as ions. The main ionic species of natural water are given in Table 2. These ions come in water body from atmospheric deposition, rock weathering, runoff etc.

Major Cations	Major Anions
Sodium (Na^{+})	Chloride (Cl^{-})
Potassium (K^{+})	Sulphate (SO_4^{2-})
Calcium (Ca^{2+})	Carbonates/Bicrabonates (CO_3^{2-}/HCO_3^{-})
Magnesium (Mg^{2+})	Nitrates (NO_3^{-})

Cations:

Sodium may be of health significance to individuals. Sodium salts are generally highly soluble in water and are leached from the terrestrial environment to groundwater and surface water

Potassium is an essential nutritional element in drinking water supplies but in its excessive quantities, it acts as a laxative.

Calcium is essential to human nutrition and a key element in the formation of teeth and bones. It is also known as limestone and is a cause of water hardness.

Magnesium is one of the most common elements in the earth's crust. Sulfates of magnesium at very high concentrations may have a laxative effect on some people. It also give an unpleasant taste at high concentration

Anions:

Chloride in drinking water is generally not harmful to human health except when present in high concentrations. The high concentration may be injurious to heart and kidney patients. The restriction on chloride concentrations in potable water are determined by taste requirements.

Water with objectionable Sulfate content may have a bitter taste. It also contributes to odor problems.

Excessive bicarbonate adds to the salinity and total solid content of water while Carbonate content of water can also be considered as the temporary water hardness as it can easily be removed by boiling.

Nitrates: Nitrates even at low concentrations can cause health problem to infants of six months of age or less and pregnant women by affecting the oxygen carrying capacity of the blood.

3.2.7 Heavy Metals: Heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentration. The some major examples of heavy metals are mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), copper (Cu), cobalt (Co) and lead (Pb) etc. These are the natural components of geological environment. They enter the human body via food, drinking water and air to small extent. Some heavy metals (e.g. copper, selenium, zinc) are necessary to keep up the metabolism of the human body as trace elements. However, they can be poisonous at higher concentrations leading to various serious diseases.

3.2.8 Dissolved Oxygen: Dissolved oxygen is the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. It gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. The oxygen in dissolved form is needed by most aquatic organisms to survive and grow. Organisms such as trout and stoneflies require high amount of DO while some others like catfish, worms and dragonflies can survive in somewhat lower amount. The absence of enough amount of oxygen in water can lead to death of adults and juveniles, reduction in growth, failure of eggs/larvae to survive, change of species present in a given water body. The hypoxic condition in water body (DO< 3mg/L) causes reduced cell functioning and disrupts circulatory fluid balance in aquatic system, eventually leading to death.

3.2.9 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand the amount of dissolved oxygen required by aerobic biological organisms to degrade the organic material present in a water body at certain temperature over a specific time period. It widely used as an indication of the organic quality of water and thus representing the pollution load. It is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days (BOD_5) of incubation at 20°C. When organic matter decomposes, microorganisms (such as bacteria and fungi) feed upon this decaying material and eventually the matter becomes oxidized. The harder the microorganisms work, the more oxygen will be used up giving a high measure of BOD, leaving less oxygen for other life in the water.

3.2.10 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) determines the quantity of oxygen required to oxidize the organic matter present in water body under specific conditions of oxidizing agent, temperature and time. COD is an important water quality parameter as it provides an index to assess the effect discharged wastewater will have on the receiving environment. Higher COD levels represent the presence of greater amount of oxidizable organic material in the sample, the degradation of which will again lead to hypoxic conditions in the water body. The ratio of BOD to COD indicates the percent of organic material in water that can be degraded by natural microorganism in the environment.

3.2 Biological Characteristics

3.3.1 Microbial Contamination: Microbial contamination is one of the major concerns of water quality. Many types of microorganisms are naturally present in the water such as

•Protozoans -Amoeba, cryptosporidium, giardia,

•Bacteria – Salmonella, typhus, cholera, shigella,

•Viruses –Polio, hepatitis A, meningitis, encephalitis,…

•Helminths –Guinea worm, hookworm, roundworm,…

3.3.2 Feacal Matter

Total Coliform and Feacal Coliform

Total coliform bacteria, fecal coliform bacteria, and E. coli are all considered indicators of water contaminated with fecal matter. Contaminated water may contain other pathogens (micro-organisms that cause illness) that are more difficult to test for. Therefore these indicator bacteria are useful in giving us a measure of contamination levels.

E. coli is a bacterial species found in the fecal matter of warm blooded animals (humans, other mammals, and birds). Total coliform bacteria are an entire group of bacterial species that are generally similar to and include the species *E. coli*. There are certain forms of coliform bacteria that do not live in fecal matter but instead live in soils. Fecal coliform bacteria are coliform bacteria that do live in fecal matter, including, but not limited to, the species *E. coli*. Most of the fecal coliform cells found in fecal matter are *E. coli*. Untreated sewage, poorly maintained septic systems, un-scooped pet waste, and farm animals with access to water bodies can cause high levels of fecal coliform bacteria to appear in and make the water unhealthy.

Box-1

The availability, quality and management of fresh water resources is one of the most concerning environmental challenges of national importance in India. To overcome these challenges, Central Pollution Control Board of Govt of India is playing a pivotal role. CPCB has established a network of 2500 monitoring locations on aquatic resources (covering 445 Rivers, 154 Lakes, 12 Tanks, 78 Ponds, 41Creeks/Seawater, 25 Canals, 45 Drains, 10 Water Treatment Plant (Raw Water) and 807 Wells) across the country under Global Environmental Monitoring System (GEMS) in 29 states and 6 Union Territories all over the country (CPCB, 2013). Water quality of these rivers in terms of pH, Conductivity, DO, BOD, Feacal Coliforms and Total Coliforms is analysed since 1977-78. The various reports published by CPCB indicated that BOD and Coliforms continue to be the major water quality issues. The Board has identified 302 polluted river stretches on 275 rivers in 27 states and 2 UTs on the basis of BOD level and has prioritized them (CPCB, 2015). Out of these 302 polluted stretches, 34 were in Priority Class-I (BOD> 30mg/l), 17 in Priority Class-II (BOD between 20 & 30mg/l), 36 in Priority Class-III (BOD between 10 & 20mg/l), 57 in Priority Class-IV (BOD between 6 & 10mg/l) and 158 in Priority Class-V (BOD between 3 & 6mg/l). The maximum number of polluted river stretches were observed in state of Maharashtra (49). The only river Yamuna flowing in Delhi is under Priority Class-I. So a large number of water bodies were identified as polluted stretches for which immediate and appropriate measures are required to restore their water quality. In present scenario, the already formulated policies and programmes on water quality management such as Ganga Action Plan and other National River Action Plans are based on this concept.

Keeping in mind all the characteristics of natural waters, the basic strategies that can be applied to combat the problem of water quality are prevention of pollution; treatment of polluted water, safe use of water and restoration and protection of aquatic as well as terrestrial ecosystems. The achievements can further form the basis of policy solutions for improving water quality.

4. Summary

Natural water is never completely pure. Most of the earth's water sources get their water supllies through precipitation. During precipitation water passes over (runoff) and through the ground (infiltration), acquiring a wide variety of dissolved or suspended impurities that intensely alters its usefulness. Water is an essential ingredient of animal and plant life crediting to its unique physical, chemical and biological properties. These characteristics also have a direct influence on the types and distribution of aquatic biota. All the standards for prescribed discharge of wastes into the water body are designed on the basis of water quality characteristics. Also, the improvement of water quality and formation of policy measures revolves around these characteristics.

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