Chapter 6

Environmental Chemistry II: Water

Time Allocation

Teaching periods = 10
Assessment period = 02
Weightage = 10%

MAJOR CONCEPTS:

6.1 Water
6.2 Soft and Hard Water
6.3 Water Pollutants
6.4 Water Borne Diseases

STUDENTS LEARNING OUT COMES (SLO'S)

- Describe the occurrence of water and its importance in the environment including Industry. (Analyzing)
- Review our dependence on water and the importance of maintaining its quality. (Analyzing)
- Describe the composition and properties of water. (Understanding)
- Differentiate among soft, temporary and permanent hard water (Analyzing)
- Describe methods for eliminating temporary and permanent hardness of water. (Applying)
- Identify water pollutants. (Analyzing)
- Describe the industrial wastes and household wastes as water pollutants. (Understanding)
- Describe the effects of water pollutants on life. (Understanding)
- Describe the various types of water borne diseases (Understanding)

Introduction:

Water is the most abundant compound on earth. It doesn't have odor, color and smell. the chemical formula of water is H_2O. A person can live no more than 4 to 5 days without water, and we rely on it for drinking, cooking, bathing, washing clothes, growing food, recreation, industry, and mining, as well as generation of electric power.

6.1 Water

Occurrence of water

Water makes up around one third of the earth's surface. Oceans, rivers, glaciers, lakes, wells, and groundwater are the primary sources of water. Water covers around 70% of the earth's surface, while land covers the remaining 30%. The majority of the water on Earth (about 97 percent) is salt water, largely found in the seas, with only 3 percent being fresh water. Fresh water accessible for human needs accounts for less than 1% of the total quantity on the planet. The issue is that fresh water is not distributed equitably across the globe.

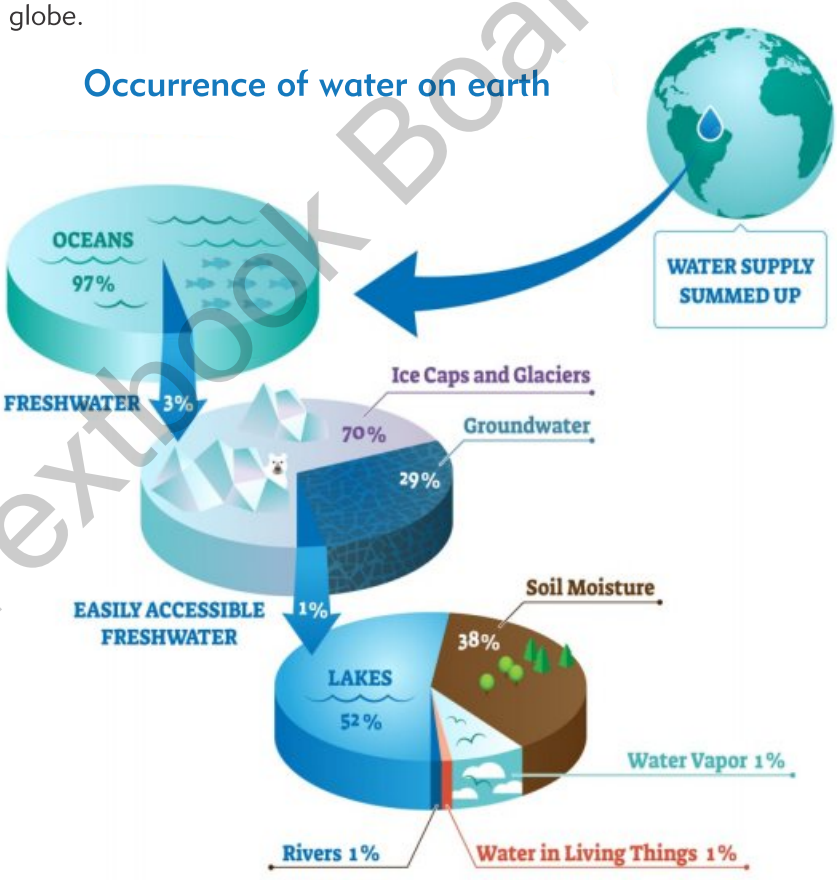


Figure 6.1 Occurrence of water

Importance of water

1. Our organs need water to work properly and toxins are removed from our body through urine.
2. Fatigue is also caused by dehydration, therefore water prevents fatigue.
3. It is necessary for washing and sanitation.
4. It is used in cooking.
5. It is used for growing food (Agriculture).
6. Thermal power plants use water for the production of energy (electricity).
7. In many medicinal procedures water act as an important component e.g: In dialysis, water containing fluid is used to remove waste from blood.
8. Fatal diseases are prevented by clean water e.g cholera, typhoid etc.

Figure 6.2 Importance of water

6.1.1 Properties of water

Pure water is a transparent, colorless, odorless, and tasteless liquid possessing the attributes listed below:

1. It is litmus-neutral.
2. At sea level, it has a freezing point of 0°C and a boiling point of 100°C.
3. At 4°C, its maximum density is 1 $g.cm^{-3}$.
4. It's a great solvent for both ionic and molecular substances.
5. It has a very high heat capacity of 4.2 $J.Kg^{-1}.K^{-1}$, which is almost six times that of rocks.
6. This feature of water is responsible for maintaining the Earth's temperature within reasonable bounds. Otherwise, the temperature during the day would have been too hot to handle, and the temperature during the night would have been too cold to freeze everything.
7. It has a lot of surface tension. Water's remarkable capillary strength is due to its one-of-a-kind action. The mechanism by which water rises from the roots of plants to the leaves is known as capillary action. The survival of terrestrial plants depends on this mechanism.

Composition of water

Water molecule is made up of one atom of oxygen and two atoms of hydrogen connected by covalent bond. Rain water is considered as purest form of water. Drinking water contain ions necessary for our body i.e. Na^{+}, Cl^{-}, K^{+} ,Mg^{2+} etc water is a polar molecule due to difference in electronegativity b/w H and O.

Structure of Water

Water is a simple molecule consisting of one oxygen atom bonded to two different hydrogen atoms. Because of the higher electro negativity of the oxygen atom, the bonds are polar covalent (polar bonds). The oxygen atom attracts the shared electrons of the covalent bonds to a significantly greater extent than the hydrogen atoms. As a result, the oxygen atom requires a partial negative charge (δ^{-}), while the hydrogen atoms each acquire a partial positive charge (δ^{+}).

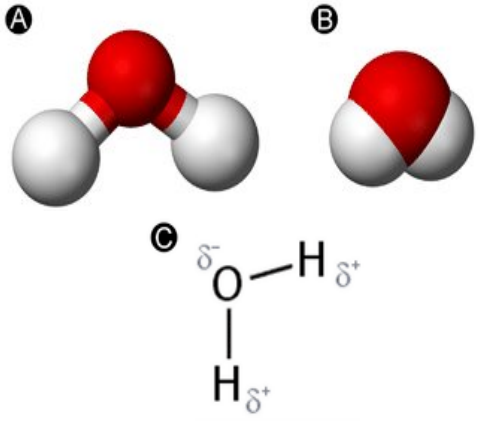


Figure 6.3 Molecular structure of water

6.1.2 Water as a solvent

Water can dissolve practically all minerals, water is known as the universal solvent. Water's capacity to dissolve compounds is due to two distinct qualities of the molecule:

1. Polar nature of water
2. Extensive hydrogen bonding ability.

Polar nature of water

The water molecule has a polar structure because of the electro negativity difference between oxygen and hydrogen atoms, which means one end of the molecule is partially positive and the other end is partially negative.

Water dissolves all other polar compounds because the positive end of the substance is drawn to the water's negative end ($O^{\delta-}$) and the negative end is attracted to the water's positive end ($H^{\delta+}$). The ion-dipole forces of attraction between ions and water molecules overcome the electrostatic interactions among the ions. The positive and negative ions of the compounds are separated in this manner. These oppositely charged ions are eventually enveloped by water molecules, which keeps them separated in solution. Most salts, such as NaCl, KCl, Na_2SO_4, and others, are soluble in water. Water molecules, on the other hand, are not attracted to numerous covalent compounds that lack polar ends or links, such as benzene, ether, oil and petrol. Non-polar chemicals do not dissolve in water as a result.

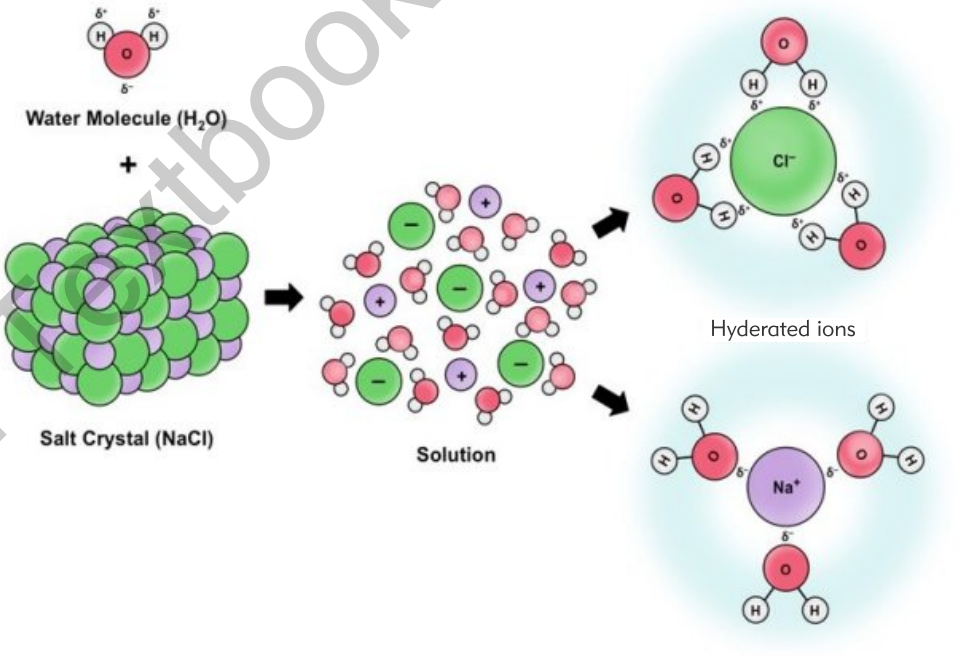


Figure 6.4 Polar structure of water

Extensive hydrogen bonding ability

The oxygen and hydrogen atoms make up the water molecule. One H_2O molecule can create hydrogen bonds with maximum four additional H_2O molecules stacked tetrahedrally around the H_2O molecule due to two O—H bonds and two lone pairs. By establishing hydrogen bonds with various polar non-ionic molecules containing hydroxyl groups (-OH), such as alcohols, organic acids, glucose, sugar, and so on, water is able to dissolve them.

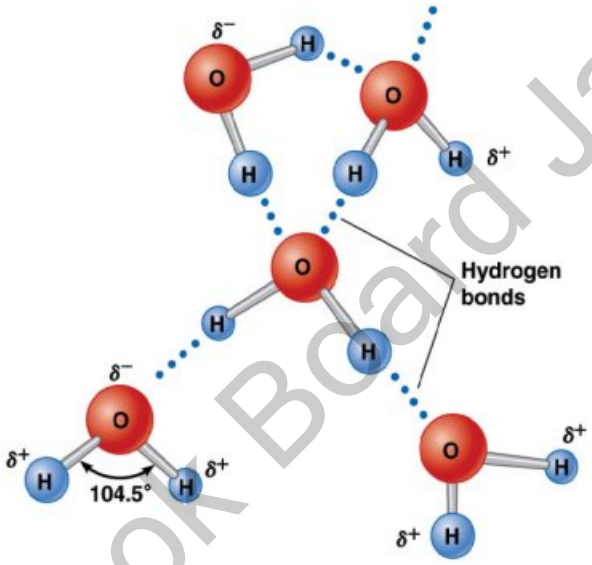


Figure 6.5 Hydrogen bonding

6.2 Soft and Hard water

Soft water

Soft water is water that generates an excellent lather when used with soap. It contain dissolved impurities but in small quantity.

Hard water

Hard water is defined as water that does not lather with soap. Hardness in water is caused by a variety of factors. Rainwater collects carbon dioxide from the atmosphere as it falls. When water combined with carbon dioxide flows through the soil layers, insoluble calcium and magnesium carbonates are converted to soluble bicarbonates. It may also dissolve calcium and magnesium chlorides and sulphates. The hardness of the water is caused by these minerals.

$$CaCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \longrightarrow Ca(HCO_3)_{2\,(aq)}$$

$$MgCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \longrightarrow Mg(HCO_3)_{2\,(aq)}$$

6.2.1 Types of Hardness of water

Water which cannot form lather with soap called hard water. A hard water has large amount of saline or dissolve salts such as calcium magnesium and other heavier metals. Hard water scaling the pipes and other in domestic alliance. Sea and ocean are the sources of hard water. There are two types of hard water:

1. Temporary hardness of water
2. Permanent hardness of water

Temporary hardness of water

Temporary hardness is caused by excessive amount of dissolved salt of calcium bicarbonate $Ca(HCO_3)_2$ and magnesium bicarbonate $Mg(HCO_3)_2$. A temporary hardness can be removed by boiling the water.

Permanent hardness of water

Permanent hardness of water is caused by the excessive amount of dissolved salts of chlorides and sulfates of Magnesium, Calcium, and Aluminum $CaCl_2$, $MgCl_2$, $CaSO_4$, $MgSO_4$, $FeSO_4$, $Al_2(SO_3)_3$. Permanent hardness of water cannot be removed by boiling. The sum of temporary and permanent hardness is referred as total hardness of water.

Degree of hardness of water on the basis of dissolved calcium (Ca^{2+})ion (mg,L^{-1})	
Soft water	0-16.1 mg/liter
Slightly hard water	16.1-60 mg/liter
Moderate hard water	61-120 mg/liter
Hard water	121-180 mg/liter
Very hard water	More than 180 mg/liter

Although hardness of water is never presence in the form of $CaCO_3$ as it is insoluble in water hardness of water is conveniently expressed in terms of equivalents of $CaCO_3$.

6.2.2 Methods of removing Hardness

Water softening is the process of removing the ions Mg^{2+} and Ca^{2+} that cause hardness.

1. Removal of temporary hardness

(a) Boiling Water

With a temporary hardness can be readily eliminated by boiling it. When calcium bicarbonate, $Ca(HCO_3)_2$, is heated, it decomposes into insoluble calcium carbonate, which precipitates out of the solution.

$$Ca(HCO_3)_{2(aq)} \xrightarrow{\Delta} CaCO_{3(s)} + H_2O + CO_{2(g)}$$

(b) Clark's method

The addition of slaked lime $Ca(OH)_2$ is a chemical approach for removing temporary hardness. Temporary hard water is treated using a determined amount of lime water. As a result of the precipitation of magnesium and calcium ions, water becomes soft.

$$Mg(HCO_3)_{2(aq)} + Ca(OH)_{2(aq)} \longrightarrow MgCO_{3(s)} + CaCO_{3(s)} + 2H_2O_{(l)}$$

$$Ca(HCO_3)_{2(aq)} + Ca(OH)_{2(aq)} \longrightarrow 2CaCO_{3(s)} + 2H_2O_{(l)}$$

2. Removal of permanent hardness

Chemicals are the only way to get rid of permanent hardness. Adding washing soda (Na_2CO_3) or sodium zeolite removes calcium (Ca^{2+}) and magnesium (Mg^{2+}) as insoluble salts.

Using washing soda:

Adding washing soda to the calcium and magnesium ions results in the formation of insoluble calcium and magnesium carbonates.

$$Na_2CO_{3(aq)} + CaSO_{4(aq)} \longrightarrow CaCO_{3(s)} + Na_2SO_{4(aq)}$$

$$Na_2CO_{3(aq)} + MgSO_{4(aq)} \longrightarrow MgCO_{3(s)} + Na_2SO_{4(aq)}$$

6.2.3 Disadvantages of water hardness

Lather Formation:

When you wash your clothing in hard water, the soap generates a white precipitate instead of lather. The scum is the white precipitate. Without the development of lather, your garments will not be cleansed.

Stains:

Hard water leaves stains on your clothes. They fade the colors of your garments. Calcium scum also causes your garments to become rough.

Bath tiles, glass, and fixtures are also stained by hard water. Calcium deposits on bath fittings may build a very difficult to remove coating if not cleaned frequently. The cloud-like watermarks on the kitchenware are caused only by hard water.

Effects on hair:

If you continue to wash your hair with hard water, you will continue to have awful hair days. Your hair becomes dry and scratchy when you wash it with hard water. This is due to the extra minerals found in hard water, which turn into a curd-like material that adheres to your hair. As a consequence, you may feel compelled to wash your hair, but this will just make it frizzier.

Effects on skin:

Bathing with hard water causes your skin to become dry and irritated. It's because the soap residue left behind adheres to your skin. Eczema-like symptoms are caused by the remaining residue. Children are more likely to have such a problem.

Reduces the life of Appliances:

If you continue to use hard water with your household equipment, the lifespan of the appliances will be dramatically reduced. The appliances steadily deteriorate due to the hard water, and they finally fail. In addition, the presence of minerals in hard water affects the machine's performance. A dishwasher has a ten-year life expectancy. If you run it with hard water, though, the life expectancy drops to seven years. A faucet should also run for nine years. With hard water, though, it will only last five years. That's how much hard water degrades your appliances.

Corrosion of pipes:

Hard water deposits may corrode pipes as well as obstruct them. As a result, the amount of water that can flow through the pipe is limited. And all that this does is slow down the flow of water. Pipe corrosion can also cause metals to leak into the water, making it unsafe to drink.

6.3 Water Pollutants

The polluting of water bodies is known as water pollution (e.g. lakes, rivers, oceans and ground water). Pollutants are dumped directly or indirectly into water bodies without proper treatment to eliminate dangerous substances, resulting in water pollution.

6.3.1 Industrial waste

Industrial units are erected to create the needed substances (chemicals, textile, leather products, paper, plastic items, petrochemicals, and rubber items) on a commercial scale. However, all industrial units, sadly, release their wastes (chemicals and solid materials) into the open land or into waterways. The term for this is industrial wastewater. Organic compounds, inorganic salts, heavy metals, mineral acids, oil and greases, and other very poisonous substances may be found in industrial waste. Water used as a cleaning agent in industries, on the other hand, is released immediately. This water is contaminated with a variety of harmful chemicals and detergents.

These effluents and used water either dissolve or float suspended in water when they reach lakes, streams, rivers, or oceans. As a result, water contamination occurs, i.e.

1. They degrade the quality of water.
2. They lower the amount of dissolved oxygen in the water, which has an impact on aquatic life and ecosystems.
3. They can also leak into the groundwater and influence the deposits.They pollute the water reserves. When this water is used by humans, it causes significant illnesses such as cancer and gastroenteritis. Soil, crops, plants, and animals are all harmed by this filthy water.
4. Heavy metals such as cadmium, lead, and mercury are harmful to humans and pose a health risk. Acute cadmium poisoning results in elevated blood pressure, renal damage, and red blood cell disintegration. Kidney, liver, brain, central nervous system, and reproductive system malfunction are all symptoms of acute lead

poisoning. Mercury toxicity damages the nervous system.

Figure 6.6 Industrial waste

6.3.2 Household waste

The usage of detergents for cleaning purposes in homes and businesses is growing by the day. It's because detergents, even in hard water, have a stronger cleaning activity than soap. They can even work in acidic environments. However, they have a significant disadvantage over soaps in that certain detergents are non-biodegradable (cannot be decomposed by microorganisms like bacteria). Water contamination occurs when domestic water containing these detergents is dumped into streams, ponds, lakes, and rivers.

The detergent lingers in the water for an extended period of time, rendering it unsuitable for aquatic life. Detergents include phosphate salts, which allow algae to develop quickly in water bodies and float on the surface. It is known as Eutrophication. These plants eventually die and decompose. Because decaying plants are biodegradable, they absorb oxygen gas in the water. As a result, aquatic life dies due to a lack of oxygen.

A wide range of dissolved and suspended pollutants can be found in domestic sewage. Food and vegetable waste, rubbish, cans, bottles, chemical soaps, washing powder, and other items are among them. It also has disease-causing bacteria in it. All of these things pollute the water.

Figure 6.7 Household waste

Do You Know?

- Less than 1 % of the earth's total water supply is suitable for drinking.
- Polluted water kills 5,000 children per day and 3 million per year globally. (UN, 2006)

6.3.3 Agricultural waste

The usage of fertilizers and pesticides causes water contamination owing to agricultural waste. Fertilizers are used to compensate for soil deficiencies in nitrogen, phosphorus, and other nutrients caused by intense crop cultivation in recent years.Pesticides, on the other hand, are used to either kill or control the growth of pests. Weeds, insects, fungus, viruses, and other pests are examples. They all harm crops and spread illnesses to both humans and animals.

Agricultural effluents have a two-fold impact:

1. Chemicals from fertilizers and pesticides leak into groundwater as a result of rain and intensive crop production, a process known as leaching. Irrigation run-off from agricultural fields is the primary source of excessive nitrate levels in ground water.
2. Runoff from agricultural land (which has been treated with fertilizers and pesticides) reaches ponds, streams, and rivers. Nitrate (NO_3^-) and phosphate (PO_4^{3-}) salts are present in this water. These compounds cause algae to develop quickly and float on the water's surface. They block the passage of sunshine and oxygen to aquatic life. When algae dies, microorganisms eat oxygen from the water to help the algae decompose. As a result, the water loses oxygen. Due to a lack of oxygen, aquatic creatures experience asphyxia and eventually perish.

Figure 6.8 Agriculture waste

Effects of water pollutants on life

Following are the effects of water pollutants:

1. It is harmful to people's health. Cholera, typhoid, and diarrhea can all be caused by drinking contaminated water.
2. The use of dirty water is harmful not only to humans, but also to animals and birds.

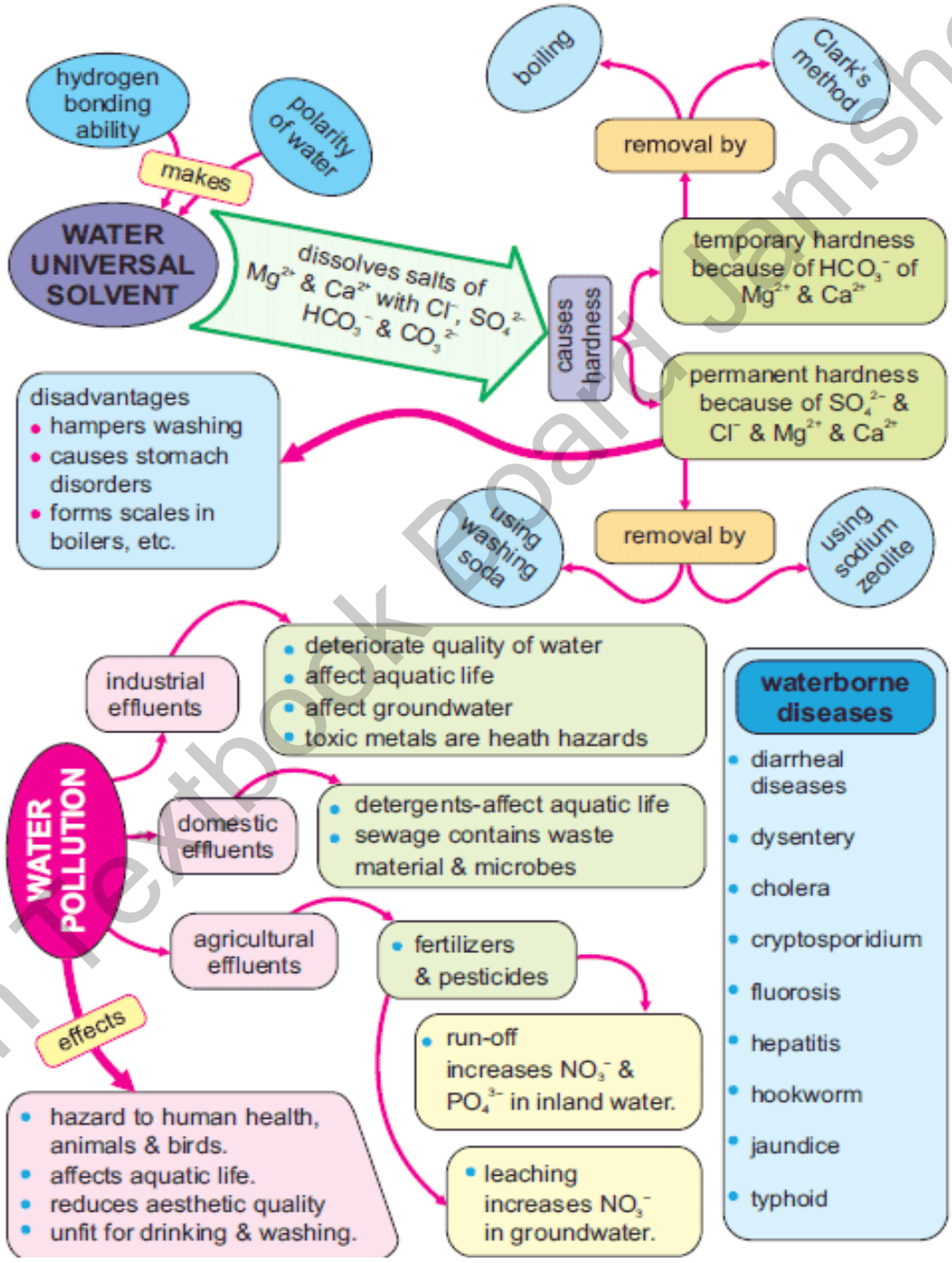
3. It promotes algae to develop quickly. The death and breakdown of algae results in a lack of oxygen in the water, which impacts aquatic organisms.
4. It harms aquatic life, causing a food chain link to be broken.
5. It degrades the appearance of lakes and rivers.
6. It is not suitable for cleaning or washing.

6.4 Water Borne diseases

Waterborne infectious illnesses are diseases that spread by drinking dirty water or eating food prepared with polluted water. Toxins or bacteria can cause water contamination. Arsenic, mercury, calcium, lead, and a variety of organic substances are examples of toxins. Viruses, bacteria, protozoa, and worms are examples of microorganisms.
The major reason of quickly spreading waterborne illnesses is a lack of sufficient sanitary facilities. Following are of the most frequent illnesses:

1. Diarrheal diseases
   Intestinal illnesses that can lead to serious dehydration, such as cholera. Viruses, bacteria, and parasites all can cause diarrhea.
2. Dysentery
   Dysentery is a kind of gastrointestinal infection caused by bacteria or parasites. It's characterized by severe diarrhea, which may include blood or mucus.
3. Cholera
   The bacteria Vibrios cholerae, which may be found in water tainted by human feces, causes cholera. Cholera is a disease that produces severe diarrhea and is potentially lethal.
4. Cryptosporidium
   Cryptosporidiosis is a gastrointestinal ailment caused by a waterborne microbe (protozoa) that causes diarrhea and vomiting. Surface water sources such as reservoirs, lakes, and rivers contain these microscopic germs
5. Fluorosis
   Fluorosis is a condition caused by too much fluoride in the body. Fluorosis can harm your bones and teeth.
6. Hepatitis
   Hepatitis A, B, C, D, and E are the five viruses that often cause liver inflammation. Viruses like hepatitis A and E can be spread through polluted water.
7. Hookworm
   Hookworm is a parasitic worm that lives in the small intestine and causes disease. Anemia and slowed development in children can occur in severe situations. Hookworm larvae enter the body via the skin, most commonly through the feet. Hookworms, which are spread by unsanitary settings, infect nearly one billion individuals each year throughout the world.
8. Jaundice
   An excess of bile pigments in the blood causes jaundice. The liver stops working, and the eyes turn yellow. The patient is weak and tired.
9. Typhoid
   A severe bacterial illness spreads often through polluted water or food cooked with contaminated water.

CONCEPT DIAGRAM



Summary

- Water is the most abundant compound on earth. Its main sources are rain, river, lakes, canal, ground and sea water.
- 97.5 percent water is saline and rest of water is fresh and able to use.
- Water is composed of two atoms of hydrogen and one atom of oxygen.
- Water is considered as a universal solvent oxygen form one fifth part of the water.
- The maximum density of water is at $4^{\circ}C$. While its freezing point is $0^{\circ}C$ and boiling point is $100^{\circ}C$.
- Water shows the anomalous behavior due to the hydrogen bonding so it freezes at $0^{\circ}C$.
- Water quality is important for the ecological process even that our own life is depends on quality of water such as watering stock, drinking, fishing and recreation, and to meet cultural and spiritual needs.
- Drinking water can proceed in to several steps such as creeks, dams, canal, treatment plants, pipes and then in taps.
- Water which have the less amount of soluble salt is known as soft water.
- If the saline salt is soluble in excess quantity than hard water is formed.
- There are two types of hardness in water: temporary and permanent hardness.
- Temporary hardness formed by the bicarbonates salt of Ca and Mg and can be removed by boiling of water.
- Permanent hardness is formed by the salt of sulfate and chloride with Ca and Mg.
- The main sources of water pollutants are sewage water causes by households and industries which effect the main pollutants in water.
- Water pollutants may be physical chemical and in microorganism.
- Diseases which are caused by contamination called the waterborne diseases.
- water borne diseases are also caused by virus, bacteria and protozoa.
- Diarrhea and cholera are the main waterborne diseases.

Exercise

SECTION- A: MULTIPLE CHOICE QUESTIONS

1. Which of the following water borne diseases is of viral origin.
   (a) Typhoid fever (b) Polio (c) Dysentery (d) diarrhea
2. How much percentage (%) of the Earth's Surface is covered with water?
   (a)70% (b) 60% (c) 90% (d) 75%
3. Which type of bond is formed between H_2O molecules:
   (a) Hydrogen bond (b) ionic bond (c) covalent bond (d) all of these
4. The permanent hardness of water is due to presence of:
   (a) $MgSO_4$ (b) $Mg(HCO_3)_2$ (c) $Ca(HCO_3)_2$ (d) all of these
5. How much fresh water is present on earth:
   (a) 0.3% (b) 3% (c) 0.2% (d) 2%
6. Which salts are excessively dissolved to make temporary hard water:
   (a) $CaSO_4$ and $CaCl_2$ (b) KNO_3 and KOH
   (c) $CaCO_3$ and $Ca(OH)_2$ (d) $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$
7. Water is a:
   (a) Polar solvent (b) Non polar solvent
   (c) Amphipathic solvent (d) Non polar charged solvent
8. The taste of water is:
   (a) Sour (b) Bitter (c) Sweet (d) Tasteless
9. Which of the following is helpful for removal of permenant hardness:
   (a) Na_2CO_3 (b) $Ca(OH)_2$ (c) $CaCO_3$ (d) Na_2SO_4

SECTION- B: SHORT QUESTIONS:

1. Describe composition of water.
2. Define hard and soft water
3. Describe water pollutant.
4. How we can remove temporary hardness of water?
5. List down the diseases due to polluted drinking water.
6. Differentiate between hard and soft water.

SECTION- C: DETAILED QUESTIONS:

1. Write down the methods for removal of permanent hardness of water.
2. Describe the water pollutants in industries.
3. Justify that "Water is solvent".
4. Describe disadvantages of hard water?
5. Explain in detail Water borne diseases.