

UNIT 4 WATER RESOURCES

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4.1 INTRODUCTION

Availability of water and, to a great extent, its proper usage contributes significantly to national economy. It is for this reason that substantial financial allocation is made for water resources sector while deciding the details of five year plans. In fact, during the First Five Year Plan (1951-56), agriculture, irrigation and power projects were accorded the highest priority with 44.6% fund allotment. In our country, agriculture generates 26% of national income and about 64% of the employment. At present, India has the largest irrigated area among all the countries of the world. This has greatly contributed to the increase in food grains production by four times between the period, 1950 and 1997. It is worth comparing the quantitative requirement of water across different production activities. The studies indicate that one acre of paddy crop requires 47.5 lakh litres of water. A steel plant requires 83600 litres of water for every ton of steel produced. A car coming out of the factory consumes 1.14 lakh litres of water in its manufacture. For refining a 200 litres barrel of petrol, 3000 litres of water are required. For producing one ton of synthetic rubber, 22.8 lakh litres of water are required. In short, location of an industry depends on the availability of water as a raw material. All these are mentioned to illustrate the fact that water is an important resource for national development.

In this unit, we shall make a brief reference to the global distribution of water and the water resources of our country. We shall indicate how there is regional imbalance in water availability. The hydrological cycle and hydrodynamics of fresh water ecosystems will be explained. Knowledge of these features could help us in optimising the available water resources for the best possible use. We shall have a detailed discussion on the need and methods for conservation and management of water resources. The aim is to focus on the remedial measures to be undertaken to overcome the problems that arise due to scarcity of water.

Objectives

After studying this unit, you should be able to :

- list the reasons for considering water as a resource,
- state the quantitative aspects of water availability at the global and national levels,
- discuss the various stages and importance of the hydrological cycle,
- indicate the basic features of the hydrodynamics of fresh water ecosystems,
- justify the need for conservation and management of water resources, and
- explain the methods that could be employed for water conservation and management.

4.2 UNITS FOR LAND AREA AND RAINFALL

Before we proceed to next section, we must be aware of some units used in describing land area (irrigated) and volume of water obtained through rainfall, snowfall or from ground sources.

Units for land area

$$\begin{aligned}
 &1 \text{ Hectare} = 2.47 \text{ acres} = 10^4 \text{ metre}^2 \\
 &\text{(i.e., } 1 \text{ ha} = 10^4 \text{ m}^2\text{)} \\
 &100 \text{ hectares} = 10^6 \text{ metre}^2 = 1 \text{ kilometre}^2 \\
 &\text{(i.e., } 100 \text{ ha} = 10^6 \text{ m}^2 = 1 \text{ km}^2\text{)} \\
 \text{Also, } &1 \text{ million hectare (1 mha)} = 10^{10} \text{ m}^2 \qquad \dots (4.1)
 \end{aligned}$$

Units for volume of water arising due to rainfall, snowfall or groundwater facility

$$\begin{aligned}
 &1000 \text{ litres} = 1 \text{ m}^3 \\
 &1 \text{ hectare metre} = 10^4 \text{ m}^3 \\
 &\text{(1 ha m)} \\
 &1 \text{ million hectare metre} = 10^{10} \text{ m}^3 = 10 \text{ km}^3 = 10^{13} \text{ litres} \qquad \dots (4.2) \\
 &\text{(i.e., } 1 \text{ mha m)}
 \end{aligned}$$

Calculation of volume of water arising due to rainfall

Keeping the area in m² unit and the rainfall in m unit, the volume of water arising due to rainfall is obtained in m³ unit using Eq. 4.3.

$$\left. \begin{array}{l} \text{Volume of water arising} \\ \text{annually due to rainfall} \\ \text{in m}^3 \text{ unit} \end{array} \right\} = \left(\begin{array}{l} \text{Surface area} \\ \text{in m}^2 \text{ unit} \end{array} \right) \times \left(\begin{array}{l} \text{average annual} \\ \text{rainfall in m unit} \end{array} \right) \qquad \dots (4.3)$$

The volume of water due to rainfall can also be calculated in mha m units as per Eq. 4.4.

$$\left. \begin{array}{l} \text{Volume of water arising} \\ \text{annually due to rainfall} \\ \text{in mha m units} \end{array} \right\} = \left(\begin{array}{l} \text{Land area in} \\ \text{mha unit} \end{array} \right) \times \left(\begin{array}{l} \text{average annual} \\ \text{rainfall in m unit} \end{array} \right) \qquad \dots (4.4)$$

Example 1

Let us calculate the volume of water arising annually due to rainfall over only the land area of our country that is equal to 304 mha. The average rainfall is 110 cm (i.e. 1.10 m). Let us express the answer in mha m, m³ and litre units.

Using Eq. 4.4,

$$\left. \begin{array}{l} \text{volume of water arising} \\ \text{annually due to rainfall} \\ \text{over the land area of our} \\ \text{country} \end{array} \right\} \begin{array}{l} = 304 \times 1.10 \text{ mha m} \\ = 334.4 \text{ mha m} \\ = 3.344 \times 10^{12} \text{ m}^3 \\ = 3.344 \times 10^{15} \text{ litres} \end{array} \quad \text{(Using Eq. 4.2)}$$

SAQ 1

The area of a location is 1483 km². The average annual rainfall is 60 cm. Calculate the volume of rainwater that falls over the location annually in m³, mha m and litre units.

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4.3 GLOBAL DISTRIBUTION OF WATER

Water covers about three quarters of the earth’s surface. The total amount of water has been estimated to be more than 1.400 x 10⁹ km³, which is enough to cover the earth with a layer of water of 300 m depth. About 97.2% of this water is in the oceans. Of the 2.8% that is fresh, 2.15% is frozen as glaciers and in ice caps. Thus, all the water in the lakes and rivers, all the moisture in the atmosphere, soil and vegetation and all the water underground amounts to about 0.65% of the total; again out of this, major portion is in the form of groundwater half of which may lie more than 1000 m below the surface. Around 0.017% is in rivers, fresh water lakes *etc.*

If earth’s total water content is 100 litres, only 17 cc is present as fresh water in rivers, lakes *etc.*

4.4 WATER RESOURCES OF INDIA

In this section, we shall discuss the availability of water in India from all sources.

4.4.1 Annual Rainfall

The Indian economy depends to a great extent on the rainfall that occurs through two monsoons, the southwest and the northeast. The average annual rainfall in India is 110 cm whereas the global mean is 99.1 cm. India has the highest rainfall when comparison is made among countries of similar size. But it is variable in space and time. The heaviest rains occur along the north-eastern states and along the west coast (from Trivandrum to Bombay). Mawsynram, near Cherrapunji, has the highest annual rainfall of 900 cm – sometimes even 1140 cm in a year with as much as 104 cm in a day. In contrast, the areas receiving less than 40 cm rainfall in a year include (i) the Thar Desert areas of Western Rajasthan that extend up to Kachchh in Gujarat and (ii) most of Jammu and Kashmir. Rajasthan has the least rainfall among the major states. Most of the rainfall occurs in our country in about three months period, especially over 200 hours and, half of it in 30 hours. Consequently, the run off is high. Rainfall during monsoon is also not certain. In Sec 4.2, we calculated rainfall over only the land area of our country as 334.4 mha m. Over the entire country, there is 395 mha m from rainfall and 5 mha m from snowfall making a total of 400 mha m of fresh water. The whole of it cannot be put to use due to reasons given under Subsec. 4.7.1.

The flow of rainwater over the land surface along the natural slope is called run off.

4.4.2 River Systems in Our Country

The rivers in India may be classified into four types as follows:

- i) The Himalayan rivers
- ii) The Deccan rivers
- iii) The Coastal rivers
- iv) Rivers of the inland drainage basin

Water

The Himalayan rivers are fed both by snow and rain and, have a continuous flow throughout the year. During the monsoon months, the Himalayas receive heavy rainfall resulting in frequent flood. The main Himalayan rivers are:

- i) The Indus and its tributaries (such as the Jhelum, the Chenab, the Ravi, the Beas, and the Satluj *etc.*)
- ii) The Brahmaputra and Barak (the latter also known as Meghna)
- iii) The Ganga and its tributaries (such as the Yamuna, the Ram Ganga *etc.*)

Drainage:

An area into which surface water flows.

Among the deccan rivers, the Godavari, the Krishna, the Pennar and the Cauvery are the major ones. Among the coastal rivers, mainly there are four on the west coast (the Sabarmati, the Mahi, the Narmada and the Tapi) and three on the east coast (the Subarnarekha, the Brahmani and the Mahanadi).

Arid Area:

A land area getting less than 25 cm rainfall, which is insufficient to support agriculture. Because of low moisture content in air (*i.e.*, low humidity) evaporation rate will be high.

The rivers of the inland drainage basins are also known as desert rivers. They flow for some distance and get lost in deserts. They flow through arid areas where evaporation equals rainfall and hence, there is no surface flow. A typical example is the Luni river which rises in the Nagaur District of Rajasthan and, after running for a total length of 482 km finally disappears in the Great Rann of Kachchh.

4.4.3 River Basins

Three divisions based on drainage are accepted for Indian rivers as shown in Table 4.1. The major river basins cater to the needs of 80% of the country's population. The names of major rivers, their catchment areas and the states falling under their river basins are given in Table 4.2. Each river basin shown in Table 4.2 includes the main rivers and their tributaries also. The medium and minor river basins cover 17% of the total drainage area and provide 15% of flow contribution. The Brahmaputra, the Ganga and the Indus basins along with that of the Godavari cover more than half of the country. The whole of the west coast stretching 1500 km between Surat in Gujarat and Kanyakumari in Tamilnadu are fed by fourteen medium and eighteen minor river basins. But important cities like Bombay, Panaji, Cochin and Trivandrum are left out of these basins.

Table 4.1: Classification of River Basins of India.

Category	Basin area/km ²	Number of basins	% of total drainage area	% of flow contribution
Major	More than 20,000	14	83	85
Medium	Between 20,000 and 2000	44	8	7
Minor and Desert	Less than 2000	55	9	8

Table 4.2: The Catchment Areas and the States Involved in Major Basins.

S.No.	River basin	Catchment area/km ²	States in which the catchment area falls
1.	Indus	3,28,000	Jammu & Kashmir, H.P., Punjab, Haryana, Rajasthan
2.	Ganga	8,60,000	Uttaranchal, U.P., H.P., West Bengal, Jharkhand, Haryana, Rajasthan, M.P., Bihar, Delhi
3.	Brahmaputra	1,87,000	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, West Bengal
4.	Sabarmati	20,000	Gujarat, Rajasthan
5.	Mahi	30,000	Gujarat, M.P., Rajasthan
6.	Narmada	98,000	Gujarat, M.P., Maharashtra
7.	Tapi	60,000	Gujarat, M.P., Maharashtra
8.	Subarnarekha	19,000	Bihar, Orissa, West Bengal
9.	Brahmani	39,000	Bihar, M.P., Orissa
10.	Mahanadi	1,40,000	Bihar, Chhatisgarh, M.P., Maharashtra, Orissa
11.	Godavari	3,10,000	A.P., Karnataka, M.P., Maharashtra, Orissa
12.	Krishna	2,58,000	A.P., Karnataka, Maharashtra
13.	Pennar	55,000	A.P., Karnataka
14.	Cauvery	87,000	Karnataka, Kerala, Tamilnadu

Each river basin shown in Table 4.2 includes the main rivers and their tributaries also.

Catchment area:
The area served by a river system.

On the east coast of peninsular India, the following three pockets are not covered under any major river basins:

- i) The area between the Mahanadi and the Godavari basins in Orissa coast
- ii) The area between the Pennar and the Cauvery basin wherein Chennai and Pondicherry are located
- iii) The area south of the Cauvery i.e., from Madurai to Kanyakumari.

Based on volume of water flow along the rivers, the following aspects are worth noting:

- Our Country has fourteen major, fortyfour medium and fifty-five minor river basins. Evidently, there is tremendous variation in the quantity of discharge from a major basin to the minor one and, also in the quality of discharge from region to region.
- The northern and eastern regions have much better water resources than southern and western parts. Among the fourteen major river basins, only four have perennial flow of water due to heavy rainfall *i.e.*, in the Brahmputra, the Ganga, the Mahanadi and the Brahmani. Six basins (the Krishna, the Indus, the Godavari, the Narmada, the Tapi and the Subernarekha) have medium rainfall. The

Water

Water flow variation of a river through different seasons has a direct influence on its efficiency to flush out and dilute sewage let into it.

remaining four (the Cauvery, the Mahi, the Sabarmati and the Pennar) occupy the area of low rainfall. The seasonal variation in water flow in the Ganga and the Brahmaputra is of the order 50:1, whereas in Cauvery and Mahi, the same is of the order 1000:1.

- The (treated or untreated) industrial waste and domestic waste can be flushed out when the rainwater flows through the rivers. During dry seasons, there is not enough flowing water to carry the waste materials. Thus, waste management need to be given a serious thought, where dumping is done into monsoon fed rivers.

4.4.4 Groundwater Availability

Groundwater is the water that occurs below the surface of the earth. Groundwater is that part of the precipitation which soaks into the soil through the openings and keeps moving underground. It is generally found in geological formations commonly referred to as aquifers. Rainfall characterised by seasonal, annual and locational variation is not a very reliable source of water supply in most parts of the country. Availability of groundwater is a major asset that can greatly influence agricultural and industrial sectors. The contribution of groundwater resource to agriculture is as high as 50%. Nearly 80% of rural water supply and over 50% of urban and industrial water supply demand is met from groundwater resource. It has been estimated that at a depth of 300 m, the groundwater reserves of the country are 3700 mha m, more than nine times the annual rainfall. But the usable portion of groundwater is only 43.2 mha m. Just as in rainfall pattern, usable groundwater availability also varies from region to region.

The groundwater is abundant in the Indo-Gangetic plain but scarce in the western and southern regions. The groundwater withdrawal needs to be replenished through rainfall. But from the point of view of its utilisation, there is unevenness. The groundwater under utilisation and over utilisation exist side by side in different parts of the country. Under utilisation occurs in areas where cheap canal water is available. Over utilisation remains a major problem in areas with no or uncertain canal water supply and, where more water-intensive agricultural production system is practised. The over use leads to deterioration of water quality due to (i) the lowering of water level thereby reaching saline water layers below or (ii) passage of sea water into the groundwater source (where the source is near a sea). Usage of such poor quality water can have adverse effect on living beings and agriculture.

SAQ 2

From the fact that the average annual rainfall in India is significantly higher than the global mean, it looks India is fairly rich in water resources. Examine this statement in the light of variability of rainfall with respect to space and time.

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SAQ 3

State the problems arising out of over utilisation of groundwater.

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4.5 HYDROLOGICAL CYCLE

Hydrological cycle is defined as the cyclic process of evaporation, cloud formation, rainfall, snowfall and refilling of water bodies. The evaporation takes place from oceans and other water sources due to solar heat. As a result of this, clouds are formed, which float around in gaseous form or in liquid droplet form along with tiny crystals. Eventually, the water returns to the earth in the form of rain or snow known as precipitation. When it reaches the earth, some of it runs across the ground into the rivers and finally flows into the ocean again. Some portion of rainwater gets absorbed into the soil and even percolates deep to form groundwater. A portion of the rainwater also immediately evaporates back into the sky.

4.5.1 Stages in Hydrological Cycle

The sun and wind control the entire hydrological cycle. During the hydrological cycle, there is transfer of heat around the earth, thereby moderating extreme conditions of temperatures. The stages of the cycle are given below.

i) Evaporation

Water from soil surface, ponds, lakes, rivers and oceans gets transferred as moisture. The factors which affect evaporation are: temperature, relative humidity, wind velocity, amount of rainfall or snowfall, quality of water, surface area of the water source, sunshine *etc.*

ii) Transpiration

Transpiration refers to loss of water in vapour form from plant leaves. The water taken into the roots of the plants from the soil replaces the transpired water. In a way, transpiration is like the action of a pump absorbing water from the soil and leaving the vapour into the atmosphere. Water loss from a vegetated area takes place both by evaporation and transpiration and it is termed, *evapotranspiration*.

iii) Interception

Interception is the retention of precipitation by thick vegetation (of trees and plants) or by shrubs that is evaporated back to atmosphere. Because of interception in densely vegetated areas, very little rain reaches the soil directly. Interception is to be particularly noted in low rainfall areas.

iv) Precipitation

Water returns to the land and sea from the atmosphere by means of condensation, deposition and precipitation. Condensation is the process of conversion of water vapour into liquid state (in the form of dew droplets). Deposition is the process by which water vapour changes into ice crystals. In the atmosphere, tiny droplets of water and ice crystals form clouds. Precipitation signifies rainfall and snowfall.

v) Run off

Some of the rainfall is soaked into the soil as ground water. The excess water flows over the land surface along the natural slope of the area and is known as run off. Run off is the main source of water for lakes, streams and rivers. The rainwater ultimately drains into the sea. Soil characteristics such as smoothness and steepness of the slope influence the rate and the magnitude of the run off.

The vapour pressure exerted by the water vapour when its concentration is maximum that can remain in a sample of air at a particular temperature is called its saturation vapour pressure. The saturation vapour pressure increases as the air temperature increases. Relative humidity, expressed as a percentage, is related to saturation vapour pressure by the following equation:

$$\text{Percent relative humidity} = \frac{\text{Vapour pressure}}{\text{Saturation vapour pressure}} \times 100$$

For cloud formation and precipitation to occur, relative humidity must have a high value. Also when relative humidity increases, water evaporation rate decreases.

The movement of water through trees standing even to a height of 200 feet or more is aided by an anomalous property of water namely, high surface tension value. Compared to many liquids, water has high surface tension. The surface tension of water is high due to strong cohesive forces caused by intermolecular hydrogen bonding. These forces help in the upward movement of water through capillary rise.

It has also been estimated that hydrological cycle uses more energy in a day than man has generated throughout history by burning all types of fuels.

Water

Water table:

The upper limit of the portion of the ground wholly saturated with water.

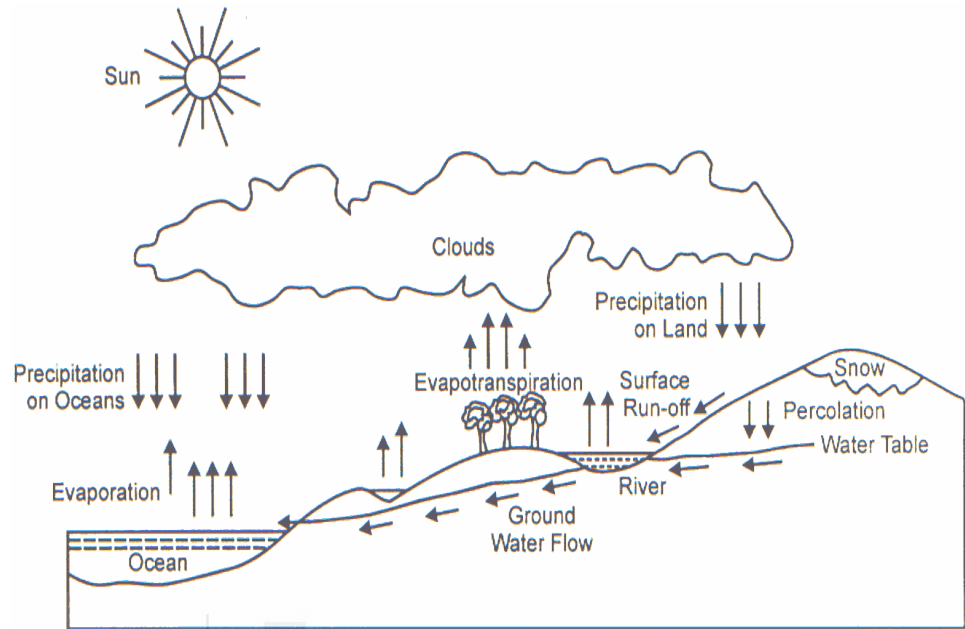


Fig. 4.1: Hydrological cycle.

vi) Infiltration

Infiltration is the absorption of part of the precipitation by the surface layers of soil. During infiltration, water moves downward vertically through various layers finally forming groundwater. The amount of water that undergoes infiltration depends on intensity of rainfall, surface conditions of the soil, vegetation cover and available storage capacity.

The entire cyclic process is represented through Fig. 4.1.

4.5.2 Abnormal Properties of Water Helping the Operations of Hydrological Cycle

It is worth mentioning that water has

- higher melting point, boiling point and heat of vaporisation than most other common liquids of comparable molecular weight
- lower density in the solid state than in the liquid state
- high heat capacity, and
- high surface tension.

Its high melting point helps in maintaining ice caps at polar regions. The lower density of ice facilitates its floatation on water surface. This enables lower layers in ocean and other water systems to remain in the liquid state, although the surface may be covered with ice. It facilitates aquatic life even in cold regions. Further, once spring sets in, surface ice begins to melt. In short, there is constant mobility of solid and liquid forms of water. But for the lower density of ice, much of the portions of deep oceans would have remained solidified forever. Also, intolerable extremes of cold and heat would have been present in the world. Further, the high heat capacity of water helps to regulate temperature conditions both during winter and summer. High surface tension helps in movement of water through plants and trees due to capillary rise. The last feature enables constant replacement of water lost by the plants and trees through evapotranspiration.

Water has high heat capacity value. It signifies that water requires/releases large heat energy while being heated/cooled. This particular quality of water helps in regulating the temperature conditions in our planet as also in plants, animals and human beings. But for this property of water, our planet might have experienced extreme conditions of heat and cold. It is reported that in the industrial side also, 90% of water is used in cooling operation, while 10% alone is used as a reactant or a solvent.

Silt consists of the following:

- fine particles of weathered rock
- dirt and
- organic matter.

4.5.3 Importance of Hydrological Cycle

Let us see how the phase transformation of water and the run off during hydrological cycle affect human life favourably and unfavourably.

- i) Climate and monsoon are directly related to the hydrological cycle. The dynamic flow of water vapour in the atmosphere contributes to climatic conditions in a place.
- ii) The physical disintegration and the chemical decomposition of the materials on the surface of the earth due to various operations of the hydrological cycle are known as weathering reactions. Water has a prominent role in weathering reactions. The rainwater trapped in the crevices of rocks solidifies during winter. Due to lower density of ice than water, it expands and helps in breaking the rocks and mountains. The rain that falls uses part of its energy over the rocks and mountains causing erosion. The run off carries lot of silt so formed from the rocks causing valleys. The silt is colloidal in nature. A part of it coagulates when coming into contact with saline water near the sea, resulting in the formation of deltas, a rich deposition of fertile soil. The silt that is still carried finally gets deposited into the oceans. In other words, hydrological cycle breaks the mountains and rocks in a slow way and fills up the oceans with the silt so formed – a process of surface leveling. Thus, the weathering reactions help in shaping the earth. Further, weathering reactions play a prominent role in the formation of minerals. You are advised to refer to Unit 1 of Block 1 to understand this aspect. In Sec 5.3 of the next unit, you shall study how minerals are formed through the weathering reactions carried out by water with rock materials.
- iii) The flow of water down the steep slopes could yield considerable hydroelectric power. Also the run off aided by the gravity on the plains enables navigation through water bodies.
- iv) An excess of rainfall within a short time may bring floods. A long interval between successive rainfalls causes drought conditions. Floods and drought are instances to show how hydrological cycle operation could adversely affect living conditions.

In this subsection, we have studied how through hydrological cycle, all the water bodies – oceans, rivers, atmosphere and glaciers – are interconnected. Next, let us study the hydrodynamic features of three major types of fresh water ecosystems.

SAQ 4

Explain the terms, evapotranspiration and interception.

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It is estimated that the rivers and streams carry around 2.7 billion tons of silt into the oceans every year.

Crevice: Small narrow cracks within rocks.

If you want to know about coagulation of colloids, go through Subsec. 20.6.5 of Unit 20 of Physical Chemistry (CHE-04) Course.

Eco system:
A community of animals, plants and bacteria and, interrelated physical and chemical environment.

Hydrodynamics:
The branch of Physics dealing with motion of water and its related characteristics.

4.6 HYDRODYNAMICS OF FRESH WATER ECOSYSTEMS

Under hydrodynamics, we shall examine the flow velocity of water, vertical mixing and stratification. First, we examine the effect of **flow velocity** on aquatic systems. The fast moving aquatic systems experience turbulence to a great extent and, agitate water layers. This process helps in enhancing dissolved oxygen content. As an analogy, remember the laboratory practice of stirring the contents of a beaker vigorously to dissolve maximum amount of a solute in a solvent. You can now understand as to why turbulent rivers have high dissolved oxygen content; slow moving rivers may have oxygen well below saturation conditions. The two terms, vertical mixing and stratification are related to each other. Due to water current and

Flow velocity:
It is the speed with which water flows through the water system.

Water

turbulence, mixing of water layers from top to bottom takes place, which is known as **vertical mixing**. Vertical mixing leads to uniformity of temperature and chemical composition (with respect to dissolved materials such as dissolved oxygen *etc.*) Lack of vertical mixing leads to stratification. **Stratification** refers to formation of distinct horizontal layers differing in temperature, chemical composition and biological properties. The difference in biological characteristics of various layers is due mainly to the difference in nutrient content and dissolved oxygen. You may go through the portion written under temperature in Sec. 5.2 of the next unit to understand the significance of the term, stratification. We explain the flow velocity, vertical mixing and stratification of three of the fresh water ecosystems.

Lateral mixing:
Mixing of water along sideways, usually at same height from the river bed.

Rivers

The rivers are characterised by unidirectional current with a relatively high, average flow ranging from 0.1 m s^{-1} to 1 m s^{-1} . The river flow is highly variable with time depending on climatic situation and the drainage pattern. In general, thorough and continuous vertical mixing is achieved in rivers due to prevailing currents and turbulence. Lateral mixing may take place only over considerable distance downstream of major confluence.

Lakes

Confluence:
Merging of two or more aquatic systems.

The lakes are characterised by low average current velocity of 0.001 m s^{-1} to 0.01 m s^{-1} (surface value). Therefore, water residence times, ranging from one month to several hundreds of years, are often used to quantify mass movement of material. Current within lakes are multidirectional. Many lakes have alternating period of stratification and vertical mixing, periodicity of which is regulated by the climatic conditions and depth.

Groundwater

The groundwaters are characterised by a rather steady flow pattern in terms of direction and velocity. The average flow velocities commonly found in aquifers (groundwater reservoirs) are in the range $10^{-10} \text{ m s}^{-1}$ – 10^{-3} m s^{-1} ; these are largely governed by the porosity and the permeability of the geological material. As a consequence, mixing is rather poor. Depending on local geological features, the groundwater dynamics can be highly diverse.

There are also several transitional forms of water bodies, which demonstrate features of more than one of those described above. We shall not go into these details.

As a consequence of the range of flow velocities noted above, large variations in water residence times occur in different types of inland water bodies. The hydrodynamic characteristics of each type of water body are highly dependent on the size of the water body and on the climatic conditions in the drainage basin. The governing factor for rivers is their discharge variability. Lakes are classified by their water residence time and stratification. Groundwaters greatly depend upon infiltration, which allows for the renewal of the groundwater body.

SAQ 5

Name two important hydrodynamic characteristics that are studied for fresh water ecosystems. State the reason for their importance.

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4.7 CRUCIAL ISSUES ASSOCIATED WITH CONSERVATION AND MANAGEMENT OF WATER RESOURCES

Conservation of water refers to the issues of development and protection of the water resources in such a way that the present and future needs for water are satisfied. The conservation aspect deals with the problems related to

- the storage of water
- retention of moisture in the soil and
- maintenance of withdrawal-recharge ratio of water bodies.

The management of water resources specifies measures to be taken to maximise the efficiency of water use. In view of huge investments to be made in increasing quantum of water supply, an efficient use of the available water is advocated by water management concept. Under water management, issues related to

- maximising production in relation to consumption and
- minimising wastage

will be considered.

We shall first examine in detail the aspects that have to be taken into consideration while thinking of solution for the problems associated with water conservation and management.

4.7.1 Features Related to Water Availability and Usage

We shall discuss the following features in this regard.

a) Regional imbalance in the availability of water resources

We have already explained that among the various regions of our country, there is

- variation in rainfall (in Subsec. 4.4.1),
- imbalance in river water availability (in Subsec. 4.4.3), and
- imbalance both with respect to availability and utilisation of groundwater (in Subsec. 4.4.4).

b) Limited availability of usable water

As mentioned earlier, our country gets around 400 mha m of fresh water both from rainfall and snowfall. The whole of it cannot be put to use due to the following reasons:

- i) Loss due to evaporation, plant transpiration, percolation into soil and interception
- ii) Constraints due to the following topographical and hydrological features:
 - rain along the hill slopes mostly get washed away (as along western ghats)
 - absence of proper storage systems like tanks results in flow of rainwater into drainage
 - capacity of dams built so far are enough only to hold around 20% of rainwater while 80% is let off.

As per the Ninth Five Year Plan document, only 69 mha m of surface water can be put to beneficial use every year. Also out of groundwater, only 43.2 mha m is usable every year. Hence a total of 112.2 mha m is the total usable water.

c) Population increase and decreasing annual per capita availability of water

The population in our country has increased from 36.11 crores in 1951 to 84.34 crores in 1991 and to 102.7 crores in 2001. The direct result of population increase is the decrease in annual per capita availability of water. It is possible to calculate annual per capita availability of water as follows:

The annual run off in the river system of the country has been assessed as 1869 km³ and it is to be divided by the population to get the above parameter.

$$\left(\begin{array}{l} \text{Annual per capita} \\ \text{availability of water} \end{array} \right) = \frac{\text{Annual run off in the river system}}{\text{Population}} = \frac{1869 \times 10^9 \text{ m}^3}{\text{Population}} \quad [1 \text{ km}^3 = 10^9 \text{ m}^3] \quad \dots (4.5)$$

Accordingly the annual per capita availability of water in our country has decreased from 5176 m³ in 1951 to 2216 m³ in 1991 and to 1820 m³ in 2001. You check these values using Eq. 4.5 and the population data given above. As per 1991 data, the global annual per capita availability was 9231 m³. It has been assessed that a per capita water supply of 2000 m³ is minimum and 1000 m³ is very low. India is likely to reach a condition known as ‘water stress’ from 2007 onwards. The water stress condition will affect the economic development besides leading to ecological degradation. In 1990, India was ranked at the 42nd position among 100 countries in relation to per capita annual water availability.

d) Problems associated with construction of big dams

The construction of big dams is considered beneficial due to the following aspects:

- a) generation of hydroelectricity
- b) increased irrigation facility and control of floods
- c) improved municipal and industrial water supply.

At the same time, the big dams have many adverse ecological and socio-economic implications also as given below:

- deforestation, soil erosion and landslides (due to clearance of site for the dam)
- seismic activity (i.e. being more susceptible to earth quakes)
- sedimentation (i.e. deposition of large amount of silts in the dam)
- water logging and salinisation
- displacement of inhabitants (along with loss of their main occupation related to agriculture, and local resources)
- epidemic eruption of water-borne diseases.

Paradoxically, it has been mentioned that as a result of construction of major dams, the total flood - prone area of India has doubled from 20 mha to 40 mha in recent times. Further, there is a substantial increase in the cost of construction of big dams due to corrective action to be taken in relation to adverse factors mentioned above.

4.7.2 Need for Conservation and Management of Water Resources

We now explain the need for conservation and management of water resources.

a) Increase in demand for water for irrigation, domestic, industrial and other uses

The increase in population evidently results in increased demand for more drinking water, food, buildings, consumer articles *etc.* These demands call for more facilities for agricultural production, industry *etc.* all of which again require huge amount of

We shall explain the terms, water logging and salinisation, in Subsec. 4.7.2.

water supply as mentioned in Sec 4.1. Based on population data, total fresh water demand for irrigation, domestic, industrial, cattle and other purposes is estimated to be 105 mha m in the year 2025. It denotes that more than 90% of utilisable potential of water resources (of 112.2 mha m) of the country has to be put to use.

b) Water scarcity, women illiteracy and rural backwardness

Water supply pattern for public consumption is highly nonuniform when we compare urban and rural sectors. In cities like Delhi and Bombay, per capita water supply is much higher as compared to many towns and villages.

Further, the anomaly is that those who live in cities or near the canal system get water mostly on government subsidy; on the other hand, others have to pay heavily for obtaining water for irrigation or for domestic use. Or else, they have to spend considerable time in fetching water. It must be mentioned that consequent to scarcity of drinking water supply, the rural women starting from girlhood have to spend considerable time in fetching water. In some cases, they have to walk even for a few kilometers to bring water. It has been identified as one of the causes, apart from other socio-cultural reasons, for illiteracy and backwardness of rural women, in particular. It is also mentioned that assured water supply could improve school attendance especially with reference to girl children. It is stressed that greater access to water supply can improve the living conditions in rural areas.

c) Need to enhance hydroelectric power production

We are generating 30% only out of the estimated hydroelectric potential of 75,400 MW. There is a huge untapped potential for hydroelectric power generation.

d) Need for control of floods and drought

The extreme variation in water availability with respect to seasons and locations is illustrated by the occurrence of droughts and floods in different parts of the country during every year. A total area of 40 mha is prone to floods. Besides crop losses, floods cause considerable damage to houses and property as also loss of human and cattle lives. During the last 25 years, on an average, 9.3 lakh houses were damaged every year along with loss of 1240 human lives and 77,000 cattle. Floods occur due to intervention in the path of rivers, obstruction of the natural drainage and invasion of the flood plain as a result of population growth. Besides the direct losses, floods destabilise economic activity also. The agricultural activities for the subsequent seasons are also affected. Note that Brahmaputra basin is particularly prone to floods.

Flood plain:
Level land that may
be submerged by
floodwaters.

Droughts are periods over which precipitation is much below normal level. Wherever rain water is the major source of water, lack of rainfall even for a few months could be disastrous. Agricultural drought arises when soil moisture gets much depleted and the yields are significantly reduced. In our country, nearly 16% of the total area of our country is drought - prone and it directly affects 12% of the population.

e) Development of fisheries, inland water transport and tourism

The fish resources of India are extremely rich. Over 1200 species are found in river and coastal water systems; one third of them is commercial. Poor maintenance of the country's water resources leads to depletion of fish catches. Our country has about 14,500 km of navigable waterways, which comprises of rivers, canals, backwaters *etc.* Only 3000 km stretch is used for transport purposes now. The river navigation is particularly a cheap mode of transport for moving cargo in bulk. It is one of the areas having high potential of development, which again depends on maintenance of water resources. In the development of tourism, the water bodies have a vital role to play.

Water

Water use efficiency =
(Mass of dry matter
produced via
photosynthesis)

(Mass of water used
during its growth)

In Subsec. 5.5.3 of the next unit, you will study in detail the adverse effects of algal growth on water systems.

f) Need to optimise use of water

As in the case of money, water saved is water procured. We can optimise the use of water by

- i) minimising loss due to evapotranspiration and
- ii) minimising wastage in agricultural and domestic sectors.

Let us discuss the second aspect in detail. In agricultural sector, the water use efficiency by conventional irrigation (known as flood irrigation) is not more than 45%. Studies indicate that India uses about three times as much water per acre as Japan and, produces only one-third as much rice. Also excess seepage leads to water logging and salinity, which we shall discuss shortly. The water losses in domestic supply system in the cities of developing countries are generally 50% and above. The wastage of water occurs due to

- faulty supply lines
- unplanned plumbing
- usage of flushing system, washing machines, shower heads, taps *etc.* that are not designed keeping in view the economic usage of water.

We must bear in mind the cost involved in procuring precious water from distant sources and also in purifying it. Further, excess water going through the drains requires further expenditure in sewage disposal. There is a need for taking measures for recycling of wastewater.

g) Need to protect the environment and ecosystems

Proper handling of the water resources is quite essential for maintaining clean environment. The environmental impacts of excess use of groundwater and construction of big dams have been mentioned earlier. Proper measures need to be taken in relation to these aspects.

- For providing water supply to cities, water is drawn from river systems in distant location. Protective action must be taken to ensure that ecosystem is not affected due to usage of paths other than natural routes followed by the river systems.
- Let us explain the bad effects of water logging and salinisation.
 - Excess stagnant water leads to accumulation of water around the roots of plants. Also underground water level may rise. The airflow to the root system of plants may get affected. The condition may be conducive for the growth of algae too that could spoil water quality. These aspects are collectively known as water logging.
 - In dry climate, water near the surface evaporates causing deposition of damaging layers of salts on the soil. This process is known as salinisation and it affects growth of crops.
- Regarding the health hazards arising out of mixing of untreated domestic sewage and industrial effluents with river systems and, the protective measures to be taken in this regard, you shall study in Units 6 and 14 of this course.

SAQ 6

What are the adverse socioeconomic implications of constructing big dams?

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4.8 METHODS OF WATER CONSERVATION AND MANAGEMENT

Now we shall discuss the methods of water conservation and management.

1) Conservation of surface water

In order to conserve the surface run off, the following methods are suggested.

a) *Construction of dams with due concern for environment*

You have studied in Subsec. 4.7.1, the environmental hazards associated with the construction of big dams. As protective measures, Govt. of India has come up with legislations such as Environmental (Protection) Act, 1986 and Environmental Impact Assessment Notification, 1994. Under these provisions, any project needs to be begun only after getting environmental clearance from the concerned government agencies. Also environmental safeguards are to be undertaken. Taking the help of Botanical Survey of India, steps are to be undertaken to develop botanical garden to conserve rich biodiversity. Biological measures such as plantation, pasture development *etc.* are to be undertaken as measures of compensatory afforestation. Special care is to be taken towards fish breeding facilitating upstream and downstream migration of fish. Socioeconomic survey of the people likely to be affected by the projects is to be carried out. The resettlement and rehabilitation plan is to be prepared in consultation with the representatives of the local people. Special care is to be taken towards housing, employment, reconstruction of culturally important places, vocational training, water supply, community facility, fuel arrangement *etc.* It must be mentioned that all these result in huge expenditure.

Considering the disadvantages of constructing big dams, it is suggested that smaller dams and mini-hydroelectric projects could be constructed for water supply and power generation at various locations. These are to be built and managed by the user groups. A cluster of small reservoirs could permit longer periods of flow of water. Due to spread of reservoir system, flood control could also be more effective.

b) *Rainwater harvesting*

Rainwater harvesting is the deliberate collection and storage of rainwater on natural or man made catchment areas. The catchment includes

- i) artificially prepared land surface
- ii) hill slopes or rocky surfaces
- iii) roof tops of buildings.

The first two types will be taken up here and the third will be discussed shortly under groundwater conservation.

i) *Catchment on artificially prepared land area*

The rainwater harvesting structures such as ponds, lakes *etc.* built in historical times on artificially prepared land surfaces exist even now in many parts of the country. Along with the British rule started the neglect of pond irrigation system. The British Government abolished the system of local tax collection for tank repair and maintenance. Without adequate funds and powers, the local communities lost interest in water resource management. The damage caused is quite high such that even now the system is not effectively reactivated. The pond irrigation needs to be properly nurtured by

- removal of silt
- ensuring water quality by preventing excess growth of algae, water hyacinth *etc.*
- preventing construction activities and encroachments on the pond sites
- putting a legal ban on discharge of domestic waste, effluent *etc.* into the ponds.

Silt gradually gets deposited on the ponds over a period of time and causes water to spill over the banks. It shortens the useful life of a pond system.

ii) *Rainwater harvesting for hill area*

In hills, a contour of steps could be arranged so that each step could store rainwater. Fig. 4.2 is a snap from Indian Council of Agricultural Research Centre Unit at Barha Pani, Meghalya, in which contour trenches and bench terraces are illustrated. Contour trenches are successive pits made for storing water. The bench terraces are stepwise cut in the slope of the hill such that considerable landspace is left in each step for retaining rainwater. This technique is especially suitable for areas having rainfall of considerable intensity spread over a large part as in Himalayan areas, North-eastern States and Andaman and Nicobar Islands. The benefits of rainwater harvesting structures are given below:

- improves groundwater level and its quality
- helps in avoiding droughts
- reduces soil erosion in rocky areas as the surface run off is reduced
- decreases the flooding of roads which generally happens during rainy days
- saves electrical energy in lifting groundwater from deeper levels
- helps in increasing the extent of cultivable land area, agricultural yield, fodder production, cattle breed capacity and, in short, improves rural economy.



The voluntary organisations like *Tarun Bharat Sangh* of Alwar have been doing remarkable work in Rajasthan reviving traditional methods of rainwater harvesting. Their efforts have helped in improving water availability for human consumption, agricultural activities and cattle breeding. Rainwater harvesting has resulted in rebuilding rural economy and developing self reliance in many villages of Rajasthan.

Fig. 4.2: Catchment on hill slopes – note a contour trench and bench terraces.

2) Groundwater conservation

In Subsec. 4.4.4, we have explained the need to conserve groundwater. Some of the techniques of groundwater management and conservation are given below.

a) Artificial recharge

Artificial recharging is done by digging recharge pits or wells; these wells admit water from surface to fresh water aquifer. In order to recharge groundwater, government recently has made rainwater harvesting as a legal requirement. The Central Groundwater Board and other government organisations have come up with models for replenishing the groundwater in rural and urban areas through rainwater harvesting.

While taking steps for rainwater harvesting, its limitations given below must also be taken into consideration:

- breeding of mosquitoes is a common problem
- studies indicate that rainwater stored for a long time could develop bacterial growth
- rainwater harvesting arrangement needs capital investment.

Monthly application of chlorine or bleaching power is considered sufficient to deal with mosquito and bacterial growth problems. The stagnation of water need to be avoided by providing proper slope towards the recharge wells. It must be borne in mind that recurring costs of maintenance are quite low. Using Eq. 4.6, you can calculate rainwater volume that can be collected.

$$\left. \begin{array}{l} \text{Volume of rainwater} \\ \text{that can be collected} \end{array} \right\} = \left\{ \begin{array}{l} \text{Rainwater} \\ \text{volume} \end{array} \right\} \times \left\{ \begin{array}{l} \text{water} \\ \text{collecting} \\ \text{efficiency} \end{array} \right\} \quad \dots (4.6)$$

Usually rainwater collecting efficiency is a fraction with value less than 1. By multiplying rainwater collecting efficiency by 100, we can get rainwater collecting efficiency as percentage.

Example 2

Calculate the volume of rainwater that can be collected annually due to rainfall over only the land area of our country. Use the data given in Example 1 in Sec 4.2. Assume that water-collecting efficiency is $\frac{1}{2}$.

Using Eq. 4.6 and the data mentioned above, annually 167.2 mha m or $1.672 \times 10^{12} \text{ m}^3$ rainwater can be collected.

b) Percolation tank method

Percolation tanks are constructed across the watercourse for artificial recharge. Many states like Maharashtra, Rajasthan, Andhra Pradesh and Karnataka have used percolation tanks. The studies conducted in Maharashtra indicates that on an average each percolation tank

- exerted influence over an area of 1.2 km^2 ,
- caused a rise of 2.5 m in groundwater level and
- led to annual artificial recharge of 1.5 ha m.

Conjunctive use of groundwater and surface water

It is emphasised that both surface and groundwater resources can be viewed as an integral resource. Their development and usage must be done in a coordinated way to prevent water logging and soil salinity and to provide adequate and assured water supply for crops. The Central Water Commission and the Central Groundwater Board have prepared guidelines for the conjunctive use of both the resources.

3. Catchment area protection

Catchment area protection plans are usually called watershed protection plans. These are adopted as an important measure to conserve and protect the quality and quantity of water in a watershed. The run off water is withheld in the hilly area. This will delay the run off so that greater time is available for water to seep underground. Such methods are used in northeastern states. Afforestation in the catchment area is also adopted for water and soil conservation.

Watershed:

An area of high ground which divides two or more river systems so that all streams on one side flow into one river and those on the other side flow into a different river.

4. Interbasin transfer of water

In Subsec 4.4.3, we have discussed in detail how northern and eastern regions are water-rich and, southern and western regions have comparatively low water resources. It is realised that interlinking of river basins is a necessary step towards equitable distribution of water resources. The Ministry of Water Resources has formulated a National Perspective for Water Development in 1980 comprising of two components.

a) *Himalayan rivers component*

The main features are given below:

- i) Conserving the monsoon flow for flood control, hydroelectric power generation and irrigation
- ii) Interlinking of Brahmaputra, Ganga and Mahanadi systems
- i) Providing additional irrigation facilities to Haryana, Rajasthan, Punjab and Gujarat
- ii) Providing additional flow to Kolkatta Port and facilitate inland navigation facilities.

b) *Peninsular rivers component*

Under this scheme, it is proposed to transfer the surplus waters from the Himalayan rivers through the interlinking of Mahanadi – Godavari – Krishna – Pennar – Cauvery. This will provide additional irrigation facilities to Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu. Further, interlinking of west and east flowing rivers in Kerala is also planned to bring additional irrigation to Kerala and Tamil Nadu. It is proposed to interlink a few small rivers flowing along the west coast north of Bombay and south of Tapi and, the southern tributaries of the Yamuna like the Chambal and the Ken.

A few basic challenges in implementing interbasin transfer are given below:

- i) Serious political issues arising out of regional consideration need to be resolved
- ii) Heavy financial investments are needed
- iii) Pooling of technical expertise is to be done.

It is often said that due to delayed decisions in the interstate sharing of waters, crops in approximately 20 mha of cultivable land are heavily affected. Special tribunals are appointed to decide the sharing of river waters among the states.

River water sharing with the neighbouring countries

Regarding the need for cooperation at the international level, we shall throw some more light using the following observations made by B.G. Verghese in his book, *Waters of Hope*: “The Ganga, Brahmaputra and Barak share a large interlinked basin spread over five nations -India, Bhutan, Nepal, Bangladesh and China’s Tibet. In spite of the fact that these river systems carry 214 mha m of water to the sea and, possess a hydroelectric potential of 2,50,000 MW, it is ironical that the people living in this basin represent the single largest concentration of one of the poorest beings living amidst the plenty of natural resources. Proper management of water resources in this region could result in improvement of standard of life in this region. In short, water is a resource to this part of the world in the same sense that petroleum is to the middle east.” In order to settle water disputes in this region, international bodies like Indo-Bangladesh Joint Rivers Commission have been set up. For sharing the Indus river water, India and Pakistan have created the Permanent Indus Commission.



a)



b)

Fig. 4.3: a) Drip irrigation through well-laid out hose pipes along the field
b) Sprinkler irrigation.

5. Methods based on modifications in agricultural practices

By making suitable changes in agricultural practices, water can be used more efficiently. The following are some of the suggested measures.

a) *Adoption of drip and sprinkler irrigation*

Surface irrigation method, which is traditionally used in our country, is unsuitable for water scarce areas, as large amount of water is lost through evaporation and percolation in this method. Drip irrigation and sprinkler irrigation are superior to surface irrigation. In drip irrigation, water pipes running through the land contain small holes which emit the water directly to the soil adjacent to the root system. This method is particularly useful in arid zones. In sprinkler method, water is sprinkled using water jets moving in different directions in the field. It has been estimated that water use efficiency is 95% for drip irrigation, 45% for surface irrigation and 75% for sprinkler irrigation. Drip irrigation facility can be done even using poor quality water or saline water since direct contact between water and leaves is avoided. Certain crops like cotton, tomato and melon tolerate salinity equivalent to 0.47% NaCl. The only condition is that cultivation is to be done in sandy or loamy sandy soils. The constant flushing of the roots helps in removal of salts from root system. Drip irrigation allows the use of minimally treated sewage water since water is delivered to the ground minimising health risks. In Figs. 4.3 (a) and (b), drip irrigation and sprinkler irrigation are illustrated; the former pertains to a field in Israel treated by drip irrigation.

Loamy sandy soil:
A sandy soil having decayed vegetable matter that makes it better than sand for growing crops. Also refer to Unit 2 of Block 1.

Water

Dry land crops have low transpiration rate.

Whenever chemical methods are used for reducing evapotranspiration, their environmental impact is also to be carefully analysed.

Israel utilises modern technology to locate, conserve and manage its limited water resources:

- 1) For location of water resources, neutron scattering devices are used, which emit high speed neutrons into the soil. Any neutron that comes into contact with hydrogen atom, one of the constituents of water molecule – shows up signals in the special device used giving a measure of the soil moisture content.
- 2) Irrigation is controlled by computers, which are programmed to operate drip and sprinkler lines.

b) Management of growing pattern and selection of crop varieties

In water scarce areas, the crop selection should be based on the efficiency of a crop to utilise water. Some of the plants suitable for water scarce areas are (i) plants having shorter growth period (ii) high yielding plants that require no increase in water supply (iii) plants with deep roots and (iv) plants which cannot tolerate surface irrigation. In water scarce areas, crops such as wheat, paddy and sugarcane are to be avoided. Instead, low water requiring crops (dry land crops) such as coarse grains, millets, edible oil seeds and pulses have to be cultivated. Certain crops, which adopt to dry or desert conditions have a tendency to reduce the water loss in transpiration.

c) Nutritional management

Adjustments in plant nutrients can play a vital role in improving water efficiency. For instance, potassium helps in increasing the water use efficiency. Experiments conducted at the Water Technology Centre, Coimbatore, indicated that foliar application of 0.5% potassium chloride can reduce the moisture stress in soyabean, sorghum and groundnut.

d) Reducing evapotranspiration

By reducing the evaporation from soil surface and transpiration from the plants, evapotranspiration loss can be reduced. In arid zones, where low humidity prevails, considerable amount of water is lost in evaporation from soil surface. This can be prevented by spreading leaves, straw *etc.* on the ground around the plants. Nonporous materials like papers, plastic foils or metal foils can also be spread over the fields for preventing loss due to evapotranspiration. Further, using windbreaks, air movement over a crop can be reduced. Other methods are given below:

- application of chemicals that reduce transpiration
- destroying the unwanted plants from the farm
- removing unproductive leaves from the crop
- enclosing crops in such structures so that the transpired water can be collected and reused
- applying monomolecular films over water bodies

6. Methods based on modifications in domestic and industrial uses

We shall discuss three methods in this context.

a) Recycling of wastewater from domestic and industrial sources

The wastewater from industrial and domestic sources can be reused after proper treatment for irrigation and recharging groundwater. While using recycled water, water quality should be appropriate for the purpose for which it is to be used. If recycled water is of high quality, it can be used for industrial or even municipal supply. The parks and nearby agricultural lands can be irrigated using treated municipal wastewater. Many industrial units are already using the wastewater after proper treatment.

b) Conservation of water in domestic usage

The municipal and panchayat administration units must try to create public awareness about the need for economic usage of water. Water saving plumbing devices like air-assisted showerheads, flow-limiting faucets (taps), front loading washing machines and air assisted toilet cisterns are available for use.

c) **Incentives for water conservation**

There is lack of incentive for efforts taken to conserve water. It also leads to overuse of water. Observance of conservation measures for irrigation and domestic water use should be encouraged through tax concession.

7. Introduction of modern technology

Some of the methods of modern technology used towards water conservation and management are given below.

a) **Locating aquifers using satellites**

The satellites can give us wealth of information regarding location of new aquifers, accumulation of winter snow in mountains, soil erosion detection, pollution levels in water bodies *etc.* Using these data, it is also possible to provide early warning about floods and drought conditions.

b) **Fresh water from brackish water and seawater**

Many desalination methods are being used for converting brackish water into drinking water. We shall discuss the principles of only three methods.

Brackish water:
Water containing considerable dissolved salts.

i) **Multiple effect distillation**

The principle used is that boiling point of a liquid is lowered, if pressure is lowered. Several condensers – evaporators are arranged in series and the vapour from one is used to boil water in the evaporator at the next lower pressure by its condensation. Successive distillation leads to production of pure water. To bring down the cost, this plant is operated in conjunction with low pressure steam obtained from a thermal power station or an industrial process.

ii) **Reverse osmosis**

During osmosis, water passes into a concentrated solution from a dilute solution when separated by a semipermeable membrane. In reverse osmosis, water passes through a plastic membrane from the concentrated solution to a dilute solution due to application of pressure. Specially treated cellulose acetate, polymethacrylate *etc.* membranes are used. The running cost for a reverse osmosis plant is low due to low energy consumed, membrane durability *etc.* It is advantageous, since it can remove ionisable and nonionisable matter as also colloidal and high molecular weight organic matter.

In reverse osmosis, water moves through semipermeable membrane leaving the dissolved ions behind. In electrodialysis, the cations and anions move through the selectively permeable membranes leaving pure water behind.

iii) **Electrodialysis**

Low electrical conductivity of pure water and the migration of ions of dissolved solids in presence of an applied electric current are made use of in electrodialysis. It is also a membrane technology used for pulling out the ions from the brackish water. Two types of membranes are used – one permeable only to cations and another permeable to anions. Two types of membranes are kept alternatively for large-scale purification of brackish water. A polystyrene polymer with sulphonic acid group is used as cation selective membrane while anion selective membrane has quaternary ammonium group. The seawater gets desalinated due to movement of cations and anions through the membranes selective to them.

SAQ7

State some measures to safeguard the socioeconomic aspects during construction of big dams.

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4.9 SUMMARY

Water is one of the resources of a country. Agricultural production, industrial growth and public health - all these depend on availability of water in good quantity and quality. In this unit, we have discussed in detail the river water and groundwater resources of our country. A short description of hydrological cycle is provided highlighting the interaction of sunlight and wind with water bodies. The constant interchange of water among its three phases and its effect on climate, mineral formation, carving out of valleys and the delta, power production and occurrence of floods and drought are explained. The crucial issues related to water conservation and management are examined from the point of view of population growth and economic development. The aspects associated with interstate and international sharing of water are indicated. The sociological aspect of rural water scarcity as a contributing factor for women illiteracy and rural backwardness is stated. The methods that could be followed for water conservation and management are explained in detail.

In this unit, we gave a dominant place to the quantitative aspects of water resources. In the next two units of this block, we shall examine quality aspects of water resources.

4.10 TERMINAL QUESTIONS

1. In what way does the low quantity water flow in a river affect the environment?
2. State the importance of weathering reactions.
3. Explain how water helps in regulating the temperature conditions in the earth.
4. Can there be stratification in a flowing river? Explain.
5. The Indian population was 68.63 crores in 1981. Calculate annual per capita water availability during that year.

$$\text{Annual run off} = 1869 \times 10^9 \text{ m}^3.$$

6. State the adverse effects of water scarcity in the rural areas that are not served by a canal system.
7. Explain the terms, water logging and salinisation.
8. What protective measures are needed to reactivate the ponds?
9. What are the main health problems associated with rainwater harvesting? What remedial measure can be adopted for the same?
10. State the difference between reverse osmosis and electro dialysis.

4.11 ANSWERS

Self-Assessment Questions

1. Area = $1483 \text{ km}^2 = 1.483 \times 10^9 \text{ m}^2$

$$\left. \begin{array}{l} \text{Using Eq.4.3,} \\ \text{the volume of} \\ \text{rainwater that falls} \\ \text{annually} \end{array} \right\} \begin{array}{l} = 1.483 \times 10^9 \times \frac{60}{100} \text{ m}^3 \\ = 8.9 \times 10^8 \text{ m}^3 \\ = 8.9 \times 10^{-2} \text{ mha m} \\ = 8.9 \times 10^{11} \text{ litres} \end{array} \quad \text{(Using Eq. 4.2)}$$

2. The heaviest rains occur along north-eastern states and along the west coast. In contrast, many other parts of the country like Western Rajasthan, part of Gujarat, most of Jammu and Kashmir have much less rainfall. Most of the rainfall occurs in our country in around 200 hours and, half of it in 30 hours. Consequently, the run-off is high.
3. Over utilisation leads to deterioration of water quality due to lowering of water level and passage of seawater into the groundwater source (where the source is near the sea). Usage of poor quality water can have adverse effect on living beings and agriculture.
4. Water loss from a vegetated area takes place both by evaporation and transpiration. It is termed evapotranspiration. Interception is the retention of precipitation by thick vegetation or by shrubs that is evaporated back to atmosphere.
5. Flow velocity and stratification are the two important factors. The flow velocity decides the solubility of gases like oxygen. Stratification indicates changes in temperature, chemical composition and biological properties down the layers.
6. The inhabitants are displaced. They have to lose their main occupation related to agriculture and local resources.
7. Socioeconomic survey of the people likely to be affected by the project is to be carried out. In consultation with the representatives of the local people, resettlement and rehabilitation plans are to be prepared. Special care is to be taken towards housing, employment, vocational training, water supply, community facility, fuel arrangement *etc.*

Terminal Questions

1. During dry seasons, there is not enough flowing water to carry the waste materials. The waste management need to be given a serious thought where dumping is done into monsoon fed rivers.
2. The weathering reactions are responsible for the formation of valleys and deltas and, for surface leveling of the seas through silt deposit. The minerals are formed by the chemical decomposition of rock materials by water.
3. The high heat capacity of water ensures that a large amount of heat is involved in heating or cooling process. So, intolerable extremes of cold and hot conditions are avoided in the earth.
4. A flowing river experiences thorough and continuous vertical mixing due to prevailing current and turbulence. Hence, stratification is not to be seen in such a river.
5. As per Eq. 4.5, annual per capita water availability must be 2723 m^3 .
6. The rural people who are away from the canal system have to pay heavily for obtaining water for irrigation or domestic use. Alternatively, the rural people, especially womenfolk, have to spend considerable time in fetching water. The water scarcity is cited as one of the reasons for illiteracy and backwardness of rural women.
7. The accumulation of stagnant water prevents airflow to the root system. It results in algal growth and spoils water quality. These are collectively known as water logging. In dry climate, water near the surface evaporates causing deposition of

Water

damaging layers of salts on the soil. This process is known as salinisation and it affects growth of crops.

8. The silt should be removed periodically. Measures must be taken to protect water quality by preventing the excess growth of algae, water hyacinth *etc.* The pond sites must be kept clear of encroachments. Domestic waste and effluents must not be discharged into the ponds.
9. Breeding of mosquitoes is a common problem. The rainwater could develop bacterial growth. Monthly application of chlorine or bleaching powder is considered sufficient to deal with these problems.
10. In reverse osmosis, water passes through the membrane leaving the ions behind; in electro dialysis, the ions are pulled out from the brackish water through the membranes leaving pure water behind.



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UNIT 5 WATER CHARACTERISTICS

Structure

- 5.1 Introduction
 - Objectives
- 5.2 Physical Properties of Water Systems
- 5.3 Chemical Characteristics of Water Systems
- 5.4 Biological Properties of Water Systems
- 5.5 Factors Affecting Water Quality
 - Natural Factors
 - Human Activities
 - Biological Transformations
- 5.6 Solubility of Gases in Water
- 5.7 Carbonate Equilibrium
- 5.8 Summary
- 5.9 Terminal Questions
- 5.10 Answers

5.1 INTRODUCTION

In Unit 4, you studied about the various sources of water. In this unit, you will get a detailed description of the characteristics of water systems. We shall discuss the physical, chemical and biological characteristics of water systems. While discussing these aspects, their relationship to the constituents in water is also indicated. The natural, human and biological factors those are responsible for the constituents of water are examined in a detailed way. Keeping in view the importance of oxygen and carbon dioxide to aquatic life, the solubility of gases is discussed in detail. The study could help you in understanding the conditions favourable for aquatic life. Towards the end of the unit, different stages of carbonic acid – bicarbonate – carbonate equilibria are discussed. Efforts have been made to relate the theoretical concepts discussed in this unit to the experiments that you will be performing in the practical component of this course. In Unit 6, you will learn about the water quality criteria for different uses.

Objectives

After studying this unit, you should be able to:

- discuss the physical, chemical and biological characteristics of water systems,
- relate the characteristics of a water system to its contents,
- explain the natural, human and biological factors that are responsible for the constituents found in water systems,
- state the factors that decide the solubility of gases in water, and
- describe the equilibria involving carbonic acid, bicarbonate ion and carbonate ion.

5.2 PHYSICAL PROPERTIES OF WATER SYSTEMS

In this section, we shall discuss the physical characteristics, which are used as parameters to specify the quality of particular type of water.

i) Turbidity

Turbidity is defined by the American Public Health Association as follows: “Turbidity is the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample”. Turbidity is mainly caused by the presence of insoluble materials in suspended and colloidal forms. The insoluble materials consist of inorganic solids (such as clay, silt and other soil

The size of particles of one of the phases must be in the range 1 to 1000 nm for a colloid. In coarse suspensions, the particle size is always larger than 1000 nm, whereas dimensions of the solute in true homogeneous solutions are less than 1 nm. For a clear understanding of colloids and their properties, you are advised to go through Unit 20 of Physical Chemistry (CHE-04) course.

Water

Aesthetics refers, in general, to the study or theory of beauty and of the psychological responses to it. Aesthetics of water refers to clear water without any offensive smell or salty taste so that one is inclined to use it for drinking or cooking or recreation.

Turbidity and intense colour of water affect light penetration through it.

Lack of light penetration could reduce photosynthetic activities and dissolved oxygen content in water. The latter aspect can have adverse effect on aquatic life.

components), organic materials, microorganisms, plant fibres, wood ashes, and coal dust. These are common constituents of surface waters arising due to factors that will be explained in Sec. 5.5. Because of the filtering capacity of the soil, suspended material is generally not found in groundwater. It is usually accepted that suspended matter is the fraction that will not pass through 450 nm pore diameter filter. Turbidity varies according to seasons and rainfall pattern. For instance, the silt content increases during rainy season as discussed in detail in Subsec. 5.5.1. Consequently river water is more turbid during rainy season.

Turbidity can be determined in the water body itself by sechhi disc. The Sechhi disc is a circular disc of 20-30 cm diameter, coloured white or with black and white sectors. To measure turbidity of a water body, the disc is lowered in water on a calibrated cable until it just disappears. The depth at which it disappears, and just reappears, is recorded as the depth of transparency. Turbidity so measured is given in **jackson turbidity unit (JTU)**. For instrumental measurement in the laboratory, nephelometry method is employed which measures the intensity of light scattered by suspended particles. The unit of turbidity measured in this way is **nephelometric turbidity unit (NTU)**. Turbidity is an important parameter to be considered in municipal water supply due to aesthetic reasons that will be explained in the next unit. Turbidity value gives indication about the availability of light in water. It is the main factor controlling photosynthetic activities in water. In Subsec. 5.5.3, you shall study how lack of light penetration could lead to biodegradation of organic matter.

ii) Colour

Like turbidity, the colour of a water sample also determines the light penetration in water. It gives the visible evidence of contamination in water, and its acceptability for any use. Further, dark coloured water absorbs heat to a large extent. The visible colour of water is the result of the different wavelengths not absorbed by the water itself. Again it is due to the dissolved and particulate substances present. It is possible to measure both true and apparent colour in water. Natural minerals (such as ferric hydroxide) and organic substances give true colour to water. The suspended matter causes apparent colour due to refraction and reflection of light. Polluted water may, therefore, have quite a strong apparent colour. Colour can be measured by the comparison of water samples with a series of dilution of a solution containing known amounts of potassium chloroplatinate (K_2PtCl_6) and crystalline cobaltous chloride. The unit is called platinum - cobalt unit. The colour of natural water may vary from less than 5 in very clean water to 300 in dark peaty waters.

iii) Odour

Odour in water systems is usually the result of volatile inorganic and organic compounds such as hydrogen sulphide, ammonia, mercaptans *etc.* Decaying aquatic plants or organic matters produce these foul smelling gases during the process of biodegradation; it is explained in Subsec. 5.5.3. Industrial and human wastes in water can also cause odour directly or as a result of biological activities. Usually, the presence of an odour suggests higher than normal biological activity. Tropical climate increases the rate of production of odour causing metabolic and decay products. Different pH may also affect the rate of chemical reactions leading to the production of odour. Organic compounds, inorganic chemicals, oil and grease can impart odour to water. Excess chlorination leads to smell of chlorine in drinking water.

Odour is a simple test for checking the suitability of drinking water, since the human sense of smell is far more sensitive up to low concentrations of substances than human taste. Odour can be measured in terms of the greatest dilution of a sample, or the number of times a sample has to be diluted with odour-free water, that yields the least definitely perceptible odour. Such methods suffer from the subjective variability of different human judges.

iv) Taste

Taste is generally associated with odour. Hence, the inference drawn during study of odour holds good for taste also. However, in some cases tastes are not associated with odour. The dissolved mineral matter produces taste but not odour. For example, a bitter taste may be due to presence of iron, manganese, aluminium, sulphate or excess lime. Water containing unusual salt contents will have a brackish taste. Dissolved gases and minerals make the water potable. It is reported that the most palatable waters are those containing nitrates and carbonic acids.

v) Temperature

The temperature of a water body decides to a large extent its biological activities. Cooler water has a wider diversity of biological species. At lower temperature, the biological activities become slower. An increase in 10°C is usually sufficient to double the biological activities, if essential nutrients are present. At elevated temperature, due to increased metabolic rates, organisms that are more efficient at food utilisation and reproduction flourish, while others decline and perhaps get eliminated. Temperature changes also affect the reaction rates and solubility level of chemicals. Most chemical reactions involving dissolution of solids are accelerated by increased temperature. The solubility of gases, on the other hand, decreases as the temperature increases. Because aquatic life and biological oxidation of organics in water body are dependent on adequate supply of dissolved oxygen, decrease in oxygen solubility is undesirable.

The variation in density of water with temperature is responsible for the stratification in lakes and reservoirs. Regarding stratification, you have already got an introductory idea through Sec. 4.6 of the last unit. Stratification refers to the formation of distinct layers within static water systems like lakes, ponds and reservoirs. Due to solar radiation, the upper layer gets heated up much more than lower layers. Due to lower density of warmer water than cold water, mixing does not take place and appreciable temperature difference exists between the layers. These layers consequently possess different chemical and biological characteristics. We may expect lower dissolved oxygen content in upper layers than in lower layers, since solubility of oxygen gas decreases with temperature increase. If the static water system has heavy growth of aquatic plants and algae, then the upper layer will have higher dissolved oxygen content during daytime. This is due to photosynthetic activity aided by the intensity of solar radiation reaching the upper level. Further, chemical species present in this level are in oxidised form. As a contrast, the waters at lower levels have less dissolved oxygen at daytime, since photosynthetic activity is less consequent to lower light intensity. Further, lower layers have chemical species in the reduced form. It is stressed that higher dissolved oxygen content is found at higher layers of static water system only during daytime. At night time, the situation may be quite different since only respiration (by all the aquatic species) takes place with oxygen consumption. It must be mentioned that with increase in temperature, there is decrease of surface tension and viscosity of water. Next, let us see the effect of all these three characteristics on electrical conductivity of water.

vi) Electrical conductivity

The electrical conductivity of a water system is related to its total dissolved solids. Since it is an easily measurable parameter, it is a very useful indicator to judge the water quality. The electrical conductivity of pure water is quite low. With increase in temperature, the conductivity of pure water increases from its value of $4.5 \times 10^{-8} \mu\text{S cm}^{-1}$ at 298 K to $7.6 \times 10^{-6} \mu\text{S cm}^{-1}$ at 359 K. The reason can be stated as follows. The combined effect of decrease in density, surface tension and viscosity of water with increase in temperature results in increase of mobility of the cations and anions. This means increase in mobility of H^+ and OH^- ions in case of high purity water. The overall effect is that the conductivity of water and hence, its corrosive character are

Let us see how temperature affects the density of water. The density of water increases from 273 K to 277 K and then decreases; a unique phenomenon among liquids. That a maxima occurs shows the operation of opposing effects. Increase of temperature results in increase of volume due to expansion; so density must decrease. But between 273 K and 277 K, decrease in volume due to breakage of hydrogen bonds is more than the increase in volume due to expansion. The net result is decrease in volume and increase of density in this temperature region.

The electrical conductivity is expressed in microsiemens per centimeter or $\mu\text{mho cm}^{-1}$ ($\mu\text{S cm}^{-1}$) units.

$$1 \mu\text{S cm}^{-1} = 1 \mu\text{mho cm}^{-1}$$

Water

Usually, a conversion factor is employed to express electrical conductivity in terms of amount of dissolved solids. Depending on the type of sample, this factor varies from 0.55 to 0.9. The estimation of dissolved solids through measurement of electrical conductivity is one of the methods useful in checking the quality of effluent discharged (from the industrial units) or of the water coming out of the sewage treatment plants or effluent treatment plants.

Low electrical conductivity of water and the migration of ions of dissolved salts under an applied electric field are made use of in electro dialysis (See Sec. 4.8 of Unit 4), a method for purification of water.

more at higher temperature than at room temperature. This aspect is quite significant for thermal power plants.

The measurement of electrical conductivity also helps in classifying water systems based on quality as given in Table 5.1. The theoretical aspects of measurement of electrical conductivity are given in Sec. 18.5 of Unit 18 of this course. In Experiment 2, the procedure for conductivity measurement is discussed.

Table 5.1: Specific Conductivity vs. Water Quality.

Specific conductivity/ ($\mu\text{S cm}^{-1}$)	Water quality
Less than 250	Excellent
250 – 750	Good
750 – 2000	Permissible
2000 – 3000	Needs treatment
> 3000	Unsuitable for most purposes

(Source: Water Chemistry - Industrial and Power Station Water Treatment by K.S. Venkateswarlu, New Age International, 1996, New Delhi, p.11)

SAQ 1

State the effects of increase of temperature on the characteristics of water.

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5.3 CHEMICAL CHARACTERISTICS OF WATER SYSTEMS

In this section, we discuss the chemical constituents of water systems both in qualitative and quantitative terms. We first focus on the units used for quantitative characterisation. Remember, the water samples drawn from different sources contain various solute constituents in small amounts. **For all practical purposes, we can consider the water samples as dilute solutions of various constituents.** You must remember that the molarity (M) unit is not convenient, since the amounts of the solutes in water samples are much less. We generally express the concentration of water sample with respect to various constituents in parts per million (ppm) or parts per billion (ppb) unit. The following discussion will help you in defining these units and understanding the steps used in transforming molarity and mole fraction into ppm unit. You are advised to go through Sec. 10.3 of Unit 10 of Physical Chemistry Course (CHE-04) to have better understanding of the units used for expressing the concentration of the solutions.

The density of a water sample can be assumed to be 1 g cc^{-1} , if the constituents are present in low concentration. Such an assumption also helps us in expressing quantity of water in terms of litre unit instead of in kg unit since, $1 \text{ kg water} = 1 \text{ litre water}$. In other words, the mass of 1 litre (*i.e.*, 1000 cc) of water (the solution) is 1 kg (*i.e.*, 1000 grams).

- Parts per million (ppm)

One ppm means one part by mass of the dissolved constituent present in one million parts by mass of a solution.

$$\begin{aligned} 1\text{ppm} &= 1 \text{ milligram/kilogram (1 mg/kg)} = 10^{-3} \text{ g/litre} \\ &= 1 \text{ mg/litre} \end{aligned}$$

- Parts per billion (ppb)

It is defined as follows:

$$\begin{aligned} 1\text{ppb} &= 1 \text{ microgram/kilogram} = 1 \text{ microgram/litre} \\ &= 10^{-6} \text{g/litre} = 1 \text{ } \mu\text{g/litre} \end{aligned}$$

Note that 'micro' refers to 10^{-6} part and can also be represented by the Greek symbol, μ , which is to be pronounced as 'mu'.

- The following relationships can be used to convert molarity into ppm unit.

$$\begin{aligned} \text{Molarity} &= \frac{\text{Number of moles of a component}}{\text{Volume of the solution (in litre unit)}} \\ &= \frac{\text{Mass of the component (in gram unit)}}{\text{Molar mass of the component (in gram mole}^{-1} \text{ units)}} \times \\ &\quad \frac{1}{(\text{volume of the solution (in litre unit)})} \end{aligned}$$

Hence,

$$\frac{\text{Mass of the component (in gram unit)}}{\text{Volume of the solution (in litre unit)}} = (\text{Molarity}) \times \left(\frac{\text{molar mass of the component}}{\text{in gram mole}^{-1} \text{ units}} \right)$$

If the volume of the solution (*i.e.*, water sample) is 1 litre, we can write as follows.

$$\begin{aligned} &\text{Mass of a component (in gram unit) in 1 litre of a solution} \\ &= (\text{Molarity}) \times \left(\frac{\text{molar mass of the component}}{\text{in gram mole}^{-1} \text{ units}} \right) \end{aligned}$$

$$\begin{aligned} &\text{Mass of a component (in milligram unit) in 1 litre of a solution} \\ &= (\text{Molarity}) \times \left(\frac{\text{molar mass of the component}}{\text{in gram mole}^{-1} \text{ units}} \right) \times 1000 \end{aligned}$$

$$\begin{aligned} \text{i.e., Concentration in ppm unit} \\ &= (\text{Molarity}) \times \left(\frac{\text{molar mass of the component}}{\text{in gram mole}^{-1} \text{ units}} \right) \times 1000 \\ &\quad \dots (5.1) \end{aligned}$$

Water

- The following steps can be used to convert mole fraction of a solute component in aqueous solution into ppm unit.

Mole fraction of a particular solute component (x_i) =

$$\frac{(\text{Number of moles of the solute } i)}{\{(\text{Number of moles of solvent}) + (\text{Total number of moles of all solutes})\}} \dots (5.2)$$

Since the water sample is a dilute solution, the total number of moles of all solute components would be negligibly small as compared to number of moles of water, the solvent. Hence Eq.5.2 can be rewritten as

$$\therefore x_i = \frac{n_i}{n_{\text{H}_2\text{O}}} \dots (5.3)$$

In Eq. 5.3, x_i and n_i refer to mole fraction and the number of moles of the solute component i , whereas $n_{\text{H}_2\text{O}}$ refers to the number of moles of water, the solvent.

If we consider 1 litre of a solution, it is equivalent to 1000 g of water as mentioned earlier.

$$\therefore n_{\text{H}_2\text{O}} = \frac{\text{Mass of water}}{\text{Molar mass of water}} = \frac{1000 \text{ g}}{18 \text{ g mol}^{-1}} = 55.6 \text{ moles}$$

Using this in Eq. 5.3,

$$\left. \begin{array}{l} \text{number of moles of the} \\ \text{component } i (n_i) \text{ in 1 litre} \\ \text{of a solution} \end{array} \right\} = n_{\text{H}_2\text{O}} x_i = 55.6 x_i$$

i.e., Molarity of the solution = $55.6 x_i \text{ mole litre}^{-1}$

Using this relationship in Eq. 5.1,

$$\left. \begin{array}{l} \text{concentration of the} \\ \text{constituent in the solution} \\ \text{in ppm unit} \end{array} \right\} = (55.6 x_i) \left(\begin{array}{l} \text{molar mass of the component} \\ \text{in gram mole}^{-1} \text{ units} \end{array} \right) \times 1000$$

$$= (5.56 \times 10^4 x_i) \left(\begin{array}{l} \text{molar mass of the component} \\ \text{in gram mole}^{-1} \text{ units} \end{array} \right) \dots (5.4)$$

Example 1

The concentration of dissolved oxygen is found to be $3.125 \times 10^{-4} \text{ M}$ in a water sample. Express the dissolved oxygen content in ppm unit. The molar mass of O_2 is 32 g mol^{-1} .

Using Eq. 5.1,

$$\begin{aligned} \text{the dissolved oxygen concentration} &= 3.125 \times 10^{-4} \times 32 \times 1000 \text{ ppm} \\ &= 10 \text{ ppm} \end{aligned}$$

Example 2

If the molarity with respect to chloride ion in water is denoted as ' M_2 ', derive a general expression that is useful in calculating the concentration with respect to chloride in ppm unit. Use Eq. 5.1. The molar mass of chloride is 35.45 g mol^{-1} .

Using Eq. 5.1,

$$\begin{aligned} &\text{the concentration with respect to chloride ion in the water sample} \\ &= M_2 \times 35.45 \times 1000 \text{ ppm} \\ &= 3.545 \times 10^4 M_2 \text{ ppm} \end{aligned}$$

You shall arrive at this relationship later in this section while deriving Eq. 5.20.

Example 3

The mole fraction of dissolved oxygen in water is 5.62×10^{-6} . Calculate its concentration in ppm unit. The molar mass of oxygen is 32 gram mole⁻¹.

Using Eq. 5.4,

$$\begin{aligned} \text{dissolved oxygen concentration} &= 5.56 \times 10^4 \times 5.62 \times 10^{-6} \times 32 \text{ ppm} \\ &= 10 \text{ ppm} \end{aligned}$$

In Example 4 that is discussed in Sec. 5.6, you will see an application of the above calculation.

You are advised to be familiar with all the above concentration units. Particularly your attention is drawn to Eq. 5.1, since it will be used often in our discussion to convert molarity into ppm unit. Let us now discuss the following chemical parameters of water samples. These are important in water quality management.

i) Total dissolved solids (TDS)

Due to the hydrological cycle, the dissolved solids mainly consist of bicarbonates, carbonates, sulphates, chlorides, nitrates and phosphates of calcium, magnesium, sodium and potassium with traces of iron, manganese and other minerals. Apart from these, water systems obtain dissolved substances through human activities. The details are given in Subsecs. 5.5.1 and 5.5.2. A method of classification of water systems based on TDS values is given in Table 5.2.

Table 5.2: Water Quality vs. Total Dissolved Solids.

Water quality	TDS/ppm
Fresh	Less than 1000
Slightly saline	1000 – 3000
Moderately saline	3000 – 10000
Very saline	10000 – 35000
Brine	> 35000

(Source: K.S. Venkateswarlu, page 6; other details as given under Table 5.1)

The TDS is estimated by evaporating a known volume of filtered water and finding the weight of the residue left behind. As mentioned earlier, the concentration of dissolved solids is also measurable in terms of electrical conductivity.

ii) Alkalinity

Alkalinity is defined as the quantity of ions in water that will react to neutralise H⁺ ions. Alkalinity is thus a measure of the ability of solutes in water to neutralise the added acid. You should differentiate alkalinity from basicity. Basicity is an **intensity**

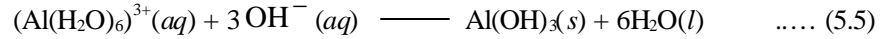
As already mentioned, TDS and electrical conductivity are related. In Sec. 6.2 of Unit 6, you will study the effect of TDS on human health, agriculture and industry.

Water

The alkalinity value of water helps in deciding the nature and the amount of coagulant to be added in removing the suspended and colloidal impurities. Alkalinity supports aquatic life by providing buffering capacity to an aqueous system. Alkalinity protects an aquatic body by chemically interacting with acids formed due to biodegradation or environmental pollution (like acid rain).

Limestone is rich in carbonates. The water samples flowing through lime stone regions have high alkalinity and have good buffering capacity. On the other hand, granite does not contribute that much to alkalinity. Therefore, the areas rich in granite have water bodies with low alkalinity and poor buffering capacity.

factor and is indicated by pH of a solution. Alkalinity is a **capacity factor** and it indicates how much H^+ ion a system can accept during the neutralisation process. For instance, let us consider the method of calculating the mass of a coagulant, $Al_2(SO_4)_3 \cdot 18H_2O$ for removing the colloidal and suspended impurities from a water source which is alkaline. The hydrated aluminium ion is acidic. On addition to water, it reacts with the bases present in it. It results in the formation of gelatinous aluminium hydroxide that settles and carries suspended matter with it.



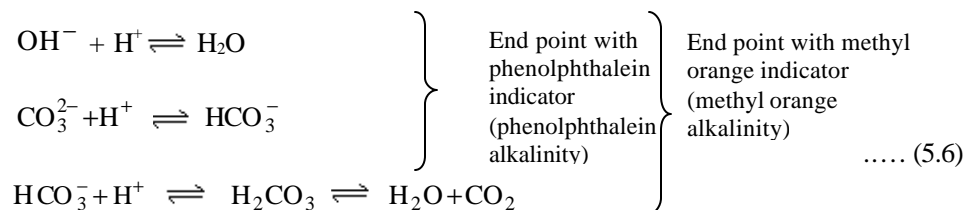
The amount of aluminium sulphate that is necessary for coagulation can be calculated based on alkalinity value of the water, since it is a type of acid – base reaction.

Alkalinity is generally caused by HCO_3^- , CO_3^{2-} and OH^- ions in water system. Other minor constituents of alkalinity are conjugate bases such as $HSiO_3^-$, HPO_4^{2-} , HS^- and NH_3 . Sometimes, conjugate bases of organic acids also are present. These ions result from the weathering reactions or human activities. The formation of HCO_3^- , CO_3^{2-} and OH^- ions is explained

- in Eqs. 5.21 to 5.25 of this section and,
- through Eqs. 5.56 and 5.64 to 5.68 of Sec. 5.7.

You can see that the weathering reactions of minerals and dissolution of CO_2 are the sources of these three ions. You are aware that atmosphere, respiration by aquatic species, and decay of dead species and organic materials are the sources for CO_2 in aquatic bodies. The formation of bases, HS^- and NH_3 , is explained in Subsec. 5.5.3. Among the various dissolved constituents in surface water and groundwater, HCO_3^- is the most important.

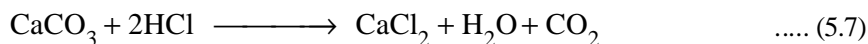
In Experiment 8 of this course, procedure is discussed to determine the concentrations of OH^- , CO_3^{2-} and HCO_3^- ions in a water sample. It is based on the principle mentioned in Experiment 11 of CHE-03 (L) course. **At pH 8.3, corresponding to phenolphthalein endpoint, neutralisation of OH^- and half neutralisation of CO_3^{2-} to HCO_3^- take place; i.e., neutralisation occurs wholly for OH^- and half way for CO_3^{2-} .** As a contrast, **at pH 4.5, corresponding to methyl orange endpoint, all the three ions - OH^- , CO_3^{2-} and HCO_3^- get neutralised.** The reactions can be summed up as follows:



The alkalinity calculated corresponding to phenolphthalein endpoint is called **phenolphthalein alkalinity (P)**. Similarly the alkalinity calculated as per methyl orange endpoint is called **methyl orange alkalinity or total alkalinity (T)**. While doing calculation of alkalinities, you use the following steps.

a) Calculation of P and T

You can calculate P and T values by titrating the water sample against standardised hydrochloric acid using the indicators mentioned above. It is customary to express the values of alkalinity in terms of concentration of CaCO_3 . You know that one mole of CaCO_3 is neutralised by 2 moles of HCl as shown in the following equation:



Therefore, the molarity equation for alkalinity can be written as,

$$M_1V_1 = 2M_2V_2$$

where M_1 and V_1 are the molarity and volume of HCl and, M_2 is the molarity of alkalinity of the water sample in terms of CaCO_3 and V_2 is the volume of the water sample. We use Eq.5.8 to calculate phenolphthalein and methyl orange alkalinity values.

$$M_2 = \frac{M_1V_1}{2V_2} \quad \dots (5.8)$$

Eq. 5.8 provides concentration of CaCO_3 in terms of molarity. The molar mass of CaCO_3 is 100 g mol^{-1} . You can use Eq. 5.1 for getting the value in ppm unit.

$$\text{Alkalinity (in ppm)} = M_2 \times 100 \times 10^3 = 10^5 M_2$$

Using Eq. 5.8 for M_2 ,

$$\text{alkalinity (in ppm)} = \frac{10^5 \times \text{molarity of HCl} \times \text{volume of HCl}}{2 \times \text{Volume of the water sample}} \quad \dots (5.9)$$

Phenolphthalein alkalinity (P) of the water sample can be determined in terms of ppm unit of CaCO_3 using the data for titration with phenolphthalein indicator in Eq.5.9.

$$\left. \begin{array}{l} \text{Phenolphthalein} \\ \text{alkalinity (P) (in ppm)} \end{array} \right\} = \frac{10^5 \left(\begin{array}{l} \text{molarity} \\ \text{of HCl} \end{array} \right) \left(\begin{array}{l} \text{volume of HCl to} \\ \text{phenolphthalein endpoint} \end{array} \right)}{2 \times \text{Volume of the water sample}} \quad \dots (5.10)$$

Similarly, we can determine methyl orange alkalinity (T) using Eq.5.11. The titre value with methyl orange indicator is to be substituted.

$$\left. \begin{array}{l} \text{Methyl orange} \\ \text{alkalinity (T)} \\ \text{(in ppm)} \end{array} \right\} = \frac{10^5 \left(\begin{array}{l} \text{molarity} \\ \text{of HCl} \end{array} \right) \left(\begin{array}{l} \text{volume of HCl to} \\ \text{methyl orange endpoint} \end{array} \right)}{2 \times \text{Volume of the water sample}} \quad \dots (5.11)$$

The alkalinity fraction equivalent to the amount of acid required to lower the pH of the water sample to 8.3 is called phenolphthalein alkalinity.

The alkalinity fraction equivalent to the amount of acid required to lower the pH of the water sample to 4.5 determines the total alkalinity or methyl orange alkalinity.

FOR YOUR ATTENTION

While applying Eqs. 5.10 and 5.11, you have to use molarity *i.e.*, moles litre⁻¹ (M) units for concentration and, cc unit for volumes. The result is to be expressed in ppm unit.

b) Deciding the type of water sample

We can relate phenolphthalein alkalinity and methyl orange alkalinity to OH^- , CO_3^{2-} and HCO_3^- alkalinities. Let us denote OH^- , CO_3^{2-} and HCO_3^- alkalinities as a , b and c , respectively.

Table 5.3: OH^- , CO_3^{2-} and HCO_3^- alkalinities in terms of P and T .

Type	Relative values of P and T	OH^- alkalinity (a)	CO_3^{2-} alkalinity (b)	HCO_3^- alkalinity (c)
Case (i)	$P = 0$ and $T > 0$	0	0	T
Case (ii)	$P < \frac{1}{2} T$ (or $T - 2P > 0$)	0	$2P$	$T - 2P$
Case (iii)	$P = T/2$ (or $2P = T$)	0	$2P$	0
Case (iv)	$P > \frac{1}{2} T$ (or $2P > T$)	$2P - T$	$2(T - P)$	0
Case (v)	$P = T$	T	0	0

Alkalinity is taken primarily as an indication of the presence of carbonate, bicarbonate and hydroxide ions.

- i) Carbonate ion is present, when phenolphthalein alkalinity is not zero (i.e. $\text{pH} > 8.3$) and a) phenolphthalein alkalinity is less than or equal to half the total alkalinity or b) phenolphthalein alkalinity is greater than half the total alkalinity but less than the latter.
- ii) Hydroxide ion is present, if phenolphthalein alkalinity is more than half the total alkalinity or is equal to total alkalinity.
- iii) Bicarbonate ion is present if phenolphthalein alkalinity is zero or is less than half the total alkalinity.

Using Eq. 5.6,

$$\left. \begin{aligned} \text{Phenolphthalein alkalinity } (P) \end{aligned} \right\} \begin{aligned} &= \text{OH}^- \text{ alkalinity} + (\text{CO}_3^{2-} \text{ alkalinity})/2 \\ &= (a + b/2) \end{aligned} \dots (5.12)$$

$$\begin{aligned} \text{Methylorange alkalinity or total alkalinity } (T) &= \left\{ \begin{aligned} &\text{OH}^- \text{ alkalinity} + \\ &\text{CO}_3^{2-} \text{ alkalinity} + \\ &\text{HCO}_3^- \text{ alkalinity} \end{aligned} \right\} \\ &= (a + b + c) \dots (5.13) \end{aligned}$$

In Experiment 8 of the practical component of this course, we shall show in a detailed way how Eqs. 5.6, 5.12 and 5.13 can be used to derive the entries found in Table 5.3. The type of the water sample is decided by comparing P and T values using column 2 of Table 5.3.

c) Calculation of alkalinities due to OH^- , CO_3^{2-} and HCO_3^-

Using columns 3, 4 and 5 of Table 5.3, you can calculate alkalinities due to OH^- , CO_3^{2-} and HCO_3^- ions.

Let us summarise the above steps. While doing calculation of alkalinities, you will use the following steps:

- Titrate the water sample against standardised HCl using phenolphthalein and methyl orange indicators as per procedure given in Experiment 8.
- Calculate P and T using Eqs.5.10 and 5.11.
- Compare P and T values and, using column (2) of Table 5.3, decide the type to which the water sample belongs (from case (i) to case (v)).
- To calculate alkalinities, use the information given in columns 3, 4 and 5 corresponding to that particular type.

The relationships between pH and the relative concentrations of OH^- , CO_3^{2-} and HCO_3^- ions are given below.

pH > 10; alkalinity due to significant amount of carbonate and hydroxide; the latter increases with pH.

pH = 8.3 to about 10; alkalinity due to bicarbonate and carbonate

pH < 8.3; alkalinity only due to bicarbonate

pH < 7; Carbonic acid or carbon dioxide species keeps increasing.

pH = 4.3; Carbonic acid or carbon dioxide species predominates.

These aspects are indicated in Fig. 5.1.

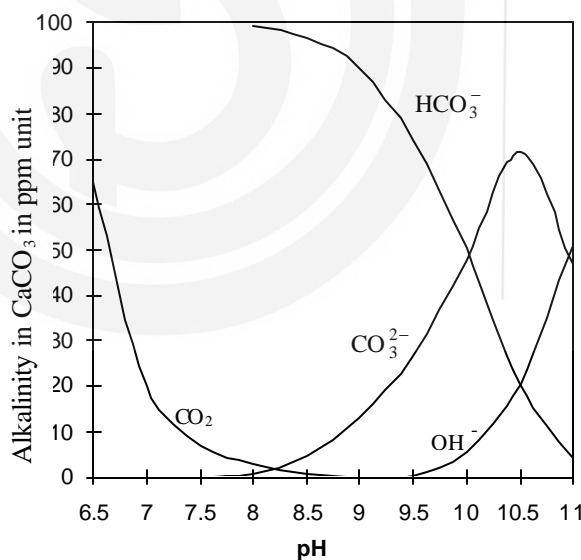


Fig. 5.1: The relationship between pH and the concentrations of CO_2 , HCO_3^- , CO_3^{2-} and OH^- ; the values calculated for water with a total alkalinity of 100 ppm at 25°C.

The principles of pH measurement are discussed in Secs.18.2 and 18.3 of Unit18 of this course. In Experiment 2, the method of determination of pH is given.

Water

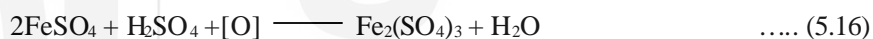
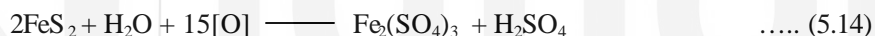
To understand the operation of Henry's law in relation to solubilities of gases, you are advised to go through Sec. 5.6 of this unit.

As regards surface water, pH range is between 6 and 8.5 and, bicarbonate is the dominant anion and CO_3^{2-} ion is uncommon. In deep soils, both CO_2 concentration and its partial pressure are much more than those in atmospheric air. As per Henry's law, if partial pressure of carbon dioxide is high, its solubility in water is also high. The water moving through such soils dissolves more CO_2 thereby increasing the concentrations of CO_3^{2-} and HCO_3^- ions. The groundwaters, in general, have significant concentration of bicarbonates and carbonates as compared to surface water.

iii) Sulphates

The sulphate concentration in rainwater is only 2 ppm. Sulphate ions occur in water systems due to the following reasons:

- Sulphate bearing minerals are common in most sedimentary rocks. In the weathering process, many of them are dissolved in water. An example of this type is gypsum (CaSO_4).
- Most of the sulphates in water systems originate from the oxidation of sulphide ores and their dissolution. The oxidation of pyrites (FeS_2) leads to the formation of sulphates of iron and sulphuric acid. Reactions due to weathering and microorganisms are involved in this conversion. Consequent to the presence of sulphuric acid, the waters from sulphide mines are low in pH and are highly corrosive.



- Sulphur dioxide occurs in the atmosphere due to the combustion of fossil fuels and the emissions from the roasting of ores during metallurgical processes. The oxides of nitrogen present in the atmosphere due to natural and human factors catalyse the conversion of sulphur dioxide to sulphur trioxide, which on dissolution in rainwater, gives rise to sulphuric acid; it is carried to the soil along with the rain.



In Experiment 10, the estimation of sulphate in water is discussed. The steps are given below:

- A standard solution of sodium sulphate is prepared. Using it, dilute solutions of known concentrations are prepared.
- From each solution prepared above, sulphate ions are precipitated as BaSO_4 in HCl medium using barium chloride.
- The turbidity of the suspension is measured as absorbance through its absorption of light at 420 nm using a spectrophotometer.
- A calibration curve is drawn with concentration of the sulphate on x – axis and absorbance on y – axis.
- The sulphate in the water sample is precipitated as BaSO_4 ; By measuring its absorbance and, by interpolation in the curve, the concentration of sulphate in the water sample is calculated.

iv) Chlorides

Chloride ions occur in water samples due to the dissolution of salt deposits, discharge of effluents, mixing of sewage wastes, seawater contamination and flow of irrigation drainage (like dissolution of salt added for coconut trees).

The chloride content of water sample can be estimated as per procedure given in Experiment 9. Here we discuss the principle of the method. Chloride ion is estimated in a neutral or slightly alkaline solution (pH between 7 and 8) by titration with standard silver nitrate, using potassium chromate as an indicator. Appearance of red coloured precipitate of silver chromate is the endpoint.

No. of moles of chloride in a water sample = No. of moles of AgNO_3 used

$$\text{i.e., } M_1V_1 = M_2V_2 \quad \dots (5.18)$$

where M_1 is the molarity of silver nitrate and V_1 is its titre value; M_2 is the molarity of chloride in the water sample and V_2 is the volume of the water sample.

$$\text{Hence, molarity of chloride } (M_2) \text{ in the water sample} = \frac{M_1V_1}{V_2} \quad \dots (5.19)$$

The molar mass of Cl^- ion is 35.45 g mol^{-1} . Using Eq. 5.1,

$$\left. \begin{array}{l} \text{concentration of chloride} \\ \text{in the water sample} \\ \text{(in ppm)} \end{array} \right\} = 3.545 \times 10^4 M_2$$

$$= \frac{3.545 \times 10^4 \times \left(\begin{array}{l} \text{molarity} \\ \text{of } \text{AgNO}_3 \end{array} \right) \left(\begin{array}{l} \text{volume of} \\ \text{AgNO}_3 \end{array} \right)}{\text{Volume of the water sample}} \quad \dots (5.20)$$

FOR YOUR ATTENTION

While applying Eq. 5.20, you have to use molarity i.e., moles litre⁻¹ (M) units for concentration and, cc unit for volumes. The result is to be expressed in ppm unit.

v) Fluorides

Fluoride occurs in almost all natural waters. The fluoride is measured by colorimetry or specific ion meter.

vi) Nitrates

The nitrates occur in water system due to decomposition of organic matter in presence of air; see Sec. 5.5.3. Other sources of nitrates are domestic wastes, chemical fertilizers, industrial effluents *etc.*

In Experiment 11, the estimation of nitrate in water is discussed. The steps are given below:

- A standard solution of KNO_3 is prepared. Using it, dilute solutions of known concentrations are prepared.
- To each solution, phenol disulphonic acid is added in alkaline medium to develop yellow colour.

Using a spectrophotometer, the concentration of a substance is measured using the extent to which a light of particular wavelength is absorbed. Beer – Lambert's law is used as a basis. In this regard, you are advised to go through Sec. 8.11 of Unit 8 of Atoms and Molecules (CHE-01) Course.

Water

In Subsec.5.5.3, biological oxidation of organic matter leading to nitrate formation is explained (see Eq.5.57).

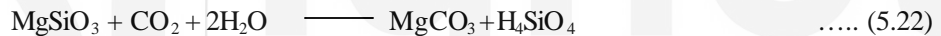
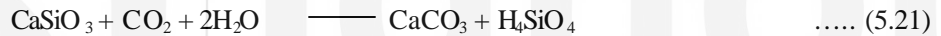
- The absorbance of each solution is measured at 410 nm using a spectrophotometer.
- A calibration curve is drawn with concentration on x -axis and absorbance on y -axis.
- The water sample is given a similar treatment with phenol disulphonic acid in alkaline medium to develop yellow colour. By measuring its absorbance and, by interpolation in the curve, the concentration of nitrate in the water sample is calculated.

vii) Metal ions

Metals in water systems can exist in dissolved, colloidal and suspended forms. In rock minerals, K^+ occurs more abundantly than Na^+ . Some clay minerals and *zeolites* are the important sources of sodium. In saline ground waters, the Na^+ content may be several hundred times greater than Ca^{2+} and Mg^{2+} .

Let us illustrate enrichment of water samples with metal ions due to weathering reactions. Consider the breakage of the minerals of calcium and magnesium ions. Calcium and magnesium silicates in rock are converted to their carbonates and bicarbonates by reactions with carbon dioxide, water and sulphuric acid. Note that sulphuric acid needed for these changes is formed through reactions indicated in Eqs. 5.14, 5.15 and 5.17. The carbonates and bicarbonates of calcium and magnesium are much more soluble in water than their silicates. Again, the bicarbonates of Ca and Mg are more soluble than their carbonates.

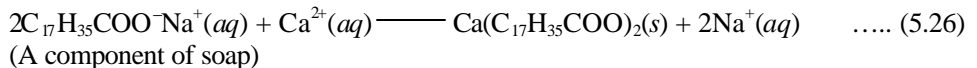
Conversion of calcium and magnesium silicates into their carbonates and bicarbonates progressively increases their solubility.



Already we have explained that partial pressure of CO_2 in deep soils is greater than that in air. Hence the solubility of $CaCO_3$ is high at deep soil condition. In presence of brine (high chloride content), calcium concentration can reach as high as 70,000 ppm. Between $CaSO_4$ and $MgSO_4$, the latter is much more soluble than the former. The metal contents in water samples can be estimated using spectrophotometry.

viii) Hardness

Hardness is the capacity of water for reducing and destroying the lather of soap. The most common manifestation of water hardness is the curdy white precipitate formed by the reaction of soap with calcium ions in hard water.



Hardness in water is due to the presence of salts acquired through contact with soil and other geological structures or may be due to pollution. Calcium and magnesium are the main cations that cause hardness. Iron, aluminium, manganese, strontium and zinc also cause hardness but to a negligible extent.

Hardness has been traditionally classified into “temporary hardness” and “permanent hardness”. The portion of hardness that disappears after prolonged boiling is called temporary hardness, and is mainly due to bicarbonates of calcium and magnesium. On

boiling, calcium carbonate or magnesium carbonate is obtained as a precipitate along with the evolution of carbon dioxide. The hardness that persists after boiling is permanent hardness. Permanent hardness is due to the chlorides and sulphates of calcium and magnesium. Generally, surface waters are softer than ground waters. Hardness is expressed in terms of concentration of calcium carbonate in ppm unit. According to the value of “total hardness”, waters are classified as follows. The term total hardness indicates the concentration of calcium and magnesium ions.

0	-	75 Soft
75	-	150 Moderately hard
150	-	300 Very hard

Under Experiment 13, you shall estimate total hardness and, hardness due to calcium and magnesium ions. In Experiments 9 and 10 of CHE-3(L), the principles behind estimation of permanent and temporary hardness using EDTA salt (disodium salt of ethylenediamine tetraacetic acid) and eriochrome black T have been explained. The calcium and magnesium ions (represented as M^{2+} in Eq.5.27) react with EDTA in the molar ratio 1:1.



$$i.e., \quad M_1V_1 = M_2V_2 \quad \dots (5.28)$$

where M_1 and V_1 are the molarity and volume of EDTA; M_2 is the molarity of hardness (due to Ca^{2+} and Mg^{2+} ions) of the water sample in terms of $CaCO_3$ and V_2 is the volume of the water sample. We use Eq.5.28 to calculate total hardness and, hardness due to Ca^{2+} and Mg^{2+} ions.

$$M_2 = \frac{M_1V_1}{V_2} \quad \dots (5.29)$$

Eq. 5.29 provides concentration of $CaCO_3$ in terms of molarity. You can calculate hardness in ppm unit using Eq. 5.1. The molar mass of $CaCO_3$ is 100 gram mole⁻¹.

$$\text{Hardness in ppm unit} = M_2 \times 100 \times 1000 = 10^5 M_2 \quad \dots (5.30)$$

For determining total hardness, the titration is carried out between water sample and EDTA in presence of $NH_4Cl - NH_4OH$ buffer and eriochrome black T indicator.

$$\left. \begin{array}{l} \text{Total hardness} \\ \text{in ppm unit as } CaCO_3 \end{array} \right\} = \frac{10^5 \left(\begin{array}{l} \text{molarity} \\ \text{of EDTA} \end{array} \right) \left(\begin{array}{l} \text{volume of EDTA to} \\ \text{eriochrome black T endpoint} \end{array} \right)}{\text{Volume of the water sample}} \quad \dots (5.31)$$

For determining hardness due to calcium ion, the water sample is titrated against EDTA at pH 12 using murexide indicator. At pH 12, Mg^{2+} becomes inactive due to precipitation.

$$\left. \begin{array}{l} \text{Hardness due to } Ca^{2+} \text{ ion} \\ \text{in ppm unit as } CaCO_3 \end{array} \right\} = \frac{10^5 \left(\begin{array}{l} \text{molarity} \\ \text{of EDTA} \end{array} \right) \left(\begin{array}{l} \text{volume of EDTA to} \\ \text{murexide endpoint} \end{array} \right)}{\text{Volume of the water sample}} \quad \dots (5.32)$$

$$\left. \begin{array}{l} \text{Hardness due to } Mg^{2+} \text{ ion} \\ \text{in ppm unit as } CaCO_3 \end{array} \right\} = \left\{ \begin{array}{l} \text{Total} \\ \text{hardness} \end{array} \right\} - \text{hardness due to } Ca^{2+} \text{ ion} \quad \dots (5.33)$$

Water

The organic matters could be categorised into two groups *i.e.* natural and synthetic. The natural organic matters generally cause depletion of oxygen only. The synthetic organic matters may also cause toxic effects that may be very serious in nature.

Eutrophication is a condition that affects water quality of an aquatic system through inflow of nutrients. It is indicated by the growth of algae and water hyacinth.

Residues of animals, plants and also microorganisms are collectively known by the name, "humus". Also refer to Unit 2 of Block 1.

FOR YOUR ATTENTION

While applying Eqs. 5.31 and 5.32, you have to use molarity *i.e.*, moles litre⁻¹ (M) units for concentration and, cc unit for volumes. The result is to be expressed in ppm unit as CaCO₃ in the case of all the three equations, Eqs. 5.31 to 5.33.

ix) Organic matter

The organic matter in water could arise in the following ways:

- i) Draining of the pesticide residues and organic pollutants released from industrial units
- ii) Mixing of animal and domestic wastes
- iii) Plant fibres and vegetable matter carried along with the run-off
- iv) Biomass accumulation due to eutrophication. (Biomass represents carbohydrates, proteins *etc.* accumulated due to decaying plant and animal waste.)

For further details see Subsec.5.5.3.

Many thousands of organic compounds enter water systems as a result of human activities. Monitoring every individual compound is not feasible. Some selected compounds are measured by gas chromatography methods. Three of the other methods used for estimating organics are given below. All these methods depend on the fact that oxidisable organic matter results in depletion of dissolved oxygen in water systems. Since dissolved oxygen content is much low due to its low solubility in water, the presence of oxidisable organic matter is harmful to aquatic life.

1) Dissolved oxygen (DO)

The dissolved oxygen

- i) is directly proportional to the partial pressure of oxygen in the air above the water surface
- ii) is directly proportional to the photosynthetic rate by aquatic green plants
- iii) decreases due to respiration of all plants and aquatic living beings
- iv) is inversely proportional to temperature
- v) is directly proportional to flow velocity and turbulence.

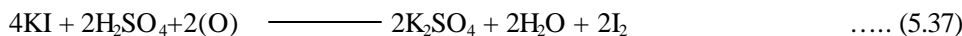
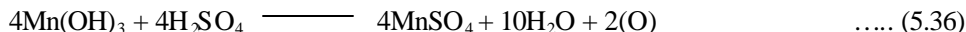
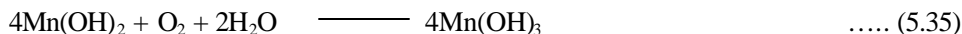
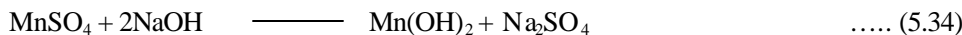
In other words, DO is dependent on the time of day, aquatic plant growth and light intensity. The variation in dissolved oxygen content with the time of the day is called diurnal variation. During daytime, dissolved oxygen is greater, since photosynthetic rate is greater than respiration rate. During night, only respiration takes place because of which dissolved oxygen decreases.

The details of estimation of dissolved oxygen are given in Experiment 12. Also, you are advised to go through Sec. 6.5.1 of Unit 6 of CHE-3(L) course to understand the principles of the method. We only outline the main steps of the method as follows:

- Water sample is treated with a solution of manganous sulphate, sodium hydroxide, potassium iodide and sodium azide. In order to overcome interference from nitrites, sodium azide is added.
- The reaction between MnSO₄ and NaOH gives rise to Mn(OH)₂, a white precipitate.
- The dissolved oxygen interacts with Mn(OH)₂ to give Mn(OH)₃, a brown precipitate.
- Concentrated sulphuric acid is added to the system to convert Mn(OH)₃ into MnSO₄ liberating oxygen.

- The liberated oxygen displaces iodine from the added KI solution in equivalent amount.
- The iodine so liberated is estimated using standardised thiosulphate solution using starch as indicator.

The series of reactions that take place are given below:



The following equation can be deduced from Eqs. 5.35 and 5.38.

$$\frac{\text{Number of moles of Na}_2\text{S}_2\text{O}_3}{\text{Number of moles of O}_2} = \frac{4}{1} \quad \dots (5.39)$$

$$\frac{M_1 V_1}{M_2 V_2} = \frac{4}{1} \text{ or } M_2 = \frac{M_1 V_1}{4V_2} \quad \dots (5.40)$$

where M_1 and V_1 stand for molarity and volume of sodium thiosulphate solution, respectively; V_2 refers to volume of water sample and M_2 refers to molarity of dissolved oxygen in the water sample. Using Eqs. 5.1 and 5.40,

$$\left. \begin{array}{l} \text{DO concentration in the} \\ \text{water sample in ppm unit} \end{array} \right\} = \begin{array}{l} M_2 \times \text{molar mass of O}_2 \times 1000 \\ = 32000 M_2 \end{array} \quad \dots (5.41)$$

$$= \frac{8000 \left(\begin{array}{l} \text{molarity of sodium} \\ \text{thiosulphate solution} \end{array} \right) \left(\begin{array}{l} \text{volume of sodium} \\ \text{thiosulphate solution} \end{array} \right)}{\text{Volume of the water sample}} \quad \dots (5.42)$$

FOR YOUR ATTENTION

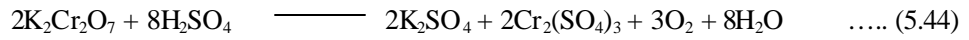
While applying Eq. 5.42, you have to use molarity *i.e.*, moles litre⁻¹ (M) units for concentration and, cc unit for volumes. The result is to be expressed in ppm unit.

2) Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a measure of oxygen required by a water sample for oxidising the organic matter that is susceptible to oxidation. The details of the method are given in Experiment 14. A mixture of potassium dichromate and sulphuric acid is used for producing oxygen necessary for oxidation. The basic aspect of COD calculation is given in the following equation:

$$\left. \begin{array}{l} \text{Number of moles of oxygen} \\ \text{demanded by the organic} \\ \text{matter in the water sample} \end{array} \right\} = \left\{ \begin{array}{l} \text{Number of moles of} \\ \text{O}_2 \text{ liberated by K}_2\text{Cr}_2\text{O}_7 \\ \text{that is consumed during oxidation} \end{array} \right\} \quad \dots (5.43)$$

Water

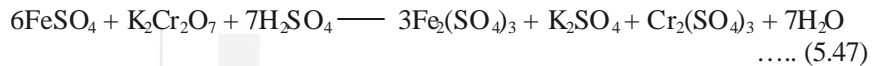


$$\frac{\text{No. of moles of O}_2 \text{ liberated}}{\text{Number of moles of K}_2\text{Cr}_2\text{O}_7 \text{ consumed}} = \frac{3}{2} \quad \dots (5.45)$$

Using Eqs. 5.43 and 5.45,

$$\text{Number of moles of oxygen demanded} = \frac{3}{2} (\text{Number of moles of K}_2\text{Cr}_2\text{O}_7 \text{ consumed}) \quad \dots (5.46)$$

A water sample is refluxed in strongly acid solution with a known excess of potassium dichromate. The unused potassium dichromate is titrated with ferrous ammonium sulphate using ferroin as indicator. From the titre value, volume (V_1) of ferrous ammonium sulphate equivalent to potassium dichromate consumed in oxidation is calculated. Note that ferrous sulphate is the chemically active part of ferrous ammonium sulphate.



$$\frac{\text{Number of moles of potassium dichromate}}{\text{Number of moles of ferrous ammonium sulphate}} = \frac{1}{6} \quad \dots (5.48)$$

$$\left. \begin{array}{l} \text{No. of moles of} \\ \text{K}_2\text{Cr}_2\text{O}_7 \text{ consumed} \\ \text{during oxidation} \end{array} \right\} = \frac{1}{6} \left(\begin{array}{l} \text{No. of moles of} \\ \text{ferrous ammonium sulphate required to} \\ \text{react with potassium dichromate that is} \\ \text{consumed during oxidation of the organic material} \end{array} \right) \quad (5.49)$$

Combining Eqs. 5.46 and 5.49,

$$\left. \begin{array}{l} \text{No. of moles of} \\ \text{O}_2 \text{ demanded} \\ \text{for oxidation} \end{array} \right\} = \frac{1}{4} \left(\begin{array}{l} \text{No. of moles of} \\ \text{ferrous ammonium sulphate required to} \\ \text{react with potassium dichromate that is} \\ \text{consumed during oxidation of the organic material} \end{array} \right) \quad \dots (5.50)$$

$$i.e., \quad M_2 V_2 = \frac{1}{4} M_1 V_1 \quad \dots (5.51)$$

where M_2 is the molarity of oxygen demanded by the water sample, V_2 is the volume of water taken; M_1 is the molarity of ferrous ammonium sulphate and V_1 its volume required to react with the volume of $\text{K}_2\text{Cr}_2\text{O}_7$ consumed for oxidation.

$$M_2 = \frac{M_1 V_1}{4V_2} \quad \dots (5.52)$$

Using Eqs. 5.1 and 5.52, we can write similar to Eq. 5.41,

$$\text{chemical oxygen demand in ppm unit} = 32000 M_2$$

$$i.e., \quad \text{COD in ppm unit} = \frac{M_1 V_1}{4V_2} \times 32000 \quad \dots (5.53)$$

(since molar mass of $\text{O}_2 = 32 \text{ g mol}^{-1}$)

$$= \frac{8000 M_1 V_1}{V_2} \text{ ppm}$$

$$= \frac{8000 \left(\begin{array}{c} \text{Molarity of ferrous} \\ \text{ammonium sulphate solution} \end{array} \right) \left(\begin{array}{c} \text{volume of ferrous ammonium sulphate} \\ \text{solution required to react with potassium} \\ \text{dichromate consumed during oxidation} \end{array} \right)}{\text{Volume of the water sample}}$$

..... (5.54)

FOR YOUR ATTENTION

While applying Eq. 5.54, you have to use molarity *i.e.*, moles litre⁻¹ (M) units for concentration and, cc unit for volumes. The result is to be expressed in ppm unit.

3) Biological oxygen demand (BOD)

BOD is the quantity of oxygen consumed at 27°C and in darkness during 3 days for the biological oxidation of organic matter present in a water sample. Let us explain this term in detail. Many organic compounds present in a water system may be used by microorganisms in their metabolic processes as sources of energy and chemicals necessary for growth. During this metabolic transformation, the microorganisms utilise the dissolved oxygen in the water system. This imposes 'biological oxygen demand' on the limited oxygen resources available in the water system. The BOD value of an aquatic system depends on

- the types and amounts of organic compounds,
- the types of organisms
- temperature
- pH and
- presence of nutrients and trace elements necessary for growth *etc.*

A water system can tolerate some BOD as far as oxygen used by the microorganism can be replenished from its dissolution from air. A reduction of DO to lower levels could seriously affect the living conditions for fish and other aquatic species. The presence of sufficient oxygen demanding materials in the water system could result in total depletion of DO and the death of all aquatic species. Added to this, the absence of dissolved oxygen could lead to the growth of microorganisms that may produce foul smelling substances like NH₃, H₂S *etc* in the water system. BOD and DO are primarily used as indicators of suitability of a water system for fish life as also for its aesthetic values; see Secs. 6.2 and 6.3 of Unit 6 for a more detailed discussion on this aspect. In our country, it has been recently decided that BOD has to be measured by making two DO measurements of a water sample – one immediately and another after incubation at 27°C for three days (*i.e.*, 3 – day BOD). The temperature for measurement is chosen keeping in view the realistic aquatic temperature of water systems in India and also the ease of maintenance of sample temperature using an incubator.

Across the world, BOD test is conducted over a 5 day period at 20°C. In countries like U.K., where the test was originally developed, room temperature is near 20°C generally and, temperature maintenance using incubator becomes easy at 20°C.

$$\text{BOD}_3 = \text{DO (initial)} - \text{DO (after incubation for 3 days)} \quad \text{..... (5.55)}$$

SAQ 2

Two 100 cc lots of a water sample were titrated individually against M/20 HCl. For one, phenolphthalein indicator was used and it required 12 cc of acid for neutralisation. For another, with methyl orange indicator, the titre value of the acid was 20 cc.

- i) calculate the phenolphthalein alkalinity (*P*) and methyl orange alkalinity (*T*) values.
(Hint: Use Eqs. 5.10 and 5.11)
- ii) State the type of alkalinity.
(Hint: Use columns 1 and 2 of Table 5.3)
- iii) Calculate the OH^- , CO_3^{2-} and HCO_3^- alkalinities.
(Hint: Use columns 3, 4 and 5 of Table 5.3).

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SAQ 3

Generally carbonate alkalinity is larger in groundwaters than in surface waters. Explain.

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SAQ 4

50 cc of a water sample requires 3.4 cc of 0.01 M EDTA for titration in presence of eriochrome black T indicator. Calculate total hardness.
(Hint: Use Eq. 5.31)

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.....

SAQ 5

50 cc of a water sample requires 5.5 cc of 0.0141 M AgNO_3 solution for titration. Calculate the concentration of chloride ion in the sample.
(Hint: Use Eq. 5.20)

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5.4 BIOLOGICAL PROPERTIES OF WATER SYSTEMS

Water Characteristics

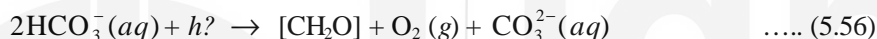
The biological properties of water are indicated by

- the generation of unusual and excessive growth of species like algae, fungi, protozoa and bacteria and
- elimination or major reduction of life forms such as fish, turtles *etc.* which are normal inhabitants of a water system.

Many of these species have a large variation in their sensitivity to the constituents of the aquatic system. Biological characteristics reflect the combined effect of all the toxicants present in an aquatic system. In that way, the study of biological characteristics is more advantageous than the study of only chemical characteristics of a water system; see Subsec. 6.5.2 of Unit 6 for a more detailed discussion on this aspect. Let us discuss some biological species that can be found in aquatic systems.

Algae

These are small plant organisms that can carry out photosynthesis. They appear in green, brown or blue-green colour. These species can use dissolved carbon dioxide or bicarbonate ion for photosynthesis. It leads to the formation of biomass. Although biomass could contain carbohydrates, proteins *etc.*, we represent it as $[\text{CH}_2\text{O}]$.



The carbohydrates, proteins and oxygen produced by the algae are used by other aquatic species for their survival. Thus, presence of algae in an aquatic system provides a favourable situation for the existence of many other species. The importance of photosynthesis by algae in relation to pH will be explained in Sec.5.7.

Fungi

Fungi are generally unicellular plants. These species cannot carry out photosynthesis but have to depend on other plants for organic nutrients. Water systems polluted by sewage contain fungus as one of the constituents.

Protozoa

Protozoa are single celled organisms that live on dead organic matter. They act as scavengers consuming bacteria and algae.

Bacteria

The bacteria feed on

- the wastes produced by other living organisms,
- the dead species and,
- any biodegradable constituents released into the river from various sources.

There are two types of bacteria. The aerobic bacteria get involved in metabolic changes using dissolved oxygen. The anaerobic bacteria make use of chemically bound oxygen for conducting their metabolic reactions. The sulphate, nitrate and phosphate compounds of the water body are used for this purpose by the anaerobic bacteria. Note that metabolic reactions are used to produce energy. In Subsec.5.5.3, we shall discuss these aspects; we shall also explain how the biological properties of water defined by the presence of algae, bacteria *etc.* could adversely affect the chemical characteristics of water and its utility.

The harmful effects of microorganisms present in drinking water shall be discussed in the next unit.

You are advised to go through Sec. 20.2 of Unit 20 of this course to understand the experimental procedures for the determination of biological characteristics of water.

The estimation of every type of microorganism requires a high degree of expertise. When resources for microbiological examination are limited, it is recommended that *Escherichia coli* (*E. coli*) be estimated. It is an important member of *coliform* group of bacteria. It is generally of intestinal origin. It is discharged as a component of faecal matter. The presence of *E.coli* in a water body suggests pollution due to domestic sewage. Though it is not a pathogen by itself, its presence indicates that the aquatic system may also contain pathogens that are secreted within the physiological systems of human beings and animals affected by various diseases. For this reason, *E.coli* is called indicator organism. Its estimation can be carried out by two methods - most probable number (MPN) of bacteria or membrane filtration (MF) method. We are not going to discuss the details of these methods.

SAQ 6

Differentiate between the functions of aerobic bacteria and anaerobic bacteria.

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5.5 FACTORS AFFECTING WATER QUALITY

In nature, water rarely occurs in chemically pure form. When rainwater falls through the atmosphere, it picks up gases and dust particles. When the rainwater reaches the earth, it is subjected to further changes in composition due to contact with the soil. Hence, the surface water has more impurities than rainwater. The groundwater has the highest content of dissolved impurities, since it dissolves further mineral matter, as it travels underground. Let us understand the origin of impurities that lower the water quality.

5.5.1 Natural Factors

Let us examine the role of climatic factors and weathering reactions in changing the composition of water.

a) Climatic factors

The climatic factors play a vital role in the formation of ions, plant communities and soil varieties. For instance, HCO_3^- is the major ion where plant growth is heavy. Some of the metal ions are formed in high concentrations in plants. These metals get into the water system during the decay of plants. The water systems fluctuate in their composition due to the variation in the volume of water flowing through. The effect of rainfall on some of the constituents of river water can be illustrated using the data obtained for one of the major rivers of our country. The data indicate that, as compared to summer season, the rainfall causes lowering of conductivity value and of the concentrations of calcium and chloride ions whereas it leads to increase in concentrations of bicarbonate and silt. Such changes result from opposing effects arising out of dilution and weathering reactions.

b) Weathering reactions

Weathering uses reactivity and solvent characteristics of water. Through dissolution, hydrolysis, carbonation, hydration and oxidation, water reacts with the components of the air and rock minerals. In Subsec. 4.5.3 of Unit 4 of this course, we have explained the weathering of rocks. In Sec.5.3, you have studied many examples of weathering reactions of water; these reactions help us in understanding the origin of insoluble and soluble components in water.

5.5.2 Human Activities

In Unit 4, you studied in detail how construction of dams, deforestation and diversion of water from its natural course could cause damage to the environmental system. You also have seen how over-pumping of aquifers results in mixing of brackish water with the sweet water above; in coastal areas, it results in seawater intrusion. Further in Unit 4, we have explained in detail the effect of increasing population on water demand. The growth in industry and uncontrolled land uses have resulted in gradual depletion of water from its sources. Each water use followed by discharge of wastewater into water systems leads to depletion of water quality. In Block 4 of this course, you will study about all these aspects in detail.

Let us see the effect of mixing of products of weathering reactions, large quantities of sewage, run off from heavily fertilized fields and, industrial effluents on water quality of a river system. Remember these are rich sources of nitrogen, phosphorus, potassium, carbon and other nutrients required for plant growth.

5.5.3 Biological Transformations

The nutrient accumulation and, the actions of algae, aerobic and anaerobic bacteria change the properties of an aquatic system drastically. We can explain this aspect as follows.

Eutrophication

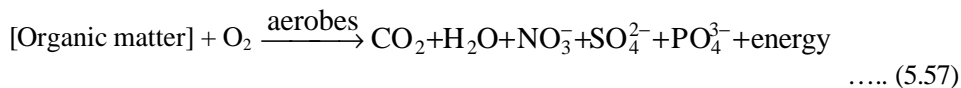
When a water system such as a lake or reservoir gets a large inflow of nutrients and organics present in domestic wastes, it may be the breeding ground for the excess growth of algae or water hyacinth. Such an aquatic system is said to be in a condition of eutrophication, which in Greek means “well-nourished”. Eutrophication refers to a condition by which an aquatic system served by inflow of nutrients undergoes severe deterioration in water quality.

Next, let us explain the reason for the quality deterioration in terms of biodegradation of organic matter.

Biodegradation

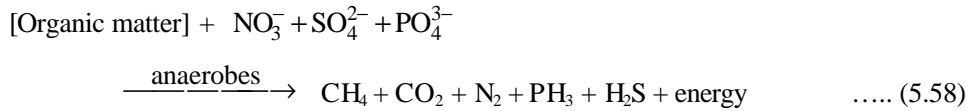
The nutrient rich body of water produces a great deal of plant biomass by photosynthesis as per Eq. 5.56. Some amount of animal biomass is also formed. With excess of algal growth, light penetration through the water layer is limited. Added to this, turbidity of water also results in reduction in penetration of light. The photosynthesis is affected. The algal cells begin to die. This increases the decomposable organic matter load on the water body. The aerobic bacteria decompose the organic matter using dissolved oxygen.

The term “organic matter” in Eq. 5.57 collectively represents carbohydrates, proteins and other oxidisable organic materials, which are present in the water body. Eq. 5.57 represents the products of aerobic oxidation of the organic matter in a general way. The actual products depend on the composition of the organic matter. Eq. 5.58 represents products of anaerobic oxidation of organic matter in a general way.



The aerobic oxidation leads to decreased DO concentration. When DO concentration becomes quite low, the anaerobic bacteria carry out further decomposition of the organic matter. The nitrates, sulphates, phosphates *etc.* produced in an aquatic system as per Eq. 5.57 and those present due to inflow of wastewaters undergo transformation into products such as ammonia, hydrogen sulphide, phosphine *etc.* in stages. Note that nitrate is first reduced to nitrogen gas. Further reduction of nitrogen gas by anaerobic bacteria leads to the formation of ammonia.

Water



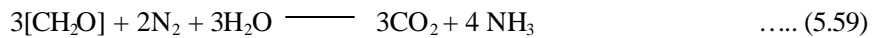
The production of methane due to biodegradation in an aquatic system, especially in a marshy place, has resulted in its common name, marsh gas.

The labourers entering the deep sewers for repair or cleaning work are exposed to a number of risks like suffocation, physical injury, infection and hazards arising due to combined action of domestic and industrial wastes. The aerobic and anaerobic oxidation of these materials produce gases such as CO₂, CH₄, H₂S etc. (as per Eqs. 5.57 to 5.61).

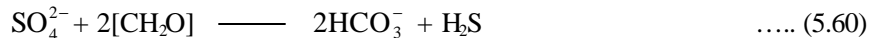
Production of these gases result in decreased oxygen gas concentration within the enclosed space of the sewer lines. Unless safety guidelines are followed, the sewer line labourers may even die, especially due to suffocation, while they are involved in an essential but the least recognised public service.

Taking the organic matter as a carbohydrate [CH₂O], we can represent the formation of ammonia and hydrogen sulphide in the water system by anaerobic bacteria as follows. Remember that [CH₂O] is only a symbolic representation of carbohydrate but not its molecular formula.

- i) For the formation of ammonia, nitrogen produced as per Eq. 5.58 or from the atmosphere is used; it is an instance of biological nitrogen fixation.



- ii) The sulphate ion present in water is reduced by an anaerobic bacteria to give H₂S; the latter gets into acid – base equilibrium with bicarbonate ion to give HS⁻.



The net result of biodegradation of an aquatic system is that pH increases with the formation of the basic species like NH₃ and HS⁻ etc. The decomposition products like NH₃, H₂S and PH₃ are toxic while the first two have foul smell; that is why, you can perceive foul smell around a water system affected severely by biodegradation. Also, due to toxicity, fish and other aquatic species die in large numbers. What could be the next stage? See below.

Marsh formation

In some water systems, dead biomass accumulates at the bottom of the lake or reservoir, where it partially decays. It leads to recycling of nutrients like C, N, P, K, Ca and Mg. The solid materials accumulated at the bottom results in the formation of a marsh thereby spoiling the utility of the water body.

SAQ 7

State the ways in which an aqueous system is affected by eutrophication.

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5.6 SOLUBILITY OF GASES IN WATER

The solubility of gases like O₂, CO₂ etc. in water needs careful consideration, since it is important from the point of view of water quality and aquatic life. Also, the transfer of gases into and out of water system is of great importance. For instance, oxygen lost due to bacterial degradation of organic waste is to be replenished by its transfer from the air into the water to maintain aquatic life. Knowledge of the principles of gas transfer is essential to understand these processes. Let us study these aspects in detail.

i) Solubility of gases in water

In Sec. 10.5 of Unit 10 of Physical chemistry (CHE-04) Course, a detailed discussion has been made on the dissolution of gases in liquids. You may go through the same to understand the basic features pertaining to this section.

The solubility of a gas in water depends on the following factors:

- temperature
- pressure
- nature of the gas
- presence of other substances in the solvent system

a) Effect of temperature

The dissolution of a gas in water is an exothermic process. Hence, according to Le Chatelier's principle explained in Sec. 14.8 of Unit 14 of Physical Chemistry (CHE-04) Course, solubility of a gas in a liquid decreases with rise in temperature. As an illustration, see the data given in Table 5.4.

Table 5.4: Solubility of Oxygen in Distilled Water and Seawater.

Temperature/°C	O ₂ Solubility/ppm	
	Distilled Water	Sea water *
10	11.3	9.0
20	9.1	7.3
30	7.5	6.2

* Sea water with 20 g chlorine equivalent of the total halide concentration in 1 kg sample is considered here.

(Source: Environmental Inorganic Chemistry; edited by Itamar Bodek and others, Pergamon, New York, 1988, p.10.6-9)

b) Effect of pressure – Henry's Law

The solubility of gases in liquids is very much affected by pressure, since gases undergo tremendous volume change on dissolution. In 1803, the English Chemist, Henry found that the solubility of a gas in a liquid increases as the gas pressure is increased at a given temperature. Henry's law can be stated as follows:

At constant temperature, the partial pressure of a gas over a solution is directly proportional to the concentration of the gas in the solution.

Mathematically, Henry's law is expressed as follows:

$$p_i = Kx_i \quad \dots (5.62)$$

p_i and x_i are the partial pressure and mole fraction of the gas component. K is called Henry's law constant and it has the dimensions of pressure. Henry's law is valid only for dilute solutions of a gas in a liquid – that too if these two do not react chemically. Of course, the concentrations of gaseous components found in water systems are reasonably low so that Henry's law could be applied. Henry's law constants for some gases are given in Table 5.5.

A crucial effect of temperature on solubility of gases is seen in water systems near thermal power stations. Release of hot water into the nearby aquatic system rises its temperature causing decreased dissolved oxygen. The problem is aggravated by the fact that hot water has lower density and, it floats above the cold water effectively screening the penetration of oxygen down below. The aquatic life is adversely affected.

Water

A serious consequence of the dependence of the gas solubility on pressure is that more nitrogen gas dissolves in the blood of deep – sea divers. When the diver returns to the surface, the excess dissolved nitrogen effervesces resulting in the formation of numerous bubbles in the blood stream. These bubbles can block the capillaries (narrow vessels that distribute blood). The cells do not get sufficient oxygen, causing the painful condition known as the “bends” which in serious cases can lead to death. The risk of bends is reduced, if helium is used to dilute the diver’s oxygen supply, for helium is much less soluble in blood than nitrogen.

If dc/dt is negative, the gas is released from the liquid surface, since it denotes decrease in concentration of the gas in the aquatic body. On the other hand, a positive value for dc/dt denotes dissolution of the gas to a greater extent.

For removing harmful gases like H_2S , NH_3 etc. from wastewaters, air is blown through the system; the escaping air carries away the dissolved gases. The aerobic treatment plants operate using this principle.

Table 5.5: Henry’s Law Constants at 25°C for Water as a Solvent.

Gas	$K/10^9$ Pa
H_2	7.12
N_2	8.68
O_2	4.40
CO_2	5.80
CO	0.17

Let us illustrate the use of Eq. 5.62 using the following example.

Example 4

Henry’s law constant for oxygen gas at 25°C is 4.4×10^9 Pa. Calculate the dissolved oxygen content, if the partial pressure of the oxygen gas over water is 2.473×10^4 Pa.

Using Eq. 5.62,

$$\begin{aligned} \text{the mole fraction of dissolved oxygen} &= \frac{p_i}{K} = \frac{2.473 \times 10^4 \text{ Pa}}{4.4 \times 10^9 \text{ Pa}} \\ &= 5.62 \times 10^{-6} \end{aligned}$$

The dissolved oxygen content corresponding to the above data has already been calculated in Example 3 (discussed in Sec. 5.3) using Eq. 5.4 as 10 ppm.

c) Nature of the gas

Generally, the gases, which chemically react with a solvent are more soluble in it than in other solvents. For example, hydrogen chloride and ammonia are more soluble in water than in benzene. Also, gases, which can be easily liquefied, are more soluble in common solvents; an example is ammonia, which is easy to be liquefied.

d) Effect of other dissolved substances

The salts present in water systems could influence the gas solubility to a great extent. Usually, solubility of gases like N_2 , O_2 etc. decreases with increasing salt concentration since under these conditions, much of the water is associated with ions as water of hydration. This is illustrated in Table 5.4 for O_2 gas.

So far, we discussed the solubility of gases in water. Let us now discuss the aspects regarding the transfer rate.

ii) Transfer rate of gases

The rate of change of concentration of a gas in a liquid is denoted by its transfer rate. The transfer rate of a gas that is mathematically denoted by the symbol, dc/dt , can be expressed as follows:

$$dc/dt = k_a(c_s - c) \quad \dots (5.63)$$

where c_s and c are the saturation concentration and the actual concentration of a solution of a gas in a liquid, respectively. The term k_a is a constant related to the physical condition. It should be noted that if $c > c_s$, i.e., actual concentration is greater than the saturation value and, the gas is released from the liquid surface; for the reverse case, gas is transferred to the liquid surface.

For instance, photosynthesis by aquatic plants and algae gives rise to pure oxygen that results in higher partial pressure than the partial pressure of oxygen in the air. As per Henry's law, the dissolved oxygen concentration (c) due to photosynthesis will therefore be greater than the saturation value (c_s). In such a condition, oxygen is released from the water system, since dc/dt gets a negative value.

The constant k_a increases with surface area and decreases with volume of water. Also, k_a depends on temperature, films on the water surface, turbulence and constituents dissolved in water. In all the aerobic treatment plants, air supply is done by mechanically increasing the surface area as per this concept.

SAQ 8

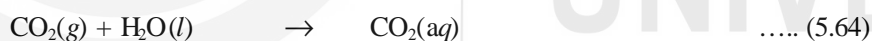
In water, ammonia gas is more soluble than nitrogen gas. Explain.

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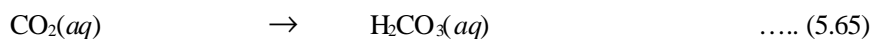
5.7 CARBONATE EQUILIBRIUM

We have already mentioned in Sec.5.3 about the origin and the role of carbonates and bicarbonates in deciding the alkalinity of the aquatic systems. In this section, we shall discuss the equilibria relating to these ions. Let us first explain the biological importance of the same. You may be aware that many biological activities need maintenance of pH. The organisms use buffer systems as a defence mechanism against any change in internal pH. The phosphate and bicarbonate systems are the two important biological buffers. The phosphate buffer system consists of H_2PO_4^- and HPO_4^{2-} ions and, it acts in the cytoplasm of all the cells. The bicarbonate buffer system represented by Eq.5.66 is part of the carbonate equilibrium that we are going to discuss here. The bicarbonate buffer system is of vital importance for maintaining the pH of aquatic systems as well as of human blood. The equilibria involving OH^- , CO_3^{2-} and HCO_3^- are given below.

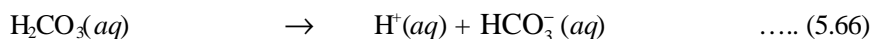
Dissolutions of CO_2 gas



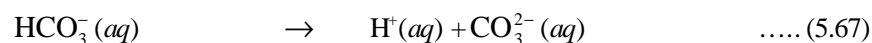
Formation of carbonic acid



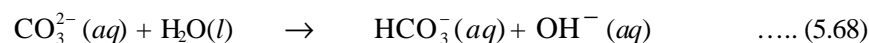
Dissociation of carbonic acid (bicarbonate buffer system)



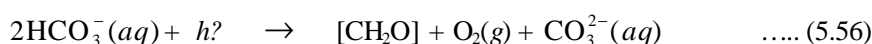
Dissociation of bicarbonate ion



Hydrolysis of carbonate ion



Photosynthesis by algae



The Eqs. 5.64 and 5.65 indicate the distinction between $\text{CO}_2(aq)$ and $\text{H}_2\text{CO}_3(aq)$. The term, $\text{CO}_2(aq)$, stands for loosely hydrated carbon dioxide whereas $\text{H}_2\text{CO}_3(aq)$ stands for carbonic acid. The conversion of $\text{CO}_2(aq)$ to $\text{H}_2\text{CO}_3(aq)$ is a slow process and is of great importance in Analytical Chemistry and Biochemistry.

From Analytical Chemistry point of view, the slow reaction can be demonstrated by the addition of a saturated solution of carbon dioxide to a dilute solution of sodium hydroxide containing phenolphthalein indicator. It takes several seconds for the disappearance of pink colour signifying that carbonic acid required for neutralisation is formed slowly from loosely hydrated carbon dioxide (as per Eq. 5.65). As a contrast, addition of dilute acetic acid to a dilute solution of sodium hydroxide containing phenolphthalein indicator results in instantaneous neutralisation as indicated by disappearance of pink colour. It has been calculated that only one in 480 molecules of dissolved carbon dioxide gets converted into carbonic acid.

As a student of Chemistry, you can appreciate the fact that the hydrolysis of carbonate ion, as per Eq. 5.68, is less favoured since it is against the basic fact that only a strong base (like hydroxide ion) can displace a weak base (like CO_3^{2-} ion) from the salt of the latter (HCO_3^- ion). In other words, only the reverse of Eq. 5.68 is expected to be favoured. However, the utilisation of bicarbonate ion as a source of carbon for photosynthesis (as per Eq. 5.56) by algae can drive the reaction represented by Eq. 5.68 in the forward direction. Consequently, concentration of OH^- ion can be significant. **Water with heavy growth of algae often has pH values as high as 10.**

Let us now examine the equilibria from Biochemistry point of view. In this context, it is worth mentioning some details regarding the role of bicarbonate buffer on respiration. The mixture, H_2CO_3 and HCO_3^- , known as the bicarbonate buffer, is responsible for controlling the pH of the blood stream near 7.4 through a process of reactions as given in Eqs. 5.64 to 5.66 or their reverse. In biological systems including human blood, the enzyme *carbonic anhydrase*, controls the equilibria governed by these equations. It is estimated that one molecule of the enzyme can catalyse the conversion of 6×10^5 molecules of $\text{CO}_2(g)$ to $\text{H}_2\text{CO}_3(aq)$ per second. The sequence of reactions is adjusted in a way that $\text{CO}_2(aq)$ mostly exists as $\text{HCO}_3^-(aq)$ in body fluids and as $\text{CO}_2(g)$ in the air spaces of lungs prior to removal. Any increase in H^+ concentration (*i.e.*, acidosis condition) is counteracted by a series of reactions, which are reverse sides of the Eqs. 5.64 to 5.67. These reactions take place in the reverse order from Eq. 5.67 to Eq. 5.64 finally resulting in the expulsion of extra amount of CO_2 during the exhalation process. Similarly an increase in OH^- due to some metabolic process (alkalosis condition) is compensated by the neutralisation by H^+ followed by the forward push and in the same sequence as denoted by Eq. 5.64 to Eq. 5.67. In other words, $\text{CO}_2(g)$ amount exhaled becomes less. We must remember that many physiological functions especially those depending on enzyme activity are pH specific. If the pH regulating mechanism of the blood is overpowered due to external factors (environmental *etc.*) or physiological factors (like excess production of metabolic acids as in the case of uncontrolled diabetes) or both, it can lead to serious health problems including death.

SAQ 9

An intense growth of algae in a water system results in increase of pH. Explain.

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5.8 SUMMARY

We discussed in detail the physical, chemical and biological characteristics of water systems. We provided an explanation for the origin of the constituents of water systems in terms of natural factors, human activities and biodegradation. The factors, which decide the solubility of gases, were stated. The various aspects of equilibria among $\text{CO}_2(g)$, $\text{CO}_2(aq)$, $\text{H}_2\text{CO}_3(aq)$, OH^- , HCO_3^- and CO_3^{2-} were indicated. The materials of this unit could help you in understanding the quality criteria, which are going to be discussed in the next unit.

5.9 TERMINAL QUESTIONS

1. River water has DO content of 11 ppm during winter and 9.4 ppm during summer. Explain.
2. In what way does the alkalinity support the aqueous bodies?
3. 100 cc of a sample of water required 10 cc of M/20 HCl for neutralisation in presence of phenolphthalein indicator. Another lot of 100 cc of same water sample required 30 cc of M/20 HCl for neutralisation when methyl orange indicator was used. Calculate HCO_3^- , CO_3^{2-} and OH^- alkalinities. Follow the steps and hints given in SAQ 2.
4. Calculate the solubility of N_2 gas in water in ppm unit at 20°C when water is in contact with air in which the partial pressure of nitrogen is 7.81×10^4 Pa. Henry's law constant for N_2 is 8.68×10^9 Pa. (Hint: Use Eqs. 5.62 and 5.4.)
5. During chemical oxygen demand determination, 20 cc of the water sample requires acidified potassium dichromate that is equivalent to 29.9 cc of 0.1 M ferrous ammonium sulphate solution. Calculate COD. (Hint: Use Eq. 5.54)
6. 50 ccs of a water sample during dissolved oxygen determination results in a titre value of 2.8 cc of 0.025 M sodium thiosulphate solution. Calculate DO. (Hint: Use Eq. 5.42).
7. The water systems flowing through sulphide mines are corrosive. Explain.
8. How is marsh formed?
9. The photosynthesis by aquatic plants and algae leads to release of oxygen by a water body to the atmosphere. Explain it in the light of transfer rate of gases.

5.10 ANSWERS

Self -Assessment Questions

1. Increase of temperature causes an increase in the metabolic reaction rates, decrease in solubility of gases (for instance, decrease in dissolved oxygen content) and, stratification of layers. Further, there is an increase in the electrical conductivity (leading to more corrosive nature) of the water sample.

2. i) Using Eq. 5.10,
 phenolphthalein alkalinity (P) as $\text{CaCO}_3 = \frac{10^5 \times 0.05 \times 12}{2 \times 100}$ ppm
 $= 300$ ppm

Using Eq. 5.11,

methyl orange alkalinity (T) as $\text{CaCO}_3 = \frac{10^5 \times 0.05 \times 20}{2 \times 100}$ ppm
 $= 500$ ppm

ii) Since $P > \frac{1}{2} T$, we can infer that the water sample belongs to case (iv) as per Table 5.3.

iii) Using columns 3, 4 and 5 of this table, we can write,

$$\therefore \text{OH}^- \text{ alkalinity as CaCO}_3 = (2 \times 300 - 500) \text{ ppm} = 100 \text{ ppm}$$

$$\text{CO}_3^{2-} \text{ alkalinity as CaCO}_3 = 2(500 - 300) \text{ ppm} = 400 \text{ ppm}$$

$$\text{HCO}_3^- \text{ alkalinity as CaCO}_3 = 0$$

3. In deep soils, both CO_2 concentration and its partial pressure are much more than that in atmospheric air. As per Henry's law, groundwater dissolves higher amount of CO_2 thereby increasing the concentrations of HCO_3^- and CO_3^{2-} .

4. Using Eq. 5.31,
 total hardness as $\text{CaCO}_3 = \frac{10^5 \times 0.01 \times 3.4}{50}$ ppm
 $= 68$ ppm

5. As per Eq. 5.20,

$$\left(\begin{array}{l} \text{concentration of chloride} \\ \text{ion in the water sample} \end{array} \right) = \frac{3.545 \times 10^4 \times 0.0141 \times 5.5}{50} \text{ ppm}$$

$$= 55 \text{ ppm}$$

6. The aerobic bacteria get involved in metabolic changes using dissolved oxygen. For conducting the metabolic reactions, the anaerobic bacteria make use of chemically bound oxygen in sulphate, nitrate and phosphate compounds of the water body.

7. Eutrophication leads to decreased DO levels, formation of foul smelling and harmful products like H_2S , NH_3 etc. and increase of pH. In short, water system is spoiled.

8. The gases that react with water are more soluble than others. Ammonia reacts with water to give ammonium hydroxide. Secondly, ammonia is an easily liquefiable gas and, this aspect also favours higher solubility. N_2 gas can neither react with water nor is it easily liquefiable.

9. Algae consume HCO_3^- ion and form biomass. This helps in the hydrolysis of carbonate ion forming OH^- ion which is otherwise an unfavourable reaction; it results in pH increase.

Terminal Questions

- DO is inversely proportional to temperature.
- The alkalinity of a water body helps in protecting it from pH change by providing buffer action.
- Using Eq. 5.10,

$$\begin{aligned} \text{phenolphthalein alkalinity (P) as CaCO}_3 &= \frac{10^5 \times 0.05 \times 10}{2 \times 100} \text{ ppm} \\ &= 250 \text{ ppm} \end{aligned}$$

Using Eq. 5.11,

$$\begin{aligned} \text{methyl orange alkalinity (T) as CaCO}_3 &= \frac{10^5 \times 0.05 \times 30}{2 \times 100} \text{ ppm} \\ &= 750 \text{ ppm} \end{aligned}$$

Note that $P < \frac{1}{2} T$. From columns 1 and 2 of Table 5.3, we can infer that the water sample belongs to case (ii). Using columns 3,4 and 5, of this table,

$$\text{OH}^- \text{ alkalinity as CaCO}_3 = 0 \text{ ppm}$$

$$\text{CO}_3^{2-} \text{ alkalinity as CaCO}_3 = 500 \text{ ppm}$$

$$\text{HCO}_3^- \text{ alkalinity as CaCO}_3 = 250 \text{ ppm.}$$

- Using Eq. 5.62, mole fraction of $\text{N}_2 = 9 \times 10^{-6}$

The molar mass of N_2 is 28 g mol^{-1}

Using these in Eq. 5.4,

$$\left(\begin{array}{l} \text{concentration of } \text{N}_2 \\ \text{in water sample} \end{array} \right) = 14.01 \text{ ppm}$$

- Using Eq. 5.54, $\text{COD} = \frac{8000 \times 0.1 \times 29.9}{20} \text{ ppm}$

$$= 1196 \text{ ppm}$$

- Using Eq. 5.42, $\text{DO} = \frac{8000 \times 0.025 \times 2.8}{50} \text{ ppm}$

$$= 11.2 \text{ ppm}$$

Water

7. The oxidation of sulphide ores leads to the formation of sulphuric acid as one of the products; it results in low pH and corrosive nature of the water systems.
8. The dead mass accumulates at the bottom of a water body after eutrophication. The solid materials so accumulated form the marsh.
9. Due to photosynthesis, oxygen is released as a product by the aquatic plants to the aquatic body first. When the actual dissolved oxygen concentration of the water body is more than the saturation concentration, the transfer rate gets a negative value as per Eq. 5.63. In other words, the water body releases oxygen to the atmosphere.



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UNIT 6 WATER QUALITY CRITERIA AND USES

Structure

- 6.1 Introduction
 - Objectives
- 6.2 Concerns for Water Quality
- 6.3 Water Quality Criteria for Various Purposes
 - Objectives, Criteria and Standards - Definition
 - Water Quality Criteria as Basis for Classification of Water Bodies
 - Factors that Influence Prescription of Criteria for Water Quality
 - Uses of Water Quality Criteria
- 6.4 Monitoring and Assessment – A Discussion
 - Water Quality Monitoring for Water Resources Management
 - Water Quality Monitoring System for Risk Assessment
 - A Comprehensive Scheme for Controlling River Water Quality
 - Uses of Monitoring Programmes
- 6.5 Analytical Techniques for Monitoring Water Quality
 - Physical and Chemical Methods of Monitoring
 - Biomonitoring
 - Need for Integrated Monitoring Mechanism
- 6.6 Summary
- 6.7 Terminal Questions
- 6.8 Answers
- 6.9 Appendix

6.1 INTRODUCTION

Water bodies have many uses such as for municipal use, agriculture, industry, fisheries, recreation *etc.* The term quality must be considered relative to the intended use. For instance, drinking water must be pure and free of suspended impurities or harmful substances. For boating, water quality conditions are less rigorous. For fish and other aquatic species present in a sea, its water is of appropriate quality since these species need the dissolved salts, trace elements and nutrients for their life. The species living in seawater would not survive long in distilled water, which we generally consider as the water of highest quality. From these examples, we can understand that “water quality” derives its meaning only in the context of its use. In Subsec. 4.7.2 of Unit 4, we mentioned that by the year 2025, more than 90% of the utilisable water potential of our country will have to be put to use. In this context, the management of quality of water is as much important as that of its quantity. In this unit, we shall explain the concern and criteria for water quality for its various uses. We shall discuss the importance and method of monitoring water quality. We shall conclude the unit by discussing some Indian initiatives for monitoring water quality. The last portion is given in the appendix.

Objectives

After studying this unit, you should be able to

- explain the need to define water quality in relation to its particular uses,
- define the terms, water quality objectives, criteria and standards,
- explain the basis for the classification of water bodies,
- describe the factors that influence prescription of water quality criteria,
- define the terms, assessment, monitoring, risk assessment, risk management and water quality management,
- explain the requirements for establishing a water quality monitoring system,
- list the steps relating to the establishment of a system for river water quality control,
- explain the uses of water quality monitoring programmes,

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- state the advantages and disadvantages of physicochemical and biological monitoring methods, and
- explain the need to have integrated approach towards water quality monitoring.

A recent study in water related diseases by a research group based in California has predicted that by 2020, water related diseases may kill 7.6 crore people all over the world, if adequate measures are not taken.

Disinfection:
Removal of disease causing germs using chlorine *etc.*

6.2 CONCERNS FOR WATER QUALITY

Let us explain the need to define water quality in relation to its use in a particular context. We shall first discuss the water quality requirements for municipal use by listing the favorable and harmful effects of some of its constituents.

Till nineteenth century, the water borne diseases used to occur frequently in different parts of the world. Detailed studies have led to establishing the cause of water - borne diseases. For instance, following is the list of microorganisms and the related diseases.

Virus	-	Hepatitis, poliomyelitis
Bacteria	-	Cholera, typhoid
Protozoa	-	Amoebic dysentery
Helminth	-	Hookworm

These species are present in large numbers in the faeces of sick individuals. For this reason, contamination of the drinking water supplies by the sewage is to be prevented. In Sec 5.4 of the last unit, we have explained that *E.coli*, a member of *coliform* group of bacteria, is used to indicate faecal pollution.

Increased access to quality drinking water helped in minimising the outbreak of water-borne diseases. Still, around parts of Africa and Asia, epidemics of water-borne diseases occur due to nonavailability of quality drinking water, mixing with sewage and inadequate disinfection. Let us give some recent examples from Indian context. In the summer of 1988, cholera epidemic broke out in trans-yamuna area of Delhi. In 1964 and 1992, West Bengal suffered 30560 and 19014 cholera deaths, respectively. Subsequently in 1997, by employing suitable measures towards provision of quality drinking water and epidemic control, the number of deaths due to cholera has been brought down to 16 in the whole country.

Apart from microbiological aspects of drinking water, physicochemical aspects also came to be scrutinised from public health point of view. For instance, turbidity is an important parameter to be considered in municipal water supply due to aesthetics, filterability and disinfection. The turbidity in drinking water gives rise to doubts about the presence of pollutants that can be harmful to health. The reason is that it provides adsorption sites for pollutants. Filtration of turbid water is difficult and costly since the suspended particles cover the filter bed. Chlorine or ozone is used to disinfect public water supplies. In order to be effective, disinfectant must come into close contact with the pathogenic organisms. In turbid water, the organisms may get trapped within the particles and escape from the action of the disinfectant. Hence, the disinfection of turbid water is difficult. In Table 6.1, we give a brief account of the effect of a few chemical components on human health.

Table 6.1: Effect of Some Components of Drinking Water on Human Health.

Water Quality Criteria and Uses

Name of the component(s)	Effect(s)
1. Sulphate	High concentration can have a laxative effect, which is enhanced in presence of Mg^{2+} .
2. Chloride and bicarbonate	Within prescribed limits, these two can help digestion process.
3. Fluoride	Within prescribed limits, which are temperature dependent, it helps in dental care; excess fluoride could cause fluorosis disease.
4. Nitrate	High concentration leads to hypertension in adults; in babies, it may cause methemoglobinemia; could also lead to dysentery.
5. DO	DO helps in increasing the taste of drinking water and decreasing the concentration of metals like Fe, Mn <i>etc.</i> (through oxidation and precipitation of salts). DO is essential to prevent anaerobic oxidation of organic substances (see below). High DO results in corrosion of water pipes.
6. Metals	<p>i) Within prescribed limits, some of the metals could facilitate physiological processes. Ca – needed for healthy bones. Mg – relaxes muscles, reduces stress, strengthens immune system and controls blood pressure. Na – needed for maintaining ion balance in the body. Fe – helps in delivering oxygen throughout the body. Cu, Zn, Mn <i>etc.</i> – help in regulating many physiological functions.</p> <p>ii) If present in excess, metals could be harmful. Ca and Mg – can lead to kidney stone formation. Cu – can lead to indigestion.</p> <p>iii) A few of the toxic metals, even in low concentration, could be harmful – e.g., Cr, Cd, Hg, Pb <i>etc.</i> Lead, for instance, has harmful effect on human nervous system and can cause mental retardation.</p>
7. Organics	<p>i) DDT is a cancer-producing agent.</p> <p>ii) Chloroform is a carcinogen while bromodichloromethane is a mutagen; these two are formed during chlorination of drinking water containing organic load.</p> <p>iii) They can consume DO for oxidation. When DO level decreases sufficiently, organic substances undergo anaerobic oxidation that could result in the formation of harmful and foul smelling products such as NH_3 or H_2S <i>etc.</i> This is particularly significant when drinking water containing organic load is stored for a long time.</p>

Fluorosis: Skeletal disease; it has a crippling effect.

Methemoglobinemia: A blue baby problem due to reactions between nitrate and hemoglobin leading to interference in oxygen transmission through the body.

A noteworthy case of mercury poisoning occurred in Minimata, Japan around 1960 due to consumption of fish containing methyl mercury. The disease occurred not through drinking water route but due to release of methyl mercury in the aquatic system, the source of fish catch. See under bioconcentration in Subsec. 6.3.3.

For disinfection, 0.5 ppm residual chlorine is enough; its smell cannot be detected up to 1 ppm.

Carcinogen:
Cancer producing agent.

Mutagen:
An agent that causes genetic change in living organisms.

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The enormity of the drinking water problem can be understood from the following statement of World Health Organisation made during November 2002: “Around 1.1 billion people in the world do not have access to safe drinking water which means that these people do not have even a protected well or a spring within half an hour walk”.

Drought is defined as a prolonged period of below average soil moisture for a long period. In contrast to this, during physiological drought, soil moisture is high and the plant is not in a position to absorb water.

Corrosion: It is the process by which the metal atoms leave their location on the surface and get stabilised in the form of ions in the solution.

In industry, 90% water is used for cooling and, only 10% for other purposes.

It is worth mentioning here about the mineral water that is sold under various brand names. It is reported that already around Rs.1000/- crores worth mineral water is sold every year in our country. Claims are made that the following processes are carried out: reverse osmosis, multilayer filtration, treatment with activated carbon, microfiltration, chlorination, ozonation and addition of minerals desirable for human body.

The physical, chemical and biological characteristics of water have a varied impact across its different uses. The data available are enormous. In Table 6.2, we mention the effect of some of the constituents and parameters of water on its various uses like agriculture, industry, aquatic life and recreation.

Table 6.2: Water Quality Concerns for Various Uses.

Type of use	Constituent(s) or parameter(s) and effect(s)
i) Agriculture	<ol style="list-style-type: none"> High TDS: It can lead to higher osmotic pressure at the soil inhibiting water absorption by the roots; this could cause a physiological drought situation for the plant, although soil moisture is high. It increases soil salinity that results in reducing plant growth and grain yield. High Na⁺ concentration: It adds to soil salinity problem mentioned above. It affects physical structure of the soil making it quite hard. Water infiltration through the soil is affected leading to stagnant water. This could cause rotting of the seeds, drowning of the crops and development of mosquito related problems and diseases such as malaria, filariasis <i>etc.</i> Further, it may affect chlorophyll and, cause yellowing, drying and early drop of leaves. High sulphate and chloride concentration: These two reduce the availability of phosphorus and organic acids to plants. High Chloride concentration also may affect chlorophyll and cause yellowing, drying and early drop of leaves. High boron: It may affect chlorophyll and cause yellowing, drying and early drop of leaves. Unusual pH: It can result in corrosion of irrigation pipelines, sprinklers <i>etc.</i>
ii) Industry	<ol style="list-style-type: none"> High TDS concentration: It can accelerate corrosion. High bicarbonate and sulphate concentration: The carbonates (formed by the decomposition of the bicarbonates), and sulphates of calcium and magnesium form scale in boilers and pipes. The deposit could lead to wastage of heat and, in extreme cases, to explosion. High DO: It can cause serious corrosion problem. Organic load: It may cause decomposition products with lower pH giving rise to corrosion problem. It may lead to formation of foam affecting steam flow. It can also damage the ion exchange resins. Microorganisms: The gradual accumulation on the engineering structures may decrease the efficiency of the moving parts of the machines. It is known as biofouling. In power stations, this could affect power production. Chloride: Above 250 ppm, it is not suitable for food processing since taste is affected. Above 1000 ppm, it is highly corrosive; water samples with such high chloride concentration cannot be used for industrial cooling.

<p>iii) Aquatic life</p>	<ol style="list-style-type: none"> Alkalinity and pH: Alkalinity protects aquatic species from acidic pollutants through its buffering action. The pH values below 5 and above 9 are toxic. Ammonia: Around 0.06 ppm, fish can suffer gill damage. Above 2 ppm, fish could even die. DO: A minimum of 4.5 ppm is required for aquatic life. For a good harvest of fish, 9 ppm level of DO is required. During summer, metabolic reactions are faster and DO should not drop below 3 ppm. During winter, DO requirement is less. Carbon dioxide: If sufficient alkalinity is present, CO₂ will help in neutralising it. If water pH is low, any increase in CO₂ concentration can damage aquatic life significantly; there is no room for its neutralisation by the aquatic body. The respiration by the fish varieties will be affected. The cloudy days can be more harmful, since photosynthesis by aquatic plants proceeds to less extent. DO availability becomes less. As respiration of all aquatic species continues, CO₂ level increases enormously. The decreased DO level and, increased CO₂ level can be harmful. Temperature: High temperature decreases DO level, which could be fatal. Turbidity: It may clog the gills of fish, killing them directly. Lack of light penetration decreases photosynthesis by aquatic plants. Consequently, the aquatic plants die resulting in scarcity of food to fish varieties. Also DO level decreases. All these are unfavorable to aquatic life.
<p>iv) Recreational uses</p>	<p>Common for all three categories of recreation *:</p> <ol style="list-style-type: none"> Blue green algae, sewage fungus etc.: These can cause physical discomfort and also be aesthetically objectionable. Excess growth of aquatic plants: These could obstruct the view of the swimmers. These plants can create panic in swimmers by entanglement. Organic load, oil, grease etc.: These substances are also aesthetically objectionable and could produce undesirable colour, odour, taste and foaming. They can be toxic too. <p>For swimming, bathing and surfing only:</p> <ol style="list-style-type: none"> Toxic chemicals and pathogenic organisms: There is the risk of contacting diseases associated with eyes, ears, nose, throat and skin. pH: The pH of water should be near 7.4, which is same as that of lachrymal fluid; otherwise it can cause eye irritation. Temperature: Temperature should not be much lower or higher than the room temperature.

Water Quality Criteria and Uses

Gill:
The organ used for breathing by aquatic living beings like fish.

Metabolic rate is the rate by which metabolic reactions are conducted. One of the important metabolic reactions has been discussed in Eq. 5.57 of Unit 5 where the nutrients use dissolved oxygen to provide the oxidised products and energy. Like any chemical reaction, rate for a metabolic reaction also increases with increase in temperature.

Surfing: The sport of riding in toward shore on the crest of a wave especially on a sturdy light boat (known as surf boat).

Water skiing: It is a sport where a person remaining on a board is towed in a speedy manner by a motorboat. The ski board is attached firmly to the motorboat through a long cable or chain.

Lachrymal fluid:
Secretion from the glands in the eyes.

* Note: There are three categories of recreational uses of water bodies. The first category requires direct contact with water as in swimming, bathing and surfing. The second category involves contact with water less frequently as in boating, fishing and skiing. The third category does not result in body contact with water and, a familiar example is tourism around aquatic bodies for enjoying the scenery. For the first category, the quality requirements are rigorous.

Water

For irrigation purposes, it is advisable to avoid using water with SAR value greater than 10. Continued use of water with high SAR value leads to hardening of the soil. Na⁺ ions reduce the soil permeability to water.

Although many other similar parameters are to be considered while deciding on the suitability of irrigation water, we have mentioned SAR as an illustration.

Although we have tried to list the effect of individual constituents and parameters of water on its uses for various purposes, their combined effect may be quite different. See the following instances:

i) When we try to understand the toxicity due to Na⁺ ion in irrigation water, its concentration needs to be considered in relation to the concentrations of Ca²⁺ and Mg²⁺ ions. For this purpose, we have to define the term, sodium absorption ratio (SAR).

$$\text{Sodium absorption ratio} = \frac{(\text{Na}^+)}{\sqrt{[(\text{Ca}^{2+} + \text{Mg}^{2+})]/2}} \quad \dots (6.1)$$

The concentrations, (Na⁺), (Ca²⁺) and (Mg²⁺) are to be expressed in the units, equivalents per million (epm), which is same as milliequivalents per litre.

$$\begin{aligned} x \text{ epm} &= x \text{ milliequivalents per litre} \\ &= \frac{x \text{ mg per litre (ppm)}}{\text{Equivalent weight of the constituent}} \quad \dots (6.2) \end{aligned}$$

It is advisable that water with SAR value greater than 10 must be avoided for agricultural purposes as it signifies high Na⁺ content and leads to water infiltration problems mentioned in Table 6.2. If water contains considerable Ca²⁺ and Mg²⁺ ions, the soil permeability is restored. The soil could then absorb these ions in preference to Na⁺ ions. On the other hand, water high in HCO₃⁻ concentration will tend to precipitate calcium and magnesium ions as their carbonates over the soil layer due to evapotranspiration process; at first, bicarbonates will be formed that decompose to give the carbonates. This means SAR value of the water sample increases that can give rise to hazards due to Na⁺ ion.

ii) The presence of one type of constituents could reduce the effect of other types of constituents; it is known as **antagonistic reaction**. For instance, irrigation water high in sulphate or chloride concentration reduces the availability of phosphorus and organic acids to plants below desired level.

iii) The combined effect of two constituents in known concentration can cause more toxicity than the effect of each individually under same concentration level. This is known as **synergistic reaction**. For example, individually pH around 5 and concentration of 0.9 ppm of iron are not that much toxic to aquatic life individually; but, if these two conditions are present together, the fish varieties die. Another example is that toxicity due to ammonia for aquatic life increases as temperature increases or as DO level decreases.

Through the above discussion, we have seen that water quality must be considered relative to the proposed use of water. **We shall therefore define water quality as “those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water”**. In the next section, we shall throw light on water quality criteria.

SAQ 1

Calculate sodium absorption ratio using the following values:
(Ca²⁺) = 2.32 epm; (Mg²⁺) = 1.44 epm; (Na⁺) = 7.73 epm.

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SAQ2

State the effect of high bicarbonate concentration in irrigation water.

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SAQ3

State the effect of continued cloudy season on water quality for aquatic life.

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6.3 WATER QUALITY CRITERIA FOR VARIOUS PURPOSES

To understand information regarding water quality in a scientific way, you must be aware of appropriate terminology. You should know three terms – objectives, criteria and standards – in a clear way.

6.3.1 Objectives, Criteria and Standards - Definition

The term “objective” in water quality control specifies a goal that will be attained or an ideal condition towards which one wishes to proceed. **The objectives are generalised statements specifying the desired outcomes in quality control.** For instance, the Indian government launched “Ganga Action Plan” in the year 1985 with the objective of bringing water quality of Ganga and its tributaries to bathing levels. We must understand that objective is an ultimate goal towards which the concerned organisation and agencies should work. Many a times, it is quite difficult to attain the goal set up as objective, although efforts are made. Further, water quality objectives do not clearly spell out the characteristics of a water system or the methodology to be followed in attaining the same.

In order to realise the objectives, the experts and specific user groups define the desirable characteristics of water for each specific use in the form of statements known as water quality criteria. Water quality criteria provide guidelines and safety margins in terms of characteristics of water. **Water quality criteria are statements broadly defining the safety margins for the physical, chemical, and biological characteristics and constituents of water.** A comparison of the characteristics of a water body with those of established criteria indicates whether the body is suitable for a particular use or not. Usually water quality criteria are presented in a tabular column such as in Table 6.3. Water quality criteria are derived from scientific facts obtained from numerous experiments. The quality criteria are the essence of hundreds of pages of data collected by the experts working in various constituents of water, soil and air as also conditions of temperature, pH *etc.* The criteria are not absolute for all times but are subject to change as further investigations are carried out.

Next, we shall define the term, water standards. **Water standards are prescribed by certain authorised agencies considering the type of use, quality criteria and also other features such as practical attainability, cost, local conditions, public need *etc.*** Although generally the standards set are in line with the quality criteria, sometimes they may be different keeping in view the requirements felt by a particular

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organisation. In India, for instance, drinking water standards set by the following four agencies are commonly used:

- 1) BIS (Bureau of Indian Standards)
- 2) ICMR (Indian Council of Medical Research)
- 3) CPHEEO (Central Public Health and Environmental Engineering Organisation)
- 4) WHO (World Health Organisation)

Among the industrial uses of water, the standards prescribed are dependent on the type of industry and its specific needs.

Three types of standards need to be adhered to by the agencies dealing with drinking water supply and wastewater disposal.

- **Design Standards** that prescribe conditions with respect to type of plants to be designed for water supply or wastewater disposal facilities, their capacity and the choice of constituent materials to be used for their construction.
- **Performance standards** stipulate restrictions regarding the final concentration of constituents in water that must be obtained using the plants mentioned above.
- **Procedural standards** specify the methods to be followed in maintaining water quality. The procedural standards apply to procedures to be adopted
 - i) in obtaining licenses and permits for construction and operation of the plants
 - ii) in monitoring their performance in terms of water quality or effluent quality
 - iii) during exchange of data and communication between
- the regulatory agencies like Pollution Control Boards and the health authorities on the one hand, and
- municipal authorities (in case of drinking water supply or wastewater disposal) or industry (in case of effluent disposal) on the other.

For ensuring compliance of these three standards, the regulatory agencies are required to carry out the monitoring work.

6.3.2 Water Quality Criteria as Basis for Classification of Water Bodies

Although many methods are available for classification of aquatic bodies, the Central Pollution Control Board (CPCB) has developed a method based on the concept of “designated best use”. According to it, out of several uses a particular water body is put to, the use that demands highest quality of water is called its “designated best use”, and accordingly the water body is designated. The CPCB has identified five such “designated best uses” for water.

- The water of a water body that can be used for drinking without conventional treatment but with disinfection (chlorination *etc.*) is termed as “A” class.
- The water of a water body that can be used for outdoor bathing is called “B” class.
- The water of a water body that can be used for drinking after conventional treatment is termed as “C” class.
- The water of a water body that can be used for propagation of wild life and fisheries is denoted as “D” class.
- The water of a water body that can be used for irrigation, industrial cooling and controlled waste disposal is termed as “E” class.

For each of these five “designated best uses”, the CPCB has identified water quality requirements in terms of a few chemical/biological characteristics, known as “primary water quality criteria”. The “designated best uses” and the respective primary water quality criteria are given in Table 6.3.

Designating a water body:
Classifying the water of a water body as A,B,C,D,E depending on the use it is put to for which highest quality is required. A denotes the highest quality and E, the lowest.

Table 6.3: Use Based Classification of Water Bodies and Their Criteria

Designated best use	Class of water	Criteria
Drinking water source without conventional treatment but after disinfection (using chlorination <i>etc.</i>)	A	<ol style="list-style-type: none"> 1. Total <i>coliform</i> organism 50 MPN/100 ml or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 6 ppm or more 4. Biochemical oxygen demand (3 days and 27°C) 2 ppm or less
Outdoor bathing	B	<ol style="list-style-type: none"> 1. Total <i>coliform</i> organism 500 MPN/100 ml or less 1. pH between 6.5 and 8.5 2. Dissolved oxygen 5 ppm or more 3. Biochemical oxygen demand (3 days and 27°C) 3 ppm or less
Drinking water source with conventional treatment	C	<ol style="list-style-type: none"> 1. Total <i>coliform</i> organism 5000 MPN/100 ml or less 2. pH between 6 and 9 3. Dissolved oxygen 4 ppm or more 4. Biochemical oxygen demand (3 days and 27°C) 3 ppm or less
Propagation of wild life and fisheries	D	<ol style="list-style-type: none"> 1. pH between 6.5 and 8.5 2. Dissolved oxygen 4 ppm or more 3. Free Ammonia (as N) 1.2 ppm or less
Irrigation, industrial cooling and controlled waste disposal	E	<ol style="list-style-type: none"> 1. pH between 6.0 and 8.5 2. Electrical conductivity at 25°C less than 2250 $\mu\text{S}/\text{cm}$ 3. Sodium absorption ratio less than 26 4. Boron less than 2 ppm

The presence or absence of the *coliform* group of bacteria decides the bacteriological quality of water. The most widely known member of the group is *Escherichia coli*.

Note: MPN denotes most probable number; it is calculated using statistical process. (Source: Water Quality Statistics of India, Central Pollution Control Board, Delhi, 1991)

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Central Pollution Control Board has classified the major water resources of the country according to their designated best uses and, a Water Use Map has been prepared. Also on the basis of observed data collected through National Water Quality Monitoring Network, Water Quality Map of India has been prepared. The idea is to superimpose Water Quality Map on Water Use Map to identify the water systems or their parts which are in need of improvement (restoration). From the available information, 86 polluted river stretches have been identified. Presently almost all policies and programmes on water quality management including Ganga Action Plan and National River Action Plans are partly based on this designated best use concept.

6.3.3 Factors that Influence Prescription of Criteria for Water Quality

While finalising the quality criteria for various classes of water usage, the following aspects have been taken into consideration.

i) Specific requirements and characteristics of the consumers of each class

In Sec. 6.2, we illustrated how quality parameters are different for different uses of water. Even within a class of water usage, there is great variety in the responses shown by the consumers to a given stimulus in the form of a pollutant. We illustrate this aspect taking for example aquatic life.

- The aquatic organisms do not receive the same degree of harm, individually or as species, from the introduction of a pollutant. For instance, sensitive fish like trout and salmon begin to die even when NH_3 level is near 0.2 ppm; whereas, fish like carp can tolerate NH_3 up to 2 ppm. The response of the more sensitive species is quite essential while formulating the quality criteria for the class.
- The aquatic food web is an intricate relationship of predator and prey organisms. A water constituent that may in some way destroy or eliminate an important segment of the food web would in all likelihood destroy or seriously damage other organisms associated with it. It is necessary to analyse the effect of as many constituents of water as possible so that sensitive parameters are not omitted.

ii) Bioconcentration

The pollutants get accumulated through predator – prey chain in the food web. Although initial concentration level of a pollutant may be within safe limits, the subsequent increases may take place each time a prey is consumed by a predator and, this process continues through the food chain. This phenomenon of successive increase in concentration of a pollutant through a food web is called **bioconcentration** or **bioaccumulation**. Let us give two examples.

- The first example is pollution by heavy metals. There is no natural elimination process for the metals. Metals shift from one part of the environment to another, often with harmful effects. In this connection, it is worth mentioning about mercury poisoning that occurred in Minimata, Japan around 1960 due to consumption of fish containing methyl mercury.
- The second example is detection of pesticides like DDT in mother's milk. DDT is nonbiodegradable and is carcinogenic (*i.e.*, cancer producing). The application of DDT to grass lands results in transfer of this nonbiodegradable chemical into the cattle. The consumption of milk from such cattle by human beings results in further transfer of DDT. Another source of pesticides in human system is the agricultural runoff mixing with drinking water source.

While formulating water quality criteria, due consideration must be given for bioconcentration and persistence.

Predator:

An animal that lives by killing and consuming other animals; the predating act is known as predation.

Prey:

An animal that is a food source and is killed and consumed by a predator.

Food Chain:

An arrangement of the organisms of an ecological community according to the order of predation in which each predator uses its next lower member as food.

Food Web:

The totality of interacting food chains in an ecological community.

The chemicals such as pesticides, which are not easily metabolised, but remain unchanged over a long time, are said to be nonbiodegradable. Such chemicals are said to have persistence. For these substances, bioconcentration is particularly important.

iii) Antagonistic and synergistic reactions

Remember, antagonistic and synergistic reactions have been discussed in Sec. 6.2. These are important in deciding the water quality criteria.

iv) Adaptation by the species

There is variability in the quality of water available in different places. Certain organism becomes adapted to a quality that may be considered extreme for other species. It is recognised that a single criterion cannot be taken to represent the water quality.

6.3.4 Uses of Water Quality Criteria

Let us now explain the uses of water quality criteria.

- 1) Water quality criteria are useful in checking the suitability of a water body for a particular use. The need for providing treatment before using a water body for a particular purpose is also brought out by comparing the water quality parameters of a sample with those set for each type of use.
- 2) The quality criteria form the basis for drawing effluent standards.
- 3) Water quality criteria have been designed to provide long term protection. To violate the quality criteria for any substantial length of time or in any substantial portion of the waterway may result in an adverse effect on aquatic life; it may cause hazards to human beings and to consumers of aquatic life.

Water quality criteria do not have regulatory impact, but they form the basis for judgment. To provide water resource protection, quality criteria should apply to all the water bodies of the country

SAQ4

Name the factors that are to be considered while formulating water quality criteria for a particular use.

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SAQ5

State the uses of water quality criteria.

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6.4 MONITORING AND ASSESSMENT – A DISCUSSION

About 50 years ago, most of the rivers of our country remained unspoiled or unpolluted. But over the decades, almost all rivers have become grossly polluted in one stretch or other. Under this situation, water quality monitoring is of prime importance in the management of water resources. Let us define the terms, assessment and monitoring, in the context of water quality control. **Assessment** refers to the method of estimating the value of specified parameters of an aquatic system. **Monitoring** is the process of carrying out a series of systematic observations to obtain data regarding physical, chemical and biological characteristics of a water body in order to verify the agreement with the standards prescribed.

The materials given in the Appendix (Sec. 6.9) of this unit could serve as illustrations for the concepts given in Subsecs. 6.4.2 and 6.4.3. The Hydrology Project is an instance of a detailed study plan for risk assessment in relation to water quality. The Ganga Action Plan illustrates operationisation of a comprehensive scheme for controlling river water quality.

6.4.1 Water Quality Monitoring for Water Resources Management

The main reason for monitoring is to detect changes in the state and functioning of ecosystems. The detection of any abnormal condition must be done at the earliest so that remedial measures can be taken as early as possible. The procedure followed for timely detection of changes in water quality is known as **risk assessment**. The outcome of risk assessment should be formulation of proposals for remedial measures or control strategy, if serious abnormalities are observed in quality parameters. The procedure followed for taking remedial measures is known as **risk management**. The combined activities of risk assessment and risk management are known under the name, **water quality management**. The risk management depends on the overall objective of the organisation – whether it is to

- provide protected water supply or
- discharge treated municipal wastewater or
- discharge effluent from an industry or
- control water quality of a river system.

Monitoring is essential both for risk assessment and risk management. If it is desired only to assess the risk to the water body periodically, **actions are planned as per details given in Subsec.6.4.2**. In case the objective of an organisation, say, a river authority, is to carry out water quality management, a comprehensive action plan is required both for risk assessment and risk management; the **details are given in Subsec. 6.4.3**.

6.4.2 Water Quality Monitoring System for Risk Assessment

Let us assume that an organisation has the objective of monitoring river water quality for risk assessment. The organisation must take into account budget provision for manpower, infrastructure, equipment, glassware, chemicals, training *etc.*, while formulating its aims. Time frame must be worked out and adhered to for all operations from sampling to reporting of the results; otherwise, efforts taken for monitoring will not show the desired results.

The following are the requirements for establishing a river water quality monitoring system for risk assessment:

- i) **The assessment endpoint and measurement endpoint** are to be specified to test the utility of monitoring. The assessment endpoint is a formal expression of the actual environmental value that is to be protected. It helps in securing social acceptance. It is the environmental characteristic that is understood and valued by the public and the decision makers. The measurement endpoint is an expression of an observed or measured response to the hazard. It is a readily measurable environmental characteristic that corresponds to the characteristic chosen as the assessment endpoint. The measurement endpoint can also be considered the performance standard of the monitoring system. For instance, let us consider the environmental problem of discharge of industrial effluent into a river. The management aim, let us say, is to make fish edible without health risk. The assessment endpoint is “no reduction allowed of fisheries volume and public demand”. The measurement endpoint is to test for bioconcentration in fish, tests for persistence of toxicity, *etc.*
- ii) A detailed study plan is to be made taking into account
 - choice of physical, chemical and biological parameters to be estimated
 - water quality criteria desired
 - standardised methods of measurement
 - choice of sampling locations
 - sampling frequencies

- available infrastructure and laboratory facilities, training and other resources
 - statistical requirements *etc.*
- iii) A pilot study is to be conducted to estimate spatial and temporal variance *etc.* and to make refinements in the choice of assessment endpoint, measurement endpoint and the study plan.
 - iv) Samples are to be collected as per standard procedures. Complete details (like location, data, sampling method *etc.*) regarding the samples are to be collected.
 - v) All analyses are to be carried out as per standard procedures and the results are to be properly documented.
 - vi) The data are to be analysed using statistical procedures.
 - vii) Inferences are to be drawn taking into account the assessment endpoint and measurement endpoint.
 - viii) A detailed report is to be prepared indicating water quality problems, remedial actions to be taken for improving water quality and refinements in the steps (i) and (ii) mentioned above.

The report serves as the risk assessment report.

6.4.3 A Comprehensive Scheme for Controlling River Water Quality

Let us examine the sequence of actions that must be followed by a river authority interested in controlling water quality. The river authority must formulate its objectives and make budget provision towards both risk assessment and risk management.

The following is the series of steps suggested:

- A river water quality monitoring system is created and operationalised as per details mentioned in Subsec.6.4.2 to assess the status of the river. The risk assessment report is to be prepared for scrutiny.
- The organisation must examine the risk assessment report and plan its action based on
 - ❖ environmental issues arising out of pollution,
 - ❖ the intensity of pollution (i.e. exposure assessment) and,
 - ❖ extent of damage to the environment (i.e. effect assessment).
- If remedial measures are needed, actions are to be executed as per risk management procedure given below:
 - Sewage treatment plants (STPs) and effluent treatment plants (ETPs) are to be built through the concerned municipal authorities or industrial units at the required locations.
 - Measures are to be taken to tackle other aspects of pollution like open defecation through construction of low cost sanitation schemes, proper street lighting (!) *etc.*
 - As mentioned in Subsec. 6.3.1, design standards, performance standards and procedural standards must be followed by the municipal and industrial units in constructing and operating STPs and ETPs.
 - There must be regular monitoring of the STPs and ETPs by the river authority at the technical, scientific and administrative levels to ensure that the above three standards are followed. The expertise of Pollution Control Boards could be used for these purposes.
 - Efforts must be made to create public awareness regarding the need to avoid river pollution at community level.
 - Proper financial management is essential; it helps in securing public credibility.
 - It is advisable to ensure public participation; it will go a long way in ensuring the success of the programme.

Water Quality Criteria and Uses

Spatial variance:
Variation along some region.

Temporal variance:
Variation with respect to time.

Sewage treatment plant:
The total facilities for the removal of harmful materials from the municipal wastewater before reusing it or allowing it to mix with a river system.

Effluent treatment plant:
The total facilities for the removal of harmful materials from the industrial wastewater before reusing it or allowing it to mix with a river system.

6.4.4 Uses of Monitoring Programmes

In practice, data from monitoring programmes are generally used for a variety of purposes as given below:

- Identification of the state of and trends in water quality is mainly important for evolving control measures. Water quality monitoring is an important aspect of overall water quality management and water resources development. It helps to take preventive and remedial measures to maintain ecological balance in the water body. The early warning received through monitoring programme indicating pollution due to unexpected sudden discharges from industry is especially important, if surface water of that particular river or water system is used for public water supply.
- The identification of pollution in rivers is of particular importance at the boundaries between countries or international water bodies. In that situation, compliance with standards is related to the water quality objectives as prescribed in both national and international standards.
- Monitoring is essential for the successful implementation of environmental legislations; it helps in ensuring that the standards and criteria set by the regulatory agencies are maintained on a continuing basis.
- The data can be used for various projects including research.

SAQ 6

State the importance of pilot study in a water quality monitoring programme.

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6.5 ANALYTICAL TECHNIQUES FOR MONITORING WATER QUALITY

There are two major analytical techniques:

- physical and chemical methods and,
- biological methods.

6.5.1 Physical and Chemical Methods of Monitoring

Traditionally, water quality is assessed by physical and chemical methods. These methods involve specifying standards and limits to physical characteristics and chemical constituents of water systems – whether surface water or wastewater bodies. In recent times, the analytical procedures have vastly improved such that a wide array of water constituents can be estimated even at low concentrations. We have explained the principles of some of these methods in the last unit.

Advantages of physical and chemical methods of monitoring

- The methods, in general, are simple to follow .
- The technology for assessment is established.
- Clear numerical standards are available.
- The data can be obtained quickly.

Problems associated with monitoring by physical and chemical methods

In spite of rapid development in physicochemical analytical procedures, there are problems due to the following reasons:

- The ecological effects of many chemicals present in water bodies are not known at ppm or ppb levels. The studies on their long term ecological effects are quite less.
- The studies on the environmental effect of combined action of pollutants that may occur in a mixture of industrial effluents, municipal wastewaters and other inputs to surface waters (like agricultural run-off) are less common.

This implies that studies based only on physical and chemical methods do not lead to comprehensive study of effect of pollutants on water bodies.

6.5.2 Biomonitoring

An ecological system in and around a clean water body usually consists of many species of organisms. This is known as diversity of biological species or biodiversity. It is considered an indicator of the well being of a water body. Any departure in the diversity among aquatic organisms suggests presence of pollutants. The effect of pollutants on aquatic biology can be of two types:

- Generation of unusual and excessive growth in water courses. (You may remember what you studied about eutrophication in Subsec. 5.5.3.)
- The elimination or major reduction of some life forms. (From time to time, we see news paper reports regarding the mass scale death of fish or turtles or other aquatic species along a region; pollution is usually cited as one of the reasons).

The study of impact of pollution on aquatic life through biological measurements is known as biomonitoring, short form of biological monitoring. Biomonitoring consists in examining biological life at various locations of a water body and comparing the species and diversity found in it with some “standard” for that type of water course. Care must be taken to consider other factors such as the season of the year, geographical aspects, characteristics of the type of water courses *etc.*

We shall discuss two types of biomonitoring:

- bioaccumulation monitoring
- ecosystem monitoring.

i) Bioaccumulation monitoring

The chemical concentration is measured in biological materials. The inferences are made based on the comparison between the tested water body and standard values recommended for it.

ii) Ecosystem monitoring

It is done through observation of changes in the community structure and functions of various species that are characteristic of location of a water body. The changes in species composition, density, diversity, rates of biological processes *etc.* are related to environmental disturbances. Three of the methods followed using this principle are discussed below:

- a) Indicator organism method rests on the principle that different varieties of organism have differing sensitivities to water quality changes. Water quality can be assessed by the study of population of each type of species in the water system and comparing it with available literature data for the effect of pollutants. The analysis of plankton in streams provides information on short time basis, since these move along the stream. The analysis of those species at the bottom of the river gives information over a longer period since these are almost fixed in position. Further their age can also

Planktons:

Organisms suspended in water, consisting chiefly of minute plants or animals; some larger forms are also included which have weak powers of movement.

Water

Flora:

The plants of a specified region or time.

Fauna:

The animals of a specified region or time.

provide more information. Such indicator organisms give information on primary level towards environmental impact of pollution. Insects, larvae, birds and the other flora and fauna offer further information on secondary impacts of pollution. The indicator organism method has the limitation that variations in biological life can occur from time to time and from place to place even without intervention by pollutants.

The Central Pollution Control Board has developed a system for water quality evaluation on the basis of the relationship between the population of certain groups of organisms and the organic load (expressed in terms of BOD). The system is known as "Biological Water Quality Evaluation System (BWQES)". The details are given in the Appendix part of this unit; this part is an additional material and you can appreciate the content, if you have Biology background. In case you don't follow the related material given in the Appendix, you need not feel worried.

As an alternative for indicator organism method, the ecologists combine biological diversity studies with indicator organism method to monitor water quality. Two ecosystem monitoring methods used by industry based on these principles are given below:

- b) A comparison of results of comprehensive analyses of aquatic life near the industrial plant site before and after its installation throws light on the indicator species, population and diversity aspects under both the conditions. The studies can yield significant information regarding the environmental impact of the industrial unit.
- c) Another way is to examine aquatic life in the water body above and below the points of effluent discharge from the industrial unit. If biological characteristics are identical at both the locations, it signifies that there is no impact of effluent on the water body. On the contrary, any disparity with respect to diversity or indicator organism population indicates that water quality is adversely affected.

Advantages of biomonitoring

The biomonitoring methods have several advantages over physicochemical monitoring.

1. First of all, a possibility arises to relate the presence of a constituent and its concentration to the ecological change.
2. Biological measurements provide the only way of studying the interactive processes of toxicants and their combined effect on the environment.
3. Biomonitoring methods are more precise and sensitive than chemical analysis to detect adverse conditions in the environment. This is due to the fact that the biological response is both integrative and accumulative in nature.
4. Biomonitoring may help in reducing the number of measurements both in space and time.

Disadvantages of biomonitoring

It is possible that biomonitoring methods may lead to misuse or oversimplification in the hands of non-biologists. It is necessary to draw attention to the limitations of biomonitoring.

- A biological response will become visible only if the intensity and exposure duration of the disturbing factor (pollutant) is matched with the sensitivity and response rate of the biological system.
- Although biological surveillance will detect ecological change indicative of a change in water quality, it will not identify the specific cause for this change. In

case of toxic pollution, the cause has to be identified by chemical analysis as a complementary method.

- To monitor all water quality criteria and many different pollutants, ecosystem monitoring should ideally involve all components of the community. Such a comprehensive assessment will not be feasible. In practice a less comprehensive evaluation will suffice for most forms of pollution.
- The data generated by ecosystem monitoring are not easily understood by nonbiologists. This requires processing of the basic data in order to provide more acceptable gradation.
- Although ecosystem monitoring will detect ecological changes, a weakness in the system is in interpreting the observed changes in terms of water quality.
- The biomonitoring methodologies may not be globally standardisable.

6.5.3 Need for Integrated Monitoring Mechanism

Physico-chemical monitoring and biomonitoring methods must be regarded as complementary to each other. Biological parameters indicate directly the “effects” of past and present exposure to pollution; then the physico-chemical variables provide the valuable clue or the “cause” that created the observed variations in the ecosystem. An integrated approach may lead to cost saving. For instance, common sampling procedure for the study of various parameters may save operational costs. As mentioned earlier, even if physico-chemical investigations show abnormal values for certain parameters, biological assessment could be of help to the industry in cost-saving with reference to treatment of effluents, if the latter indicates that there is no observable effect on the ecosystem. Further, biomonitoring helps in reducing the number of standard estimations.

SAQ 7

State the advantages of biomonitoring over chemical monitoring.

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6.6 SUMMARY

The factors that decide the water quality are large and interlinked. Many variables are required to describe the status of water bodies in quantitative terms. Moreover, our understanding of water quality has evolved over the past century with the expansion of water use requirements and the ability to measure and interpret water characteristics. The process of water quality assessment is done through an evaluation of the physical, chemical and biological characteristics of water. With the advent of industrialisation and increasing population, water requirements have increased together with greater demand for higher quality of water. Each of the water uses has specific water quality requirements. The water quality requirements for different uses are specified through water quality criteria. The water quality is to be maintained through monitoring and assessment. There is a need to design an integrated system of monitoring using physicochemical and biological monitoring methods.

6.7 TERMINAL QUESTIONS

1. State the significance of SAR value of a water sample.
2. Give one example each for antagonistic reaction and synergistic reaction, which are of importance in deciding water quality criteria.
3. State the water quality factors that spoil the aesthetics of its recreational uses.
4. In what way are the organic substances harmful as a content of

- i) municipal water supply, and
- ii) industrial water supply ?
5. Define the term, water quality criteria.
6. How are the water quality criteria derived?
7. Why is it advantageous to have integrated monitoring mechanism?

6.8 ANSWERS

Self-Assessment Questions

1. Substituting in Eq. 6.1, SAR = 5.64.
2. Water high in HCO_3^- concentration will tend to precipitate calcium and magnesium ions as their carbonates over the soil layer due to evapotranspiration process. The SAR value of the water sample increases thereby giving rise to sodium hazard.
3. The cloudy days affect an aquatic system to a significant extent since the aquatic plants cannot carry out photosynthesis and, only respiration continues thereby decreasing DO level and increasing CO_2 level in water.
4.
 - i) Specific requirements and characteristics of the consumers of each class.
 - ii) Bioconcentration
 - iii) Antagonistic and synergistic reactions
 - iv) Adaptation by the species.
5. Water quality criteria are useful in checking the suitability of a water body for a particular use. The quality criteria form the basis for deriving effluent standards. These are designed to provide long term protection to the water body.
6. A pilot study gives us information about the variations in water quality that occur along some region and time. It helps us to make refinements in the choice of assessment endpoint, measurement endpoint and the study plan of the monitoring programme.
7. Biomonitoring helps us to relate the presence of a constituent and its concentration to the ecological change. It helps to study the interactive processes among various pollutants. Biomonitoring is more precise than chemical methods since biological response is integrative and accumulative in nature. Biomonitoring may help in reducing the number of measurements both in space and time.

Terminal Questions

1. Generally, water with SAR value greater than 10 must be avoided for agricultural purposes, as it signifies high Na^+ content. High Na^+ content could result in reducing water absorption by the plants. Soil permeability is reduced and adds to soil salinity problems.
2. An example for antagonistic reaction:
Excess sulphates or chlorides in irrigation water reduce the availability of phosphorus and organic acids to plants.
An example for synergistic reaction:
Individually, water sample of pH near 5 or with iron concentration of 0.9 ppm is not that much toxic to aquatic life; but if these two conditions are present together, the fish varieties die.
3.
 - i) Growth of plants and organisms like blue green algae, sewage fungus *etc.*
 - ii) Organic load, oil, grease *etc.* that cause odour, colour or foaming.
4.
 - i) Some of the organics even could lead to cancer or they could give rise to this hazard after chlorination (due to formation of substances like chloroform). They can lead to decrease of DO and production of foul smelling and harmful substances like NH_3 , H_2S *etc.*
 - ii) Organic load can increase corrosion problem and also damage the ion exchange resins.
5. Water quality criteria are statements broadly defining the safety margins for the physical, chemical, and biological characteristics and constituents of water.

6. Water quality criteria are derived from scientific facts obtained from numerous experiments. The quality criteria are the essence of hundreds of pages of data collected by many experts working in varying constituents of water, soil and air as also conditions of temperature, pH *etc.*
7. Biological parameters indicate the effects of past and present exposure to pollution; the physio-chemical variables provide a valuable clue for the 'cause' that created the variations in the ecosystem. An integrated approach may also help in cost saving by restricting the samples required and measurements needed.

6.9 APPENDIX

Let us now focus on the efforts made at government level in our country towards water quality monitoring. Primarily water quality is controlled through regulation of municipal and industrial wastewaters. Just like many other countries, legislations have been passed in relation to water quality maintenance. Some of these are mentioned below:

- The Water (Prevention and Control of Pollution) Act – 1974 and 1988 Amendment
- The Water (Prevention and Control of Pollution) Cess Act – 1977
- The Environment (Protection) Act – 1986
- Environmental Impact Assessment Notification – 1994

Through all these legislations, substantial provisions have been made to protect water bodies. The Central Pollution Control Board and the State Pollution Control Boards were created as a result of Water Act. These bodies have to function as regulatory agencies for controlling water pollution. The amendment made in 1988 empowers these Boards to issue orders even to close down the polluting industrial units.

In the field of water quality monitoring, many organisations of Central and State Governments are involved as mentioned below:

- Central Water Commission - through 319 out of 877 Observation Stations to monitor river water quality across the country (as per IX Five Year Plan document)
- Central Ground Water Board - through 14995 Stations set up to monitor groundwater quality (as per IX Five Year Plan document)
- Central Pollution Control Board and State Pollution Control Boards - through around 784 Stations established all over the country (as per year 2003 Statistics of CPCB)
- Irrigation, Groundwater, Municipal and other Public Health Authorities, Water & Sewerage Boards *etc.* of State Governments.

In many cases, there is need for exchange of data and information as also for sharing of resources and manpower to save time and cost.

Now, we shall deal with two case studies to highlight some of the features of water quality monitoring. The first is on Hydrology Project, which was launched for specifying a detailed plan for obtaining water quality monitoring data. The other, Ganga Action Plan, is a programme operationalised for improving river water quality. Finally, we shall also give details regarding Biological Water Quality Evaluation System (BWQES).

Case Study 1: Hydrology Project

The Government of India launched in September 1995 for a period of six years the “Hydrology Project” with assistance from the World Bank and the Government of Netherlands. The purpose was to develop Hydrological Information System (HIS); it represents collection of a comprehensive water related data at agency (like CPCB *etc.*), state and national levels. HIS helps in collecting data regarding:

- rainfall and other weather parameters
- quality and quantity of surface water and
- quality and quantity of groundwater.

The project was expected to provide a sound base for improving the infrastructure and staff capabilities of the laboratories of Central Water Commission, Central Groundwater Board and Irrigation and Groundwater agencies of the State Governments. As the desired outcome, these organisations were to be trained in collection and processing of data for water quality monitoring and, water resources evaluation. The following is the list of activities under the project:

- upgrading the infrastructure for collection of hydrological and weather data,
- provision of equipment and materials
- preparation of training modules
(wherein detailed procedures are given for estimating important physico-chemical and biological parameters)
- imparting training to improve the human resources of the organisations
- development of interactive computerised data banks within the participating agencies.

Computer software was also developed to organise the vast amount of groundwater data.

Hydrology Project, thus, has provided a technical framework as also basic material support for monitoring and assessment of water quality. Let us now know the particular features of a mass scale operation carried over the river Ganga and its tributaries to monitor and manage water quality.

Case Study 2: Ganga Action Plan

Ganga is a river to which the people of the country are attached emotionally and spiritually; millions of pilgrims bathe annually at Varanasi alone. The population increase and industrial growth have resulted in mixing of wastewaters of around 5000 million liters per day (mld) along the river Ganga and its tributaries. Added to the above, agricultural run-off containing pesticides and fertilizers also mix with the river at various places. In one of the pilgrim centres located on the banks of the river, thousands of burnt and partially burnt human bodies along with animal carcasses are thrown into the river. There are visible signs to show that biodiversity of the river system has got affected significantly. With the objective of bringing down pollution level in the river to bathing quality (Class B) level, the Central Government launched Ganga Action Plan (GAP) in January 1985. Some of the recommendations made in this regard are given below:

- Interception and diversion of sewages
- Construction of sewage treatment plants
- Designing low cost sanitation systems to tackle open defecation
- Building electric and improved wood crematoria for dealing with unburnt/half burnt dead bodies *etc.*
- Monitoring of water quality

We shall concentrate our attention only on the water quality monitoring aspect of GAP. The following standards were specified for three parameters as attainable levels for the purpose of bringing water quality to bathing levels:

Dissolved oxygen	not less than 5 ppm
Biochemical oxygen demand	not more than 3 ppm
Bacterial load (<i>coliform</i> count)	not more than 10000 MPN per 100 ml

Note that as per Table 6.3, criteria for total *coliform* for a water body to be used for outdoor bathing is 500 MPN per 100 ml.

The Principal Director of Audit, Scientific Departments of the Government of India, has prepared a report on the project. The report presents a detailed analysis of the project implementation. The report is available on the website:

Ganga Action Plan –

<http://www.cagindia.org/reports/scientific/2000-book2/gangaactionplan.htm>

Confining ourselves to water quality aspects, we can note a prominent feature. The parameters studied indicate that during the period 1993-1999, water quality of the river Ganga has not improved significantly in many places. The lessons that flow out of the project are that, for successful implementation of water quality management programme, there is a need to strengthen technical and administrative monitoring and, to facilitate competent technological support.

Biological Water Quality Evaluation System

The CPCB has developed a system for water quality evaluation known as “Biological Water Quality Evaluation System (BWQES)”. It is a system that specifies water quality by relating the population of certain families of organisms to organic load (expressed in terms of BOD). It is based on the calibration study carried out using the data collected from the river Yamuna from the point of view of distribution of certain organisms. To show the results of a particular water system in an easily understandable way, the abundance ranges of the indicator organisms have been calibrated in relation to their BOD ranges. On the basis of the population of different kinds of organisms that vary in their response to pollution load of water, the degrees of water quality deterioration are categorised into the following five different classes: clean, slightly polluted, moderately polluted, highly polluted and severely polluted. In conformity with this categorisation, the indicator organisms have also been placed into five different classes. On the basis of measurement of biological parameters, biomapping of water systems has been carried out by the Pollution Control Boards in India. The biomapping is quite useful for making inferences on water quality of water systems. During the process of biomapping, a colour coding system is used to indicate the five different degrees of water quality deterioration as per details given in Table A.1. Note that this table also indicates the organisms which are sensitive to or tolerant of water pollution. The explanation for abundancy notation (A to G) is given as the foot note of the table.

Table A.1: Different Degrees of Water Quality Deterioration in Relation to Indicator Organism Population.

Organism	Water Quality	(BOD Range)/ ppm	Abundancy*	Class	Indicator Colour
<i>Ephemeroptera</i> <i>Trichoptera</i> <i>Plecoptera</i>	Clean	< 1	C-D	I	Blue
<i>Odonata</i>	Slightly polluted	1-5	A-E	II	Light Blue
<i>Crustacea</i> <i>Hemiptera</i> <i>Coleoptera</i>	Moderately polluted	1-10	A-E	III	Green
<i>Diptera</i> <i>Mollusca</i> <i>Hirudenia</i>	Highly polluted	1-15	A-E	IV	Orange
<i>Diptera</i> <i>Oligochaeta</i> No animals	Severely polluted	20-30	A-C	V	Red

*NB: The abundancy classes can be defined as follows.

Abundancy

A
B
C
D
E
F
G

Population Level

Single
Scarce
Common
More than common
Dominant
Excessive
Only this species

Numbers

1
2-10
11-50
51-100
101-1000
1001-10,000
More than 10,000