Chapter

Water Quality Parameters

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Abstract

Since the industrial revolution in the late eighteenth century, the world has discovered new sources of pollution nearly every day. So, air and water can potentially become polluted everywhere. Little is known about changes in pollution rates. The increase in water-related diseases provides a real assessment of the degree of pollution in the environment. This chapter summarizes water quality parameters from an ecological perspective not only for humans but also for other living things. According to its quality, water can be classified into four types. Those four water quality types are discussed through an extensive review of their important common attributes including physical, chemical, and biological parameters. These water quality parameters are reviewed in terms of definition, sources, impacts, effects, and measuring methods.

Keywords: water quality, physical parameters, chemical parameters, biological parameters, radioactive substances, toxic substances, indicator organisms

1. Introduction

Water is the second most important need for life to exist after air. As a result, water quality has been described extensively in the scientific literature. The most popular definition of water quality is "it is the physical, chemical, and biological characteristics of water" [1, 2]. Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose [3, 4].

2. Classification of water

Based on its source, water can be divided into ground water and surface water [5]. Both types of water can be exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils [6].

Water quality can be classified into four types—potable water, palatable water, contaminated (polluted) water, and infected water [7]. The most common scientific definitions of these types of water quality are as follows:

1. *Potable water:* It is safe to drink, pleasant to taste, and usable for domestic purposes [1, 7].

2. *Palatable water:* It is esthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health [7].

3. *Contaminated (polluted) water:* It is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use [7].

4. *Infected water:* It is contaminated with pathogenic organism [7].

3. Parameters of water quality

There are three types of water quality parameters physical, chemical, and biological [8, 9]. They are summarized in **Table 1**.

3.1 Physical parameters of water quality

3.1.1 Turbidity

Turbidity is the cloudiness of water [10]. It is a measure of the ability of light to pass through water. It is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water [2].

No.	**Types of water quality parameters**		
	Physical parameters	**Chemical parameters**	**Biological parameters**
1	Turbidity	pH	Bacteria
2	Temperature	Acidity	Algae
3	Color	Alkalinity	Viruses
4	Taste and odor	Chloride	Protozoa
5	Solids	Chlorine residual	
6	Electrical conductivity (EC)	Sulfate	
7		Nitrogen	
8		Fluoride	
9		Iron and manganese	
10		Copper and zinc	
11		Hardness	
12		Dissolved oxygen	
13		Biochemical oxygen demand (BOD)	
14		Chemical oxygen demand (COD)	
15		Toxic inorganic substances	
16		Toxic organic substances	
17		Radioactive substances	

Table 1.
Parameters of water quality.

Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. The impact of turbidity can be summarized in the following points:

1. It can increase the cost of water treatment for various uses [11].

2. The particulates can provide hiding places for harmful microorganisms and thereby shield them from the disinfection process [12].

3. Suspended materials can clog or damage fish gills, decreasing its resistance to diseases, reducing its growth rates, affecting egg and larval maturing, and affecting the efficiency of fish catching method [13, 14].

4. Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides [15].

5. The amount of available food is reduced [15] because higher turbidity raises water temperatures in light of the fact that suspended particles absorb more sun heat. Consequently, the concentration of the dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water.

Turbidity is measured by an instrument called nephelometric turbidimeter, which expresses turbidity in terms of NTU or TU. A TU is equivalent to 1 mg/L of silica in suspension [10].

Turbidity more than 5 NTU can be visible to the average person while turbidity in muddy water, it exceeds 100 NTU [10]. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil [9, 16].

3.1.2 Temperature

Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature [10]. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent [11]. It also affects the biosorption process of the dissolved heavy metals in water [17, 18]. Most people find water at temperatures of 10–15°C most palatable [10, 19].

3.1.3 Color

Materials decayed from organic matter, namely, vegetation and inorganic matter such as soil, stones, and rocks impart color to water, which is objectionable for esthetic reasons, not for health reasons [10, 20].

Color is measured by comparing the water sample with standard color solutions or colored glass disks [10]. One color unit is equivalent to the color produced by a 1 mg/L solution of platinum (potassium chloroplatinate (K_2PtCl_6)) [10].

The color of a water sample can be reported as follows:

- *Apparent color* is the entire water sample color and consists of both dissolved and suspended components color [10].

- *True color* is measured after filtering the water sample to remove all suspended material [19].

Color is graded on scale of 0 (clear) to 70 color units. Pure water is colorless, which is equivalent to 0 color units [10].

3.1.4 Taste and odor

Taste and odor in water can be caused by foreign matter such as organic materials, inorganic compounds, or dissolved gasses [19]. These materials may come from natural, domestic, or agricultural sources [21].

The numerical value of odor or taste is determined quantitatively by measuring a volume of sample A and diluting it with a volume of sample B of an odor-free distilled water so that the odor of the resulting mixture is just detectable at a total mixture volume of 200 ml [19, 22]. The unit of odor or taste is expressed in terms of a threshold number as follows:

$$\text{TON or TTN} = (A + B)/A \tag{1}$$

where TON is the threshold odor number and TTN is the threshold taste number.

3.1.5 Solids

Solids occur in water either in solution or in suspension [22]. These two types of solids can be identified by using a glass fiber filter that the water sample passes through [22]. By definition, the suspended solids are retained on the top of the filter and the dissolved solids pass through the filter with the water [10].

If the filtered portion of the water sample is placed in a small dish and then evaporated, the solids as a residue. This material is usually called total dissolved solids or TDS [10].

$$\text{Total solid (TS)} = \text{Total dissolved solid (TDS)} + \text{Total suspended solid (TSS)} \tag{2}$$

Water can be classified by the amount of TDS per liter as follows:

- freshwater: <1500 mg/L TDS;
- brackish water: 1500–5000 mg/L TDS;
- saline water: >5000 mg/L TDS.

The residue of TSS and TDS after heating to dryness for a defined period of time and at a specific temperature is defined as fixed solids. Volatile solids are those solids lost on ignition (heating to 550°C) [10].

These measures are helpful to the operators of the wastewater treatment plant because they roughly approximate the amount of organic matter existing in the total solids of wastewater, activated sludge, and industrial wastes [1, 22]. **Figure 1** describes the interrelationship of solids found in water [22]. They are calculated as follows [10]:

- Total solids:

$$\text{Total solids (mg/L)} = [(\text{TSA}-\text{TSB})] \times 1000/\text{sample (mL)} \tag{3}$$

where TSA = weight of dried residue + dish in milligrams and TSB = weight of dish in milligrams.

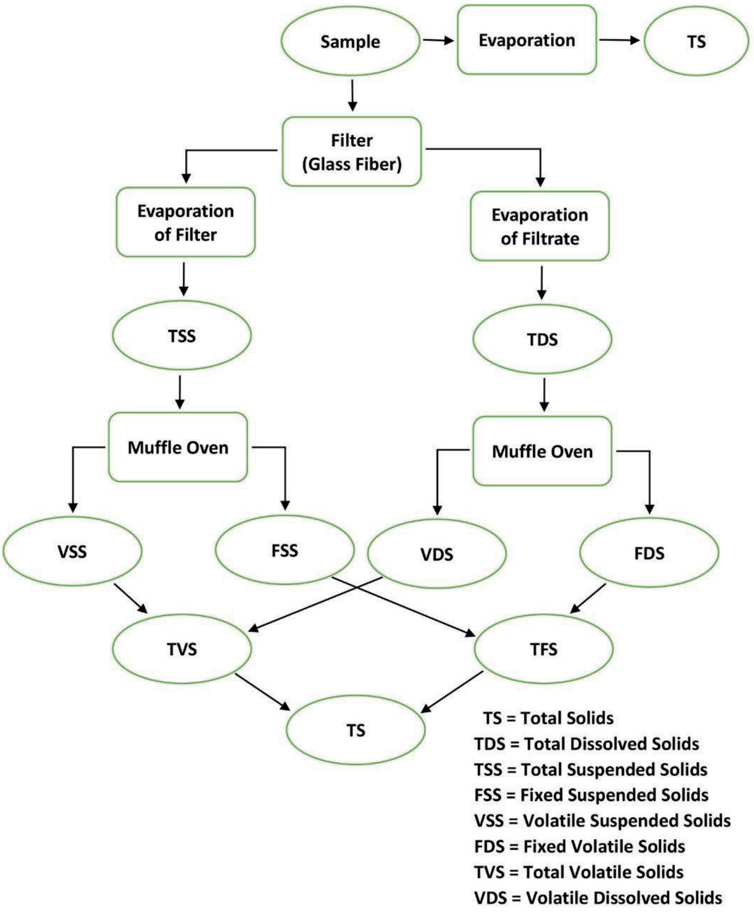

Figure 1.
Interrelationship of solids found in water [22].

- Total dissolved solids:

$$\text{Total dissolved solids (mg/L)} = [(\text{TDSA} - \text{TDSB})] \times 1000/\text{sample (mL)} \quad (4)$$

where TDSA = weight of dried residue + dish in milligrams and TDSB = weight of dish in milligrams.

- Total suspended solids:

$$\text{Total suspended solids (mg/L)} = [(\text{TSSA} - \text{TSSB})] \times 1000/\text{sample (mL)} \quad (5)$$

where TSSA = weight of dish and filter paper + dried residue and TSSB = weight of dish and filter paper in milligram.

- Fixed and volatile suspended solids:

$$\text{Volatile suspended solids (mg/L)} = [(\text{VSSA} - \text{VSSB})] \times 1000/\text{sample (mL)} \quad (6)$$

where VSSA = weight of residue + dish and filter before ignition, mg and VSSB = weight of residue + dish and filter after ignition, mg.

3.1.6 Electrical conductivity (EC)

The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current [22]. Since the electrical current is carried by ions in solution, the conductivity increases as the concentration [10] of ions increases. Therefore, it is one of the main parameters used to determine the suitability of water for irrigation and firefighting.

Units of its measurement are as follows:

- U.S. units = micromhos/cm
- S.I. units = milliSiemens/m (mS/m) or dS/m (deciSiemens/m)

where (mS/m) = 10 umho/cm (1000 μS/cm = 1 dS/m).

Pure water is not a good conductor of electricity [2, 10]. Typical conductivity of water is as follows:

- Ultra-pure water: 5.5×10^{-6} S/m;
- Drinking water: 0.005–0.05 S/m;
- Seawater: 5 S/m.

The electrical conductivity can be used to estimate the TDS value of water as follows [10, 22]:

$$\text{TDS (mg/L)} \cong \text{EC (dS/m or umho/cm)} \times (0.55\text{–}0.7) \qquad (7)$$

TDS can be used to estimate the ionic strength of water in the applications of groundwater recharging by treated wastewater [22]. The normal method of measurement is electrometric method [10].

3.2 Chemical parameters of water quality

3.2.1 pH

pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration [9, 12]. It is a dimensionless number indicating the strength of an acidic or a basic solution [23]. Actually, pH of water is a measure of how acidic/basic water is [19, 20]. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions [2].

As shown in **Figure 2**, pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution [2, 24]. Pure water is neutral, with a pH close to 7.0 at 25°C. Normal rainfall has a pH of approximately 5.6 (slightly acidic) owing to atmospheric carbon dioxide gas [10]. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need [24].

A change of 1 unit on a pH scale represents a 10-fold change in the pH [10], so that water with pH of 7 is 10 times more acidic than water with a pH of 8, and water with a pH of 5 is 100 times more acidic than water with a pH of 7. There are two methods available for the determination of pH: electrometric and colorimetric methods [10].

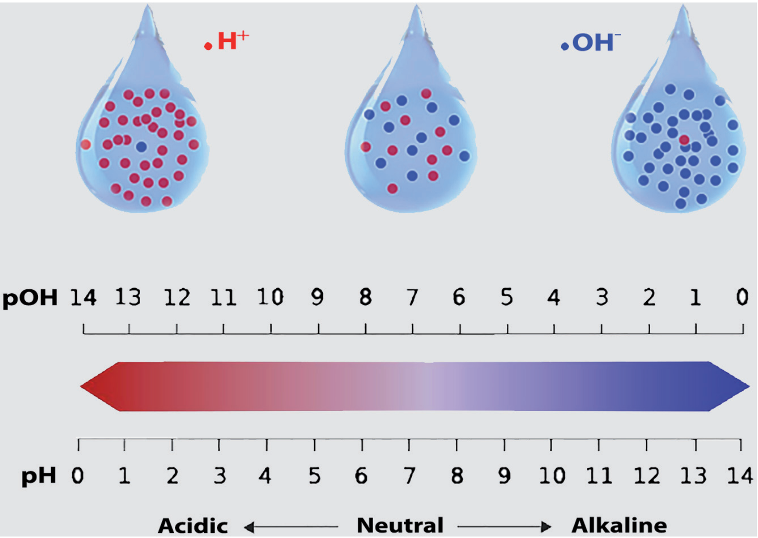

Figure 2.
pH of water.

Excessively high and low pHs can be detrimental for the use of water. A high pH makes the taste bitter and decreases the effectiveness of the chlorine disinfection, thereby causing the need for additional chlorine [21]. The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances [10].

Pollution can modify the pH of water, which can damage animals and plants that live in the water [10].

The effects of pH on animals and plants can be summarized as follows:

- Most aquatic animals and plants have adapted to life in water with a specific pH and may suffer from even a slight change [15].
- Even moderately acidic water (low pH) can decrease the number of hatched fish eggs, irritate fish and aquatic insect gills, and damage membranes [14].
- Water with very low or high pH is fatal. A pH below 4 or above 10 will kill most fish, and very few animals can endure water with a pH below 3 or above 11 [15].
- Amphibians are extremely endangered by low pH because their skin is very sensitive to contaminants [15]. Some scientists believe that the current decrease in amphibian population throughout the globe may be due to low pH levels induced by acid rain.

The effects of pH on other chemicals in water can be summarized as follows:

- Heavy metals such as cadmium, lead, and chromium dissolve more easily in highly acidic water (lower pH). This is important because many heavy metals become much more toxic when dissolved in water [21].
- A change in the pH can change the forms of some chemicals in the water. Therefore, it may affect aquatic plants and animals [21]. For instance, ammonia is relatively harmless to fish in neutral or acidic water. However, as the water becomes more alkaline (the pH increases), ammonia becomes progressively more poisonous to these same organisms.

3.2.2 Acidity

Acidity is the measure of acids in a solution. The acidity of water is its quantitative capacity to neutralize a strong base to a selected pH level [10]. Acidity in water is usually due to carbon dioxide, mineral acids, and hydrolyzed salts such as ferric and aluminum sulfates [10]. Acids can influence many processes such as corrosion, chemical reactions and biological activities [10].

Carbon dioxide from the atmosphere or from the respiration of aquatic organisms causes acidity when dissolved in water by forming carbonic acid (H_2CO_3). The level of acidity is determined by titration with standard sodium hydroxide (0.02 N) using phenolphthalein as an indicator [10, 20].

3.2.3 Alkalinity

The alkalinity of water is its acid-neutralizing capacity comprised of the total of all titratable bases [10]. The measurement of alkalinity of water is necessary to determine the amount of lime and soda needed for water softening (e.g., for corrosion control in conditioning the boiler feed water) [22]. Alkalinity of water is mainly caused by the presence of hydroxide ions (OH^-), bicarbonate ions (HCO^{3-}), and carbonate ions (CO_3^{2-}), or a mixture of two of these ions in water. As stated in the following equation, the possibility of OH^- and HCO_3^- ions together are not possible because they react together to produce CO_3^{2-} ions:

$$OH^- + HCO_3^- \rightarrow CO_3^{2-} + H_2O \qquad (8)$$

Alkalinity is determined by titration with a standard acid solution (H_2SO_4 of 0.02 N) using selective indicators (methyl orange or phenolphthalein).

The high levels of either acidity or alkalinity in water may be an indication of industrial or chemical pollution. Alkalinity or acidity can also occur from natural sources such as volcanoes. The acidity and alkalinity in natural waters provide a buffering action that protects fish and other aquatic organisms from sudden changes in pH. For instance, if an acidic chemical has somehow contaminated a lake that had natural alkalinity, a neutralization reaction occurs between the acid and alkaline substances; the pH of the lake water remains unchanged. For the protection of aquatic life, the buffering capacity should be at least 20 mg/L as calcium carbonate.

3.2.4 Chloride

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution [7]. Chlorides may enter surface water from several sources including chloride-containing rock, agricultural runoff, and wastewater.

Chloride ions Cl^- in drinking water do not cause any harmful effects on public health, but high concentrations can cause an unpleasant salty taste for most people. Chlorides are not usually harmful to people; however, the sodium part of table salt has been connected to kidney and heart diseases [25]. Small amounts of chlorides are essential for ordinary cell functions in animal and plant life.

Sodium chloride may impart a salty taste at 250 mg/L; however, magnesium or calcium chloride are generally not detected by taste until reaching levels of

1000 mg/L [10]. Standards for public drinking water require chloride levels that do not exceed 250 mg/L. There are many methods to measure the chloride concentration in water, but the normal one is the titration method by silver nitrate [10].

3.2.5 Chlorine residual

Chlorine (Cl_2) does not occur naturally in water but is added to water and wastewater for disinfection [10]. While chlorine itself is a toxic gas, in dilute aqueous solution, it is not harmful to human health. In drinking water, a residual of about 0.2 mg/L is optimal. The residual concentration which is maintained in the water distribution system ensures good sanitary quality of water [11].

Chlorine can react with organics in water forming toxic compounds called trihalomethanes or THMs, which are carcinogens such as chloroform $CHCl_3$ [11, 22]. Chlorine residual is normally measured by a color comparator test kit or spectrophotometer [10].

3.2.6 Sulfate

Sulfate ions (SO_4^{2-}) occur in natural water and in wastewater. The high concentration of sulfate in natural water is usually caused by leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt) [11, 26]. If high concentrations are consumed in drinking water, there may be objectionable tastes or unwanted laxative effects [26], but there is no significant danger to public health.

3.2.7 Nitrogen

There are four forms of nitrogen in water and wastewater: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen [10]. If water is contaminated with sewage, most of the nitrogen is in the forms of organic and ammonia, which are transformed by microbes to form nitrites and nitrates [22]. Nitrogen in the nitrate form is a basic nutrient to the growth of plants and can be a growth-limiting nutrient factor [10].

A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality [22]. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas [22]. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants [19]. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia [10, 19].

3.2.8 Fluoride

A moderate amount of fluoride ions (F^-) in drinking water contributes to good dental health [10, 19]. About 1.0 mg/L is effective in preventing tooth decay, particularly in children [10].

Excessive amounts of fluoride cause discolored teeth, a condition known as dental fluorosis [11, 19, 26]. The maximum allowable levels of fluoride in public water supplies depend on local climate [26]. In the warmer regions of the country, the maximum allowable concentration of fluoride for potable water is 1.4 mg/L; in colder climates, up to 2.4 mg/L is allowed.

There are four methods to determine ion fluoride in water; the selection of the used method depends on the type of water sample [10].

3.2.9 Iron and manganese

Although iron (Fe) and manganese (Mn) do not cause health problems, they impart a noticeable bitter taste to drinking water even at very low concentration [10, 11].

These metals usually occur in groundwater in solution as ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions. When these ions are exposed to air, they form the insoluble ferric (Fe^{3+}) and manganic ($Mn^{3+)}$ forms making the water turbid and unacceptable to most people [10].

These ions can also cause black or brown stains on laundry and plumbing fixtures [7]. They are measured by many instrumental methods such as atomic absorption spectrometry, flame atomic absorption spectrometry, cold vapor atomic absorption spectrometry, electrothermal atomic absorption spectrometry, and inductively coupled plasma (ICP) [10].

3.2.10 Copper and zinc

Copper (Cu) and zinc (Zn) are nontoxic if found in small concentrations [10]. Actually, they are both essential and beneficial for human health and growth of plants and animals [25]. They can cause undesirable tastes in drinking water. At high concentrations, zinc imparts a milky appearance to the water [10]. They are measured by the same methods used for iron and manganese measurements [10].

3.2.11 Hardness

Hardness is a term used to express the properties of highly mineralized waters [10]. The dissolved minerals in water cause problems such as scale deposits in hot water pipes and difficulty in producing lather with soap [11].

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions cause the greatest portion of hardness in naturally occurring waters [9]. They enter water mainly from contact with soil and rock, particularly limestone deposits [10, 27].

These ions are present as bicarbonates, sulfates, and sometimes as chlorides and nitrates [10, 26]. Generally, groundwater is harder than surface water. There are two types of hardness:

- *Temporary hardness* which is due to carbonates and bicarbonates can be removed by boiling, and

- *Permanent hardness* which is remaining after boiling is caused mainly by sulfates and chlorides [10, 21, 22]

Water with more than 300 mg/L of hardness is generally considered to be hard, and more than 150 mg/L of hardness is noticed by most people, and water with less than 75 mg/L is considered to be soft.

From health viewpoint, hardness up to 500 mg/L is safe, but more than that may cause a laxative effect [10]. Hardness is normally determined by titration with ethylene diamine tetra acidic acid or (EDTA) and Eriochrome Black and Blue indicators. It is usually expressed in terms of mg/L of $CaCO_3$ [10, 19].

$$\text{Total hardness mg/L as CaCO}_3 = \text{calcium hardness mg/L as CaCO}_3 + \text{magnesium hardness mg/L as CaCO}_3 \tag{9}$$

An accepted water classification according to its hardness is as in **Table 2** [19].

3.2.12 Dissolved oxygen

Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution [10]. The higher the concentration of dissolved oxygen, the better the water quality.

Oxygen is slightly soluble in water and very sensitive to temperature. For example, the saturation concentration at 20°C is about 9 mg/L and at 0°C is 14.6 mg/L [22].

The actual amount of dissolved oxygen varies depending on pressure, temperature, and salinity of the water. Dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people.

There are three main methods used for measuring dissolved oxygen concentrations: the colorimetric method—quick and inexpensive, the Winkler titration method—traditional method, and the electrometric method [10].

3.2.13 Biochemical oxygen demand (BOD)

Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen [10, 22]. The organics are broken down into simpler compounds, such as CO_2 and H_2O, and the microbes use the energy released for growth and reproduction [22].

When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD). The more organic material there is in the water, the higher the BOD used by the microbes will be. BOD is used as a measure of the power of sewage; strong sewage has a high BOD and weak sewage has low BOD [22].

The complete decomposition of organic material by microorganisms takes time, usually 20 d or more under ordinary circumstances [22]. The quantity of oxygen used in a specified volume of water to fully decompose or stabilize all biodegradable organic substances is called the ultimate BOD or BOD_L.

BOD is a function of time. At time = 0, no oxygen will have been consumed and the BOD = 0. As each day goes by, oxygen is used by the microbes and the BOD increases. Ultimately, the BOD_L is reached and the organic materials are completely decomposed.

Water classification	Total hardness concentration as mg/L as $CaCO_3$
Soft water	<50 mg/L as $CaCO_3$
Moderately hard	50–150 mg/L as $CaCO_3$
Hard water	150–300 mg/L as $CaCO_3$
Very hard	>300 mg/L as $CaCO_3$

Table 2.
Classification of water according to its hardness.

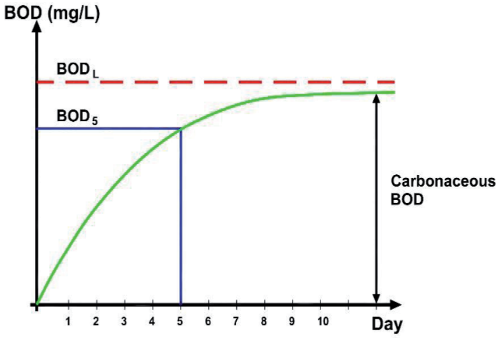

Figure 3.
BOD curve [22].

A graph of the BOD versus time is illustrated as in **Figure 3**. This is called the BOD curve, which can be expressed mathematically by the following equation:

$$BOD_t = BOD_L \times \left(1 - 10^{-kt}\right) \quad (10)$$

where BOD_t = BOD at any time t, mg/L; BOD_L = ultimate BOD, mg/L; k = a constant representing the rate of the BOD reaction; t = time, d.

The value of the constant rate k depends on the temperature, the type of organic materials, and the type of microbes exerting the BOD [22].

3.2.14 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a parameter that measures all organics: the biodegradable and the non-biodegradable substances [22]. It is a chemical test using strong oxidizing chemicals (potassium dichromate), sulfuric acid, and heat, and the result can be available in just 2 h [10]. COD values are always higher than BOD values for the same sample [22].

3.2.15 Toxic inorganic substances

A wide variety of inorganic toxic substances may be found in water in very small or trace amounts. Even in trace amounts, they can be a danger to public health [11]. Some toxic substances occur from natural sources but many others occur due to industrial activities and/or improper management of hazardous waste [22]. They can be divided into two groups:

- *Metallic compounds:* This group includes some heavy metals that are toxic, namely, cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), silver (Ag), arsenic (As), barium (Ba), thallium (Tl), and selenium (Se) [22, 28]. They have a wide range of dangerous effects that differ from one metal to another. They may be acute fatal poisons such as (As) and (Cr^{6+}) or may produce chronic diseases such as (Cd, Hg, Pb, and Tl) [21, 29–32]. The heavy metals concentration can be determined by atomic absorption photometers, spectrophotometer, or inductively coupled plasma (ICP) for very low concentration [10].

- *Nonmetallic compounds:* This group includes nitrates (NO_3^-) and cyanides (CN^-), nitrate has been discussed with the nitrogen in the previous section. Regarding cyanide, as Mackenzie stated [11] it causes oxygen deprivation by binding the hemoglobin sites and prevents the red blood cell from carrying the oxygen [11]. This causes a blue skin color syndrome, which is called cyanosis [33]. It also causes chronic effects on the central nervous system and thyroid [33]. Cyanide is normally measured by colorimetric, titrimetric, or electrometric methods [10].

3.2.16 Toxic organic substances

There are more than 100 compounds in water that have been listed in the literature as toxic organic compounds [11, 22]. They will not be found naturally in water; they are usually man-made pollutants. These compounds include insecticides, pesticides, solvents, detergents, and disinfectants [11, 21, 22]. They are measured by highly sophisticated instrumental methods, namely, gas chromatographic (GC), high-performance liquid chromatographic (HPLC), and mass spectrophotometric [10].

3.2.17 Radioactive substances

Potential sources of radioactive substances in water include wastes from nuclear power plants, industries, or medical research using radioactive chemicals and mining of uranium ores or other radioactive materials [11, 21]. When radioactive substances decay, they release beta, alpha, and gamma radiation [34]. Exposure of humans and other living things to radiation can cause genetic and somatic damage to the living tissues [34, 35].

Radon gas is of a great health concern because it occurs naturally in groundwater and is a highly volatile gas, which can be inhaled during the showering process [35]. For drinking water, there are established standards commonly used for alpha particles, beta particles, photons emitters, radium-226 and -228, and uranium [34, 35].

The unit of radioactivity used in water quality applications is the picocurie per liter (pCi/L); 1 pCi is equivalent to about two atoms disintegrating per minute. There are many sophisticated instrumental methods to measure it [35].

3.3 Biological parameters of water quality

One of the most helpful indicators of water quality may be the presence or lack of living organisms [10, 15]. Biologists can survey fish and insect life of natural waters and assess the water quality on the basis of a computed species diversity index (SDI) [15, 19, 36, 37]; hence, a water body with a large number of well-balanced species is regarded as a healthy system [17]. Some organisms can be used as an indication for the existence of pollutants based on their known tolerance for a specified pollutant [17].

Microorganisms exist everywhere in nature [38]. Human bodies maintain a normal population of microbes in the intestinal tract; a big portion of which is made up of coliform bacteria [38]. Although there are millions of microbes per milliliter in wastewater, most of them are harmless [37]. It is only harmful when wastewater contains wastes from people infected with diseases that the presence of harmful microorganisms in wastewater is likely to occur [38].

3.3.1 Bacteria

Bacteria are considered to be single-celled plants because of their cell structure and the way they ingest food [10, 37]. Bacteria occur in three basic cell shapes: rod-shaped or bacillus, sphere-shaped or coccus, and spiral-shaped or spirellus [19]. In less than 30 min, a single bacterial cell can mature and divide into two new cells [39].

Under favorable conditions of food supply, temperature, and pH, bacteria can reproduce so rapidly that a bacterial culture may contain 20 million cells per milliliter after just 1 day [22, 37]. This rapid growth of visible colonies of bacteria on a suitable nutrient medium makes it possible to detect and count the number of bacteria in water [39].

There are several distinctions among the various species of bacteria. One distinction depends on how they metabolize their food [38]. Bacteria that require oxygen for their metabolism are called aerobic bacteria, while those live only in an oxygen-free environment are called anaerobic bacteria. Some species called facultative bacteria can live in either the absence or the presence of oxygen [37–39].

At low temperatures, bacteria grow and reproduce slowly. As the temperature increases, the rate of growth and reproduction doubles in every additional 10°C (up to the optimum temperature for the species) [38]. The majority of the species of bacteria having an optimal temperature of about 35°C [39].

A lot of dangerous waterborne diseases are caused by bacteria, namely, typhoid and paratyphoid fever, leptospirosis, tularemia, shigellosis, and cholera [19]. Sometimes, the absence of good sanitary practices results in gastroenteritis outbreaks of one or more of those diseases [19].

3.3.2 Algae

Algae are microscopic plants, which contain photosynthetic pigments, such as chlorophyll [37, 39]. They are autotrophic organisms and support themselves by converting inorganic materials into organic matter by using energy from the sun, during this process they take in carbon dioxide and give off oxygen [38, 39]. They are also important for wastewater treatment in stabilization ponds [22]. Algae are primarily nuisance organisms in the water supply because of the taste and odor problems they create [2, 16]. Certain species of algae cause serious environmental and public health problems; for example, blue-green algae can kill cattle and other domestic animals if the animals drink water containing those species [37, 39].

3.3.3 Viruses

Viruses are the smallest biological structures known to contain all genetic information necessary for their own reproduction [19]. They can only be seen by a powerful electronic microscope [39]. Viruses are parasites that need a host to live [39]. They can pass through filters that do not permit the passage of bacteria [37]. Waterborne viral pathogens are known to cause infectious hepatitis and poliomyelitis [19, 25, 37]. Most of the waterborne viruses can be deactivated by the disinfection process conducted in the water treatment plant [19].

3.3.4 Protozoa

Protozoa are single-celled microscopic animal [19], consume solid organic particles, bacteria, and algae for food, and they are in turn ingested as food by higher level multicellular animals [37]. Aquatic protozoa are floating freely in water and sometimes called zooplankton [37]. They form cysts that are difficult to inactivate by disinfection [19].

3.3.5 Indicator organisms

A very important biological indicator of water and pollution is the group of bacteria called coliforms [20]. Pathogenic coliforms always exist in the intestinal system of humans, and millions are excreted with body wastes [37]. Consequently, water that has been recently contaminated with sewage will always contain coliforms [19].

A particular species of coliforms found in domestic sewage is *Escherichia coli* or *E. coli* [22]. Even if the water is only slightly polluted, they are very likely to be found. There are roughly 3 million of *E. coli* bacteria in 100 mL volume of untreated sewage [10]. Coliform bacteria are aggressive organisms and survive in the water longer than most pathogens. There are normally two methods to test the coliform bacteria—the membrane filter method and multiple-tube fermentation method [10, 37]. Since the test of coliform bacteria is very important for public health, the first method will be described in details in the coming section.

3.3.5.1 Testing for coliforms: membrane filter method

A measured volume of sample is filtered through a special membrane filter by applying a partial vacuum [10, 39].

The filter, a flat paper-like disk, has uniform microscopic pores small enough to retain the bacteria on its surface while allowing the water to pass through. The filter paper is then placed in a sterile container called a petri dish, which contains a special culture medium that the bacteria use as a food source [39].

Then, the petri dish is usually placed in an incubator, which keeps the temperature at 35°C, for 24 h. After incubation, colonies of coliform bacteria each containing millions of organisms will be visible [10]. The coliform concentration is obtained by counting the number of colonies on the filter; each colony counted represents only one coliform in the original sample [10, 39].

Coliform concentrations are expressed in terms of the number of organisms per 100 mL of water as follows:

$$\text{coliforms per 100 mL} = \text{number of colonies} \times 100/\text{mL of sample} \tag{11}$$

4. Water quality requirements

Water quality requirements differ depending on the proposed used of water [19]. As reported by Tchobanoglous et al. [19], “water unsuitable for one use may be quite satisfactory for another and water may be considered acceptable for a particular use if water of better quality is not available.”

Water quality requirements should be agreed with the water quality standards, which are put down by the governmental agency and represent the legislation requirements. In general, there are three types of standards: in-stream, potable water, and wastewater effluent [19], each type has its own criteria by using the same methods of measurement. The World Health Organization (WHO) has established minimum standards for drinking water that all countries are recommended to meet [25].

5. Conclusion

The physical, chemical, and biological parameters of water quality are reviewed in terms of definition, sources, impacts, effects, and measuring methods. The classification of water according to its quality is also covered with a specific definition for each type.

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References

[1] Spellman FR. Handbook of Water and Wastewater Treatment Plant Operations. 3rd ed. Boca Raton: CRC Press; 2013

[2] Alley ER. Water Quality Control Handbook. Vol. 2. New York: McGraw-Hill; 2007

[3] Shah C. Which Physical, Chemical and Biological Parameters of Water Determine Its Quality?; 2017

[4] Tchobanoglous G, Schroeder E. Water Quality: Characteristics, Modeling, Modification. 1985

[5] Gray N. Water Technology. 3rd ed. London: CRC Press; 2017

[6] Davis ML, Masten SJ. Principles of Environmental Engineering and Science. New York: McGraw-Hill; 2004

[7] Chatterjee A. Water Supply Waste Disposal and Environmental Pollution Engineering (Including Odour, Noise and Air Pollution and its Control). 7th ed. Delhi: Khanna Publishers; 2001

[8] Gray NF. Drinking Water Quality: Problems and Solutions. 2nd ed. Cambridge: Cambridge University Press; 2008

[9] Spellman FR. The Drinking Water Handbook. 3rd ed. Boca Raton: CRC Press; 2017

[10] APHA. Standard Methods for the Examination of Water and Wastewater. 21st ed. Washington, DC: American Public Health Association; 2005

[11] Davis ML. Water and Wastewater Engineering—Design Principles and Practice. New York: McGraw-Hill; 2010

[12] Edzwald JK. Water Quality and Treatment a Handbook on Drinking Water. New York: McGraw-Hill; 2010

[13] Tarras-Wahlberg H, Harper D, Tarras-Wahlberg N. A first limnological description of Lake Kichiritith, Kenya: A possible reference site for the freshwater lakes of the Gregory Rift valley. South African Journal of Science. 2003;**99**:494-496

[14] Kiprono SW. Fish Parasites and Fisheries Productivity in Relation to Exreme Flooding of Lake Baringo, Kenya [PhD]. Nairobi: Kenyatta University; 2017

[15] Cole S, Codling I, Parr W, Zabel T, Nature E, Heritage SN. Guidelines for Managing Water Quality Impacts within UK European Marine Sites; 1999

[16] Viessman W, Hammer MJ. Water Supply and Pollution Control. 7th ed. Upper Saddle River: New Jersey Pearson Prentice Hall; 2004

[17] Abbas SH, Ismail IM, Mostafa TM, Sulaymon AH. Biosorption of heavy metals: A review. Journal of Chemical Science and Technology. 2014;**3**:74-102

[18] White C, Sayer J, Gadd G. Microbial solubilization and immobilization of toxic metals: Key biogeochemical processes for treatment of contamination. FEMS Microbiology Reviews. 1997;**20**:503-516

[19] Tchobanoglous G, Peavy HS, Rowe DR. Environmental Engineering. New York: McGraw-Hill Interamericana; 1985

[20] Tomar M. Quality Assessment of Water and Wastewater. Boca Raton: CRC Press; 1999

[21] DeZuane J. Handbook of Drinking Water Quality. 2nd ed. New York: John Wiley & Sons; 1997

[22] Tchobanoglous G, Burton FL, Stensel HD. Metcalf & Eddy Wastewater Engineering: Treatment and Reuse.

4th ed. New Delhi: Tata McGraw-Hill Limited; 2003

[23] Hammer MJ. Water and Wastewater Technology. 7th ed. Upper Saddle River: Pearson education; 2011

[24] World Health Organization Guidelines for drinking-water quality. 4th ed. Geneva: WHO; 2011

[25] World Health Organization. Guidelines for Drinking-Water Q, Vol. 2, Health criteria and other supporting information. 1996

[26] Davis ML, David A. Introduction to Environmental Engineering. 4th ed. New York: McGraw-Hill Companies; 2008

[27] McGhee TJ, Steel EW. Water Supply and Sewerage. New York: McGraw-Hill; 1991

[28] Järup L. Hazards of heavy metal contamination. British Medical Bulletin. 2003;**68**:167-182

[29] Campanella B, Onor M, D'Ulivo A, Giannecchini R, D'Orazio M, Petrini R, et al. Human exposure to thallium through tap water: A study from Valdicastello Carducci and Pietrasanta (northern Tuscany, Italy). Science of the Total Environment. 2016;**548**:33-42

[30] Das AK, Dutta M, Cervera ML, de la Guardia M. Determination of thallium in water samples. Microchemical Journal. 2007;**86**:2-8

[31] Lasheen MR, Shehata SA, Ali GH. Effect of cadmium, copper and chromium (VI) on the growth of Nile water algae. Water, Air, & Soil Pollution. 1990;**50**:19-30

[32] World Health Organization. Chromium in Drinking-Water. Geneva: World Health Organization (WHO); 2003

[33] Dojlido J, Best GA. Chemistry of Water and Water Pollution. Chichester: Ellis Horwood Limited; 1993

[34] Skeppström K, Olofsson B. Uranium and radon in groundwater. European Water. 2007;**17**:51-62

[35] Cothern CR. Radon, Radium, and Uranium in Drinking Water. Boca Raton: CRC Press; 2014

[36] Alabaster JS, Lloyd RS. Water Quality Criteria for Freshwater Fish. 2nd ed. Cambridge: Butterworths; 1984

[37] Nathanson JA. Basic Environmental Technology: Water Supply. New Delhi: Printice-Hall of India; 2004

[38] Wiesmann U, Choi IS, Dombrowski E-M. Fundamentals of Biological Wastewater Treatment. Darmstadt: John Wiley & Sons; 2007

[39] Mara D, Horan NJ. Handbook of Water and Wastewater Microbiology. London: Elsevier; 2003