COURSE GUIDE

AFM 510
WATER QUALITY MANAGEMENT AND POLLUTION CONTROL

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INTRODUCTION

One of the most important functions of *Water Quality Management and Pollution Control* is to expose you to the importance of water quality in terms of its ability to meet designated uses. Several natural and anthropogenic activities introduce contaminants and pollutants into the aquatic environment. These must be controlled or prevented in order to keep the water in good quality to meet current and further human needs. In this course, you will be introduced to the different topics necessary to manage water quality and control aquatic pollution.

WHAT YOU WILL LEARN IN THIS COURSE

Welcome to *AFM 510 Water Quality Management and Pollution Control*. You are beginning a course on water quality management and pollution control. The course consists of 15 study units. Your study time for each unit will vary from one to four weeks. Each study unit contains a number of self-assessment exercises which helps you to assess your progress as you work through each topic. At the end of each self-assessment exercise, you may have to relate your own experience to the topics discussed. It is advisable that you think very well about these questions. You are requested to apply the material you have read to your experience in your community, local government area, state or country.

All the questions are discussed in the final unit and tutorials. Some of your recommended textbooks are written by non-Nigerians. You will therefore, judge whether all or some of the materials contained in them apply in the Nigerian environment. Your opinion here is important as there are various answers to these questions. You will learn some new terms and expressions during the course of the study. You will also come into contact with new ideas, which may help you consider water quality management and pollution control in Nigerian context from an entirely different perspective.

The study units, references, materials recommended for further reading and exercises will help you master the topics over a period of about 18 weeks. Before looking at study units or your textbooks, you should read this course guide thoroughly. It tells you:

- The aims and objectives of the course
- What the course covers
- The components of the course
- The amount of study time you need to cover the course successfully
- How your performance in assignments and the examination will be assessed
- How the tutorial system works.

You will probably need to refer to this Course Guide throughout the course to clarify important points about studying with the National Open University of Nigeria (NOUN).

COURSE AIMS

Water Quality Management and Pollution Control aims to provide you with the basic introduction to the composition of water bodies, water chemistry, nutrient cycling in aquatic environments, biological characteristics of natural and polluted water, sampling methods, the management of selected marine, brackish and fresh waters, framework for water pollution control and the methods of water pollution prevention and control. At the end of each unit you are expected to answer the questions posed and submit them as part of your continuous assessment. Do take each study unit seriously and go through them diligently. Each unit should take about one hour, thirty minutes to read, though you will require more time to write the assignments. I do hope you will enjoy the course. At the end of the course we shall be able to explain water, different characteristics of water, water quality management and pollution control. Relevant examples are used to illustrate certain issues.

COURSE OBJECTIVES

On completing the course, you should be able to:

- define and explain the contents and chemistry of water
- discuss the biological and ecological characteristics of polluted water
- explain the effects of pollutants on fish, plankton, benthic macro invertebrates, algae and water quality
- explain the clean-up and control of specific pollutants
- explain the framework for water pollution control.

There are five modules of 15 units in this course:

Module 1

Unit 1	Physical Composition of Water Bodies
Unit 2	Water Chemistry

Module 2

Unit 1	Nutrient Cycles
Unit 2	Impacts of Human Activities on Nutrient Cycles
Unit 3	Biological Characteristics of Water

Module 3

Unit 1	Sampling Methods
Unit 2	Sampling for Specific Water Quality Parameters
Unit 3	Management of Selected Marine, Brackish and Fresh Waters

Module 4

Unit 1	Framework for Water Pollution Control
Unit 2	Water Quality Standards
Unit 3	Water Quality Monitoring
Unit 4	Clean Up and Control of Specific Pollutants

Module 5

Unit 1	Chemical, Mechanical and Biological Methods of Improving Water Quality
Unit 2	Biological and Ecological Characteristics of Polluted Waters
Unit 3	Effects of Pollutants on Fish, Plankton, Benthic Macro Invertebrates, Algae and Water Quality

In this course, you will understand that water quality and pollution control are important to man and other living organisms to successfully adapt to life on earth and be able to carry out all required activities. For the fisheries and aquaculture sectors, these activities definitely require adequate water both in quality and quantity.

There are adequate tutorial hours designed to assist you. Try to take a full advantage from tutorials you need to be up to date with your study. Tutorials are not lectures but are designed to allow group discussions and inputs. You get the most from a tutorial session, if you contribute your ideas and opinions. Tutorials do not assist learners when they make no input. Your tutor will lead discussions and needs your help to make sessions successful.

The course calendar provides an overview of the course. It suggests the amount of time you should use to complete the units and helps you to plan your study schedule. It can be adjusted to fit your personal needs more closely.

The time needed to complete the study units, work through the practice exercises and assignments, and complete the other work involved in this course depends on your analytical ability and background. You need to plan your own study schedule carefully. The estimated time you need to spend on this course is about 10 hours per week. This estimate includes time for reading the study units and studying the textbooks, completing self-tests and practice exercises, completing your assignments, undertaking the suggested reviews, attending tutorials and preparing for your final examination.

You must complete and hand in your written assignments on time. Therefore, you need to plan and distribute your study time accordingly. There are four assignments altogether to be marked by your tutor. The best three out of the four will be counted towards your assessment. You can find more information on assignments in a later section of this course guide.

COURSE MATERIAL

In addition to this course guide, there are the following important components of the course. At this time, please ensure that you have all of these materials available and can identify the various components in the course; if you do not have the NOUN produced materials, you should contact your study centre immediately. The textbooks, however, are your own responsibility. These can be obtained from the academic and professional book centres.

STUDY UNITS

Although we have recommended the amount of time you should spend on each study unit, you may prefer to study material in a slightly different way. There is provision to detour from the pattern of the course, but you must complete the practice exercises, assignments and examination successfully. The course is structured so that each unit builds upon previous knowledge. Each unit includes at least seven different ways to help you study *Water Quality Management and Pollution Control.* These are:

1. Reading the study unit.
2. Reading the textbooks recommended journal articles.
3. Testing your comprehension and analytical skills by working through the self- test Questions which appears throughout the units.
4. Undertaking the activities that appear throughout the units. These activities will ask you to think, observe, or under take some activities designed to help you apply your knowledge to your own experience.
5. Completing the practice exercises in each unit.

6. Preparing and writing problem-solving assignment.
7. Asking you questions about your own experiences. Your answers help you link your experience to the course material and to Nigerian environment.

You must read each unit carefully. It provides a commentary on the textbooks and introduces you to additional material. If you don't read the study units carefully, you may miss important information. Your study notes are designed to guide you through your textbooks. You must read both the study notes and the texts. They are not alternatives to each other. It is helpful to read as widely as possible. Try to read articles in newspapers and journals, other books on the topic, and related cases. The more you read, the better your appreciation and understanding of the subject will be.

Each unit directs you to read specific pages from chapters in textbooks or journals. You are expected to study and understand the principles and concepts involved. Each unit contains self-test question, usually short ones, providing a test on your understanding of a technique or principle you have just read about. By attempting these short questions, you will have instant feedback on your progress. You should attempt to answer all the self-text questions before looking at the answers. This will help you to prepare for your assignments and examination.

At the end of each unit there is one practice exercise, which covers all areas you have studied in that unit. It is important to complete all the practice exercises. This will expose you to the types of questions you will be required to answer in assignments and in your final examination and also introduce you to some problems encountered in business, organisations and real life-situations. The questions reflect the demands of the unit objectives; they are designed to help you understand and apply those principles covered in the unit.

SET TEXT BOOKS

There are no compulsory textbooks for this course.
Read as many textbook /journal articles on the subject as possible.

ASSIGNMENT FILE

Assignment questions for the units of this course are contained in the section of the course materials entitled assignment file. You are required to complete your assignments and mail them together with a tutor-marked assignment (TMA) form to your tutor.

COURSE ASSESSMENT

Your assessment for this course is made up of two components:

- tutor-marked assignment (TMAs)
- a final examination.

The practice exercise is not part of your assessment but it is important to complete all of them.

TUTOR-MARKED ASSIGNMENTS

This course has assignments at the end of each unit, which you will find in your Assessment File with detailed instructions on how to complete them. Your tutor will mark and comment on them. Pay attention to the feedback and use it to improve your other assignments.

You will see from the course time table the dates to submit in your assignments. The marks for the required TMAs and the best three out of four will be recorded and count towards your final mark for the credit for this course. Presently, the university has adopted electronic e-TMA which comprises eighty multiple or objective questions since 2009/2010 session.

You can write the assignments using the materials from your study units and textbooks. But it is preferable in all degree level education to demonstrate that you have read and researched more widely than the required minimum. Using other references will give you a different viewpoint and a deeper understanding of the subject. **But do remember that copying from any sources without acknowledgement is plagiarism and is not acceptable.** You must make reference when you refer to or quote from others' work. The minimum information needed is: author's name, date of publication, title, edition, publisher and place of publication.

The nature of the assignments varies, but they normally consist of either case **studies or questions** relating to the cases, short essays or short answer questions. It is useful to illustrate any theoretical points with examples from your own experience. This allows you to demonstrate your understanding of the application of theory to real life situations. Below are the total marks allocated to the assignments and to your final examination:

Title	**Value**
TMA	30%
Exam	70%
100%	

FINAL EXAMINATION AND GRADING

There is a three-hour examination at the end of this course. Use the time between finishing the last unit and the examination to review the whole course. Review your practice exercises and assignments and your tutor's comments on them before sitting for the examination. You will be advised of examination arrangements after you send in your examination registration card.

The final examination for AFM 510 covers information from all parts of the course and has the same format as the specimen examination paper, which will be discussed in the half-day school. The examination will not contain "trick" questions or questions that try to confuse you. That is, not consistent with the open approach, the NOUN approach is difference. To earn a passing grade for the course you must submit at least three TMAs and attain a passing grade (i.e. at least score 40) on these and on your final examination.

TUTOR AND TUTORIALS

Your tutor marks and comments on your assignments, keep close watch on your progress and on any difficulties you encounter, and provide you with assistance. Assignments should be mailed in accordance with the **course calendar**. They will be marked by your tutor and returned to you as soon as possible.

It is a good idea to keep a copy of all the assignments you send to your tutor for marking. The copies will prove useful, should you wish to make reference to them during telephone conversations, or if they are lost in the mail.

Do not hesitate to contact your tutor by telephone if you need help. Here are typical circumstances in which help is necessary. Contact your tutor if:

- you do not understand any part of the study units or the assigned readings
- you have any difficulty with self-tests or practices exercises
- you have a question or problem with assignments, with your tutor's comments, or grading on an assignment.

Tutors have complete authority on two points. First, they are responsible for the grade you receive on assignments. If you disagree with a mark, discuss it with your tutor. Second, they alone decide if you may or may not rewrite an assignment.

To assist you in this course, regular tutorials are organised with your assigned tutor. Very interesting activities are designed for the tutorials.

They also give you an opportunity to sort out any problems. You will be notified of their dates, times, and location, together with the name and phone number of your tutor, as soon as you are allocated a tutorial group. We strongly recommend that you attend these tutorials and the half-day school. They provide considerable assistance in your study of this course and improve your chances of gaining high marks. They also let you meet other learners studying through the NOUN.

Tutors are required to start tutorial day school sessions on time. If a tutor fails to turn up 30 minutes after the scheduled starting time, students may assume that the session is cancelled and they should report the case to the course coordinator so that a make-up session can be arranged.

CONCLUSION

AFM 510 Water Quality Management and Pollution Control is a subject that should interest anybody who is interested in the quality of water for designated uses such as aquaculture and fisheries in Nigeria or any Third world country of Africa and Asia. The course has therefore, been designed to help you as a student of Aquaculture and Fisheries Management understand the complex problems of water quality management and pollution control. It requires both conceptual and analytical skills. You must analyse and apply concepts to understand the nature of water quality, pollution, effects on aquatic organisms and the means to control, clean up and protect the aquatic environment.

Hopefully, you will find it fun, interesting and useful as a student, administrator or a policymaker (or potential one) interested in the development of your country. Good luck, and enjoy the course.

MAIN COURSE

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MODULE 1

UNIT 1 PHYSICAL COMPOSITION OF WATER BODIES

CONTENTS

1.0 INTRODUCTION

In this unit, we shall discuss the structure and physical properties of water, its unique properties that differentiate water from other liquids.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the structure of the water molecule
- mention the properties that give water its unique behaviour that differs from other liquids.

3.0 MAIN CONTENT

3.1 Structure and Physical Properties of Water

Water (dihydrogen monoxide) covers over 70% of the earth's surface. The hydrosphere (water from all sources on earth) contains about 1.36 billion cubic kilometres of water mostly in the form of liquid. Water is essential for life on earth and is found in all living organisms.

Water molecule contains two atoms of hydrogen bound covalently to one atom of oxygen. The two hydrogen atoms are attached to one side of the oxygen molecule giving it unique electrochemical properties. The side containing hydrogen atoms is positively charged while the side dominated by oxygen atom is negatively charged (see figure 1). There are strong forces of attraction between different molecules of water. The polarity of the water molecule makes water a powerful **solvent** and also gives it **strong surface tension.**

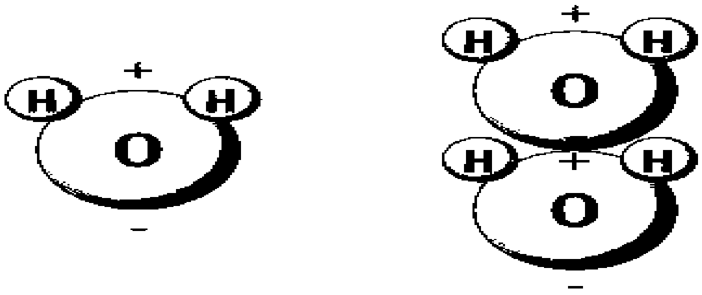

Fig. 1: The Structure of a Water Molecule. O Represents Oxygen while H Represents Hydrogen (Pidwirny, 2006)

Water exists in three states **-** solid (ice), liquid (liquid water) and gas (steam or water vapour). It can change from one state to another. When water changes its state, molecules rearrange themselves differently. The molecular arrangement of ice leads to increase in volume but a decrease in density. Water expands when frozen and becomes less dense or lighter causing ice to float on liquid water. Ice molecules arrange themselves in a very orderly manner but steam or water vapour molecules are highly charged with little bonding between molecules (Pidwirny, 2006).

3.2 The Unique Properties of Water

a. Water has a **high specific heat capacity.** The specific heat capacity is the amount of energy required to raise the temperature of water by 1˚C. Water can absorb large amounts of heat before increasing in temperature and also releases heat slowly while cooling. This property allows the moderation of the earth’s climate and helps organisms to regulate their body temperatures. Water can transfer heat from places of high temperature to those of low temperature e.g. from equator or tropics to the Poles.

b. Pure water has a pH of 7 indicating its **neutrality** (neither acidic nor basic). The pH of water changes due to its content of dissolved substances. Rainwater is naturally acidic having a pH of 5.6 because it contains dissolved carbon dioxide.

c. Water conducts heat more easily than other liquids except mercury. This gives large bodies of water almost uniform vertical temperature profiles.

d. Water exists as a liquid over a wide range of temperature (0-100ºC).This means that water remains a liquid in most parts of the world and can sustain living organisms.

e. Water dissolves many substances and is called a **universal solvent** because it interacts easily with polar substances. Water can transport dissolved nutrients in runoff, infiltration, groundwater and within living organisms. This is also why water can carry different impurities and dissolved pollutants. Water does not dissolve oil because oil is not polar. Water mixes easily with liquids like ethanol forming homogenous liquid. However it cannot mix with oil but forms layers depending on density. Water vapour completely mixes with air.

f. Water has a **high surface tension.** This makes water molecules adhesive sticking to surfaces; molecules sticking together (**cohesion**) in drops due to hydrogen bonding rather than spreading out over a surface as a thin film. This property allows water to stick to sides of vertical structures despite downward pull by gravity; formation of water droplets, waves, movement of water and nutrients from roots to the leaves of plants, circulation of blood in bodies of animals (**capillary action**).

g. Changes in states of water lead to massive heat exchanges re-distributing heat around the world majorly through **evaporation** and **condensation** of water. Molecules of water take up heat from their surroundings during evaporation thereby cooling the surface but lose heat to the environment during condensation.

h. Water expands on cooling and occupies more volume. It has a maximum density at 4ºC.Water is the only substance whose maximum density does not occur when frozen or solidified. This property is called **anomalous behaviour**of water.

i. Pure water has no colour, odour or taste. These are imparted by dissolved substances in water. Water can be split by hydrolysis into hydrogen and oxygen atoms.

j. Elements which are more electropositive than hydrogen usually replace hydrogen in water forming oxides. e.g. sodium, calcium, lithium, potassium and caesium.

4.0 CONCLUSION

Water behaves differently from other liquids as temperature increases or falls. This is described as the anomalous behaviour of water. Water has a high heat capacity, exists in three different states as solid, liquid and gas. The various unique characteristics of water allow the propagation of life on earth.

5.0 SUMMARY

In this unit, we discussed the structure of water (dihydrogen monoxide) molecule and the unique properties of water that differentiate it from other liquids. The unique characteristics allow life on earth and the regulation of the climate.

6.0 TUTOR–MARKED ASSIGNMENT

1. Describe the molecular structure and physical properties of water.
2. Explain the unique properties of water that differentiates it from other substances.

7.0 REFERENCES/FURTHER READING

Alekin, O.A. (1970). The Fundamentals of Water Chemistry. In: *Types and Properties of Water, Vol. II.* Water Chemical Composition of Rivers, Lakes and Wetlands (Nikanorov, A.M. & Brazhnikova, L.V.).

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UNIT 2 WATER CHEMISTRY

CONTENTS

1.0 INTRODUCTION

Natural waters have many substances dissolved in them such as ions, dissolved gases, organic matter and others (Nikamanov and Brazhnikova, 2013). These dissolved substances influence the chemical characteristics of water. In this unit we shall discuss some of these characteristics of natural water.

2.0 OBJECTIVE

At the end of this unit, you should be able to:

- state the chemical composition of natural water.

3.0 MAIN CONTENT

3.1 Water Chemistry

a. Ions or mineral elements

These are dissolved minerals in water mainly present as macro and micro minerals. Macronutrients constitute about 95% in highly mineralised waters while micronutrients occur only under some conditions in trace quantities. The quantities of minerals in water depend on their abundance in the water shed (land around the water body) and their solubility in the water.

Anions in natural waters include chloride (Cl^-) and sulphate (SO_4^{2-}) while cations are calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}) and potassium (K^+). Hydrocarbonate (bicarbonate, HCO_3^-) and carbonates (CO_3^{2-}) are present in natural waters in equilibrium with carbonic acid and dissolve from rocks like limestone, dolomite and magnesites. At pH 7-8.5 the bicarbonate ion dominates but is close to 0 at pH less than 5. Carbonates dominate in water at pH greater than 8. The bicarbonate or hydrocarbonate ions form carbonates with calcium ions which is less soluble.

b. Phosphorus

Phosphorus is present in natural waters in dissolved and colloidal forms depending on the pH of the water. Phosphorus occurs in very low concentrations due to low solubility of its compounds and intensive consumption by living organisms. Increases are caused by human activities

c. Ions of hydrogen

These are hydroxyl (OH^-) and hydrogen (H^+) ions. They result from the electrolysis of water. The reactions in water are normally expressed according to the hydrogen ions. When pH is 7, the water is neutral, less than 7 is acidic and greater than 7 basic or alkaline.

d. Dissolved gases

Dissolved gases in water are nitrogen (N), oxygen (O_2), and CO_2) and make up about 99.9% of dissolved gases in water. Oxygen produced during photosynthesis is involved in most reactions occurring in water. Other gases include methane, hydrogen sulphide. These gases result from volcanic activity, degassing of the earth’s mantle (supplies oxides and dioxides of methane, carbon, ammonia (NH_3), hydrogen sulphide (H_2S), hydrogen, hydrogen chloride, sulphorous gas) in natural waters. Thunder storm discharges nitric oxide while anthropogenic activities increase sulphorus gas, vapours of iodine, ammonia and carbonic oxide. Un-ionised hydrogen sulphide (H_2S) is very toxic to fish and may also cause slow growth of fish. Detectable concentrations of hydrogen sulphide are considered detrimental to fish production (Boyd, 1981).

Nitrogen occurs in natural water as inorganic ions (ammonium-NH_4^+, ammonia-NH_3, nitrite –NO_2^-, and nitrate –NO_3^-) and organic compounds like amino acids, protein, their metabolic wastes; products of plant and animal decay. They are present in suspended, dissolved and colloidal forms. Conversions occur in the forms of nitrogen in water e.g. ammonia is converted under oxidising conditions to nitrite and nitrate.

Dissolved oxygen analysis measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Oxygen diffuses into water from surrounding air, by aeration (rapid movement of water), and as a product of photosynthesis. The dissolved oxygen in water should not be less than 5mg/l in farms for salmonids but carp and tilapia can withstand 3-4 mg/L DO. Warm water fish can withstand as low as 1mg/l but prolonged exposure leads to slow growth. Dissolved oxygen is expressed as a concentration (in mg/L), or as percentage saturation(an expression of the proportion of dissolved oxygen in the water relative to the maximum concentration of oxygen that water holds at a particular temperature, pressure, and salinity). The amount of dissolved oxygen in water depends on the water temperature. Warm water absorbs less oxygen than cold water.

e. Biogenous substances

These are substances connected by their origin with vital activities of aquatic organisms. e.g. silicon, nitrogen, phosphorus, and iron. Silicate materials are not very soluble in natural waters. They are present in both dissolved and colloidal forms.

f. Soluble organic matter

These include, sugar, acids, humic acids, tannin, vitamins, amino-acids, peptides, proteins, plant pigments, urea and many other biochemical compounds.

g. Suspended organic matter

Colloidal clay, and coarse suspensions of soil particles, colloidal or suspended remains of organisms in various stages of decay, living phytoplankton, zooplankton, fungi and bacteria.

h. Electrical conductivity

Electrical conductivity is the measure of the ability of water to conduct an electric current. It depends on the number of ions or charged particles in the water, and is measured by passing a current between two electrodes (a known distance apart) that are placed into a sample of water. Electrical conductivity is expressed in micro Siemens per centimetre (µS/cm) or milli Siemens per centimetre (mS/cm) and provides a direct indication of dissolved ionic matter in the water. Low values characterise high-quality, low-nutrient waters.

High values of conductance indicate salinity problems but also are observed in eutrophic waterways where plant nutrients are in greater abundance. Very high values are good indicators of possible polluted sites. A sudden change in electrical conductivity can indicate a direct discharge or other source of pollution into the water. However, electrical conductivity readings do not provide information on the specific ionic composition and concentrations in the water.

i. Ph

The pH of water is the concentration of hydrogen ions, expressed as a negative logarithm. It shows the acidity or alkalinity of water. At a pH of 7, water is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasing alkalinity. At high or low pH, toxicants may become more or less available in water which may be toxic to aquatic organisms. The acid death point of organisms is at pH 4 while the alkaline death point is pH 11. The desirable range for fish production is 6.5–9.0 at daybreak (Boyd, 1981).

j. Salinity

Concentrations of ions in water and is usually expressed in parts per thousand (PPT, ‰). Classes of salinity for water are fresh water (less than 5 ‰), brackish water (from 5 ‰ to 25 ‰), saline water (from 25 ‰ to 36 ‰), Super-saline (or hyper-saline) water (greater than 36 ‰, more saline than seawater).Open ocean salinities are generally in the range between 32 ‰ and 37 ‰.

k. Temperature

Water temperature regulates various biochemical reactions that affect water quality. Heat sources and sinks to a water body include incident solar radiation, back radiation, evaporative cooling and heat conduction, thermal dischargers (e.g. cooling water from power plants), tributary inflows and groundwater discharge. Since the solubility of dissolved oxygen decreases with increasing water temperature, high water temperatures limit the availability of dissolved oxygen for aquatic life.

l. Turbidity

Turbidity is a measure of the clarity of a water body. It is an optical measurement that compares the intensity of light scattered by a water sample with the light scattered by a standard reference suspension. Turbidity is caused by suspended and colloidal matter e.g. clay, silt, finely divided organic, inorganic matter, plankton and other microscopic organisms. It is commonly recorded in nephelometric turbidity units (NTUs).Turbidity restricts light penetration and limits photosynthesis.

m. Total suspended solids (TSS)

Total suspended solids (TSS) is the portion of total solids in a water sample retained by a glass fibre (GF/C) filter of pore size >2 μm. Once the filter has been dried at 103–105°C and weighed, the amount of total suspended solids is recorded in units of mg/L.

n. Volatile suspended solids (VSS)

Volatile suspended solids (VSS) is the portion of total suspended solids (TSS) lost on ignition (heating to 550°C). It gives an idea of the amount of organic matter present in the solid fraction of wastewater, activated sludge or industrial wastes.

4.0 CONCLUSION

Several substances such as ions of metals, gases and suspended solids are present in water. These substances change the characteristics of water from its pure form. The different aspects of water chemistry are important in determining the quality of water which is the habitat for fish and other aquatic organisms

5.0 SUMMARY

In this unit, we discussed the characteristics of water such as dissolved gases, metals, suspended solids. It is necessary to understand water chemistry as this affects the ability of water to serve as a good habitat for fish**.**

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss five parameters that can be used to describe natural waters.

7.0 REFERENCES/FURTHER READING

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MODULE 2

Unit 1	Nutrient Cycles
Unit 2	Impacts of Human Activities on Nutrient Cycles
Unit 3	Biological Characteristics of Water

UNIT 1 NUTRIENT CYCLES

CONTENTS

1.0 INTRODUCTION

Living organisms require several nutrients either in trace or macro amounts for growth, maintenance, production and reproduction. The atmosphere contains about 78% nitrogen though this is not directly usable by living organisms. Nutrient cycles describe the processes of inter-conversions that occur in nature. These transformations can occur due to biological and non-biological processes. In this unit, we shall discuss the nutrient cycles as they occur in the aquatic environment.

2.0 OBJECTIVES

- At the end of this unit, you should be able to:
- discuss the processes of the nitrogen cycle
- discuss the carbon cycle
- discuss the phosphorus cycle
- discuss the iron cycle and silica cycle in aquatic ecosystems
- discuss the sulphur cycle in aquatic ecosystems.

3.0 MAIN CONTENT

3.1 The Processes of the Nitrogen Cycle

Many forms of nitrogen are present in the environment such as organic nitrogen, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and nitrogen gas (N_2). Microorganisms are involved in many of the processes either to produce energy for their own use or to accumulate nitrogen for growth.

a. Nitrogen fixation

During nitrogen fixation, atmospheric nitrogen is converted to ammonium by lightening or by the activities of microorganisms. Free-living bacteria such as *Cyanobacteria, Azobacter*; or symbiotic bacteria (e.g. *Rhizobium* species) also fix nitrogen. The bacteria change atmospheric nitrogen to ammonia and then to organic compounds. *Rhizobium* spp inhabit the root nodules of leguminous plants (e.g. peas or cowpea). The bacteria share the ammonia with the host plant in exchange for carbohydrate and accommodation.

Small amounts of nitrogen can be fixed by other natural activities such as forest fires and volcanic activities. The nitrogen is converted to protein by the plant.

Ammonia is also fixed industrially using Haber-Bosch process. Under great pressure at 600˚C, with iron acting as catalyst, atmospheric nitrogen and hydrogen (from natural gas or petroleum) are combined to form ammonia (NH_3) for producing fertiliser and explosives.

b. Assimilation

Plants absorb nitrogen from the soil as nitrate or ammonium ions. Animals meet their requirements for nitrogen by eating plants. The nitrate absorbed by plants is reduced to nitrite then ammonium ions before conversion to amino acids, nucleic acids and chlorophyll. In plants that have a mutualistic relationship with *Rhizobium* spp, some nitrogen is assimilated in the form of ammonium ions directly from the nodules. Animals, fungi, and other heterotrophic organisms absorb nitrogen as amino acids, nucleotides and other small organic molecules.

c. Ammonification (mineralisation)

Ammonification or mineralisation involves the conversion of organic nitrogen from dead plants and animals or metabolic wastes from animals and plants back into ammonium ions (NH_4^+) by bacteria or fungi.

d. Nitrification

This is the conversion of ammonium to nitrate by nitrifying bacteria. Ammonium (NH_4^+) is oxidised to nitrite (NO_2^-) by *Nitrosomonas* species while *Nitrobacter* species is responsible for oxidation of nitrites to nitrates (NO_3^-). It is important for the nitrites to be converted to nitrates because accumulated nitrites are toxic to plants. Ammonia and nitrite are toxic while nitrate is the least toxic. However high nitrate concentration in drinking water causes methhemoglobinuria or blue baby syndrome. It may also add to nutrient excess in receiving waters.

e. Denitrification

This is the conversion of oxidised forms (e.g. nitrates, nitrites) of nitrogen to the gaseous forms dinitrogen or to a lesser extent nitrous oxide gas (N_2, N_2O). This process is carried out by denitrifying bacteria such as *Pseudomonas* and *Clostridium* under anaerobic conditions (without oxygen) though these bacteria can also survive under aerobic conditions.

$$\rightarrow NO_3^- \quad \rightarrow NO_2^- \quad \rightarrow NO \quad \rightarrow N_2O \quad N_2$$

Anaerobic ammonium oxidation

In this process, nitrite and ammonium are converted directly into dinitrogen gas (N_2). This process makes up a major proportion of dinitrogen conversion in the oceans.

f. Nitrogen mineralisation

After nitrogen is incorporated into organic matter, it can be converted back into inorganic nitrogen by a process called nitrogen mineralisation or decay. When organisms die, decomposers (bacteria and fungi) consume the organic matter during decomposition. A significant amount of the nitrogen contained in the dead organism is converted to ammonium which can be used by plants or transformed into nitrate (NO_3^-) through nitrification.

3.1.2 Importance of Nitrogen Cycle

Nitrogen is an essential component of important substances such amino acids, proteins, and nucleic acids (deoxyribonucleic acids and ribonucleic acid). In plants, much of the nitrogen is used in chlorophyll molecules necessary for photosynthesis and growth. The processesof the nitrogen cycle are important to convert gaseous nitrogen into forms that can be used by living organisms.

3.1.3 Human Influences on the Nitrogen Cycle

1. Large scale growing of legumes, fertilisers production, pollution by vehicles and industrial plants, have increasingly changed nitrogen into biologically-available forms.
2. Fertiliser application, burning of biomass, livestock feed lots and industry increase nitrous oxide (N_2O) in the air. N_2O breaks down ozone in the stratosphere. N_2O in the atmosphere is a greenhouse gas and contributes to global warming.
3. Increasing ammonia in the air decreases air quality. It is converted to nitric acid (HNO_3, a part of acid deposition. Ammonia is also toxic in the aquatic system. Both ammonia and nitric acid in the air cause respiratory damage to living organisms.
4. Burning of fossil fuels, biofuel and hydrogen produce nitrogen oxides (NOx). NH_3 and NO_x are involved in lower atmospheric ozone production.

3.2 Carbon Cycle

Carbon is needed for the formation of all organic matter. It is present as carbon dioxide (CO_2), bicarbonate (HCO_3^-), carbonic acid (H_2CO_3) and organic compounds in aquatic systems. The atmosphere and sedimentary rocks are the major stores of carbon. Large amount of carbon is present in the aquatic system in form of organic and inorganic carbonates. Organic forms result from biological and chemical breakdown of plants and animals. Major inorganic forms are carbon dioxide, bicarbonate and carbonate. Dead plants and animals are broken down by biological and chemical activities into inorganic carbon or can be converted to part of the sediment after partial decay.

Exchange between carbon dioxide in the atmosphere and water produces an equilibrium concentration of carbon in water. Plants absorb inorganic forms of carbon (e.g. carbon dioxide, CO_2) and in the presence of light convert them into organic compounds. Plants need carbon dioxide for photosynthesis and get carbon directly from the air but non rooted aquatic plants get carbon dioxide directly from the water. CO_2 produced by plants and animals during respiration is absorbed by water but if concentrations are too high, water gives up carbon dioxide to the atmosphere.

Inorganic and organic forms of carbon can be exchanged between sediment and water. Carbonate rock stores carbon and when dissolved, helps to control the pH of salt and freshwater ecosystems. Organic carbon is present on the bottom of lakes and oceans. Biological and chemical breakdown of the organic carbon adds carbon to the water column. Sinking of dead plants and animals contributes carbon to the sediments. Burning of fossil fuels and deforestation disturbs the carbon cycle.

3.3 The Phosphorus Cycle

Phosphorus is an essential nutrient for plants, animals and plays a major role in biological metabolism. Phosphorous is the least abundant and most limiting for biological productivity of a water body. Phosphorus is present in aquatic systems as inorganic phosphate ions, organic molecules like sugars and DNA. Phosphorus forms in water are particulate organic, dissolved organic, particulate inorganic and dissolved inorganic (see Figure 2 for aquatic phosphorus cycle).

The four forms of phosphorus interact where organic forms may be converted to inorganic forms by either chemical or biological reactions. Inorganic forms can also be converted to organic forms through biological processes. Conversions from dissolved to particulate and vice versa may be through biological or chemical processes. All four forms can be used by various organisms and converted into bodies of living organisms. The primary biological function of phosphorus is in the formation of nucleotides. Orthophosphate(PO_4^{3-}) is the only directly utilisable form of soluble inorganic phosphorous.

The balance among the forms of phosphorus depends on pH, concentrations of metal ions e.g. calcium and aluminium; oxidation–reduction potential, extent of stirring of bottom sediments and the presence of pollution. Interactions occur between the various forms of phosphorus in the water column and those in the sediments. The release of phosphorus from sediments depends on the environment and the interactions of other ions with phosphorus. For example, a large quantity of phosphorus is absorbed in ferric hydroxides and oxides. A reduction in the oxidation potential (such as reduction in dissolved oxygen) in water causes ferric hydroxides and ferric oxides to dissolve. Phosphorus is released in the process and increases in concentration in the water column.

Phosphorus is transported adsorbed (attached to surfaces) or absorbed (within the material) into soil particles rather than in solution. Where intensive animal husbandry is practiced, P can be lost in large quantities in surface runoff or erosion into aquatic environments. Specialised symbiotic fungi, known as mycorrhizae, transfer P from inaccessible forms to plants and help to reduce leakage of P from the system.

Phosphorus from agriculture is the principal cause of eutrophication in water. Phosphorus is also contributed by sewage effluents, animal and industrial wastes, including phosphorus-containing detergents and atmospheric deposition. After death, organisms decay through chemical or biological processes.

Phosphateis extremely reactive and interacts with many cations to form relatively insoluble compounds. A large proportion of phosphorous in freshwaters is bound in organic phosphates. Total phosphorous in freshwater ranges from < 5 μg/L - > 100 μg/L (in unproductive waters to highly productive or eutrophic water respectively).Most uncontaminated freshwaters contain between 10 and 50 μg/L total phosphorus per litre.

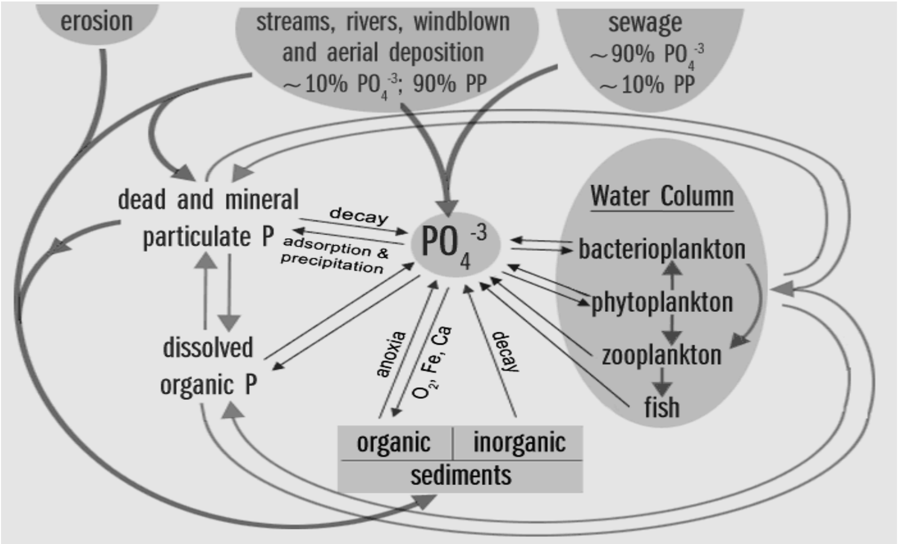

Fig. 2: Phosphorus Cycle – Major Transformations (Source: Horne and Goldman, 1994. Limnology. McGraw Hill)

3.4 Iron Cycle

The most common form of iron in natural waters is hydrated ferric hydroxide (Fe OH_3).Under low pH and low redox potential, ferrous iron diffuses from the sediments and accumulates in anaerobic hypolimnetic water of productive lakes. Iron is an essential micronutrient to freshwater flora and fauna.

- Under restricted availability of iron, photosynthetic productivity can be limited.
- Certain chemosynthetic bacteria can utilise the energy of inorganic oxidations of ferrous salts in relatively inefficient reactions involving carbon fixation.
- Other autotrophic and heterotropic iron oxidising bacteria deposit oxidised iron. These bacteria are restricted to zones of steep redox gradients between reduced metal ions and oxygenated water.

3.5 Sulphur Cycle in Aquatic Ecosystems

Sulphur is one of the components of proteins and vitamins. Sulphur is important for the functioning of proteins and enzymes in plants and animals that depend upon plants for sulphur. Plants absorb sulphur when it is dissolved in water. Animals will consume these plants, so that they will take up enough sulphur to maintain their health.

Most of the earth's sulphur is tied up in rocks and salts or buried deep in the ocean in oceanic sediments. Sulphur can also be found in the atmosphere. It enters the atmosphere through both natural and human sources. Natural sources include volcanic eruptions, bacterial processes, evaporation from water, or decaying organisms.

When sulphur enters the atmosphere through human activity, this is mainly a consequence of industrial processes where sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) gases are emitted on a wide scale. Sulphur dioxide in the atmosphere reacts with oxygen to produce sulphur trioxide gas (SO_3), or with other chemicals in the atmosphere, to produce sulphur salts.

Sulphur dioxide may also react with water to produce sulphuric acid (H_2SO_4). Sulphuric acid may also be produced from dimethyl sulphide, emitted to the atmosphere by plankton species. All these particles will settle back onto earth, or react with rain and fall back onto earth as acid deposition. The particles will are absorbed by plants again and are released back into the atmosphere, so that the sulphur cycle starts over again (Figure 3).

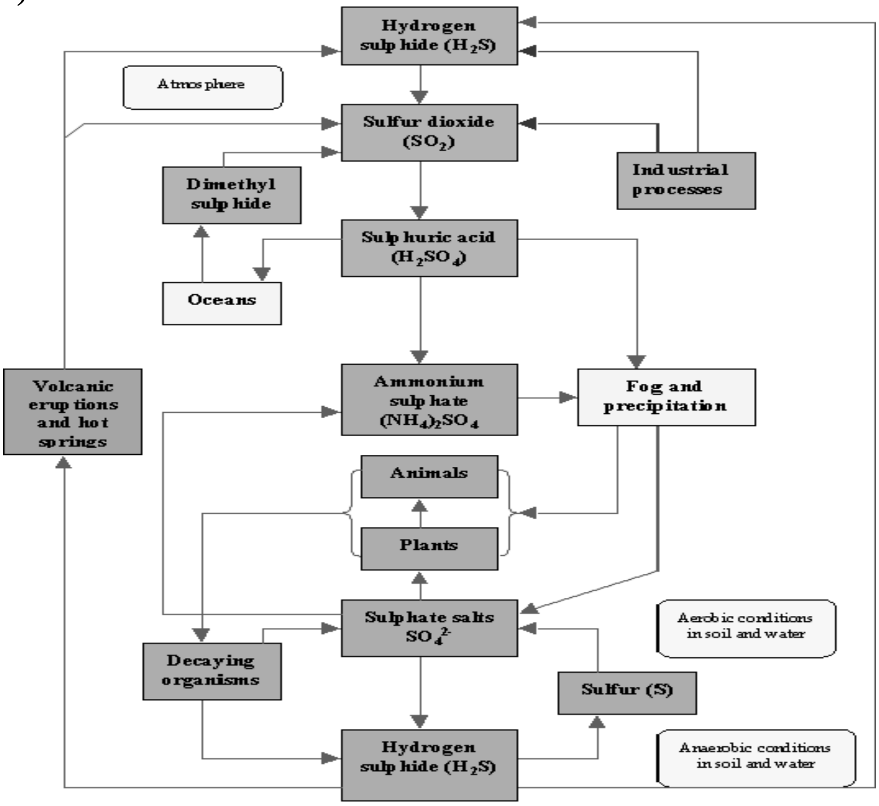

Fig. 3: Schematic Representation of the Sulphur Cycle. (Source: Horne and Goldman, 1994. Limnology, McGraw Hill)

The sulphur cycle is similar to nitrogen cycle, except for a large input through volcanic activity and the absence of a biological process of sulphur fixation from atmosphere to the land or water. The two main forms in water are hydrogen sulphide (H_2S) and sulphate ions (SO_4^{2-}). Hydrogen sulphide is produced from anaerobic decomposition of organic matter. The sulphate ion is the form most readily absorbed by plants.

Decomposition of organic sulphur produces inorganic forms which are absorbed by plants while animals obtain it indirectly through plants. Aerobic bacteria transform hydrogen sulphide into elemental sulphur and then to sulphate. The oxidation of hydrogen sulphide produces energy for bacterial cellular functions and toxic hydrogen sulphide is converted to sulphate, a less toxic form. Anaerobic bacteria convert sulphate to hydrogen sulphide.

The release of sulphur oxides (Sox) as sulphur dioxide (SO_2) and sulphur trioxide (SO_3) to the air is the main human contribution through burning of sulphur-containing coal, petrol and the smelting of sulphite ores. Sulphur oxides cause respiratory problems and may be toxic or have offensive odour (Smil, 1997). Sulphur oxides are involved in climate change. When sulphate dissolves in water, it forms dilute sulphuric acid (H_2SO_4).

3.6 Silica Cycle in Aquatic Ecosystems

The silica cycle is similar to phosphorus in that there is no atmospheric reservoir as with nitrogen and carbon. Silica occurs in relative abundance in natural waters as dissolved silicon acid and particulate silica. Diatom algae assimilate large quantities of silica and markedly modify the flux rates of silica in lakes and streams.

When the concentration of silica is reduced below about 0.5mg/L, many diatoms species cannot compete effectively with non-siliceous algae, and their growth rates decline until silica supplies are renewed, usually during autumnal circulation.

4.0 CONCLUSION

The cycling of nutrients such as nitrogen, carbon, phosphorus, iron, sulphur and silica is important in the aquatic environment enabling the continual availability of such nutrients for use by living organisms. Human influences on some nutrient cycles were also stated.

5.0 SUMMARY

In this unit, we discussed the cycling of some nutrients including nitrogen, phosphorus, carbon and sulphur in the aquatic environment. These nutrients sustain life both in the aquatic and terrestrial environments. Human activities have also influenced the cycles especially through the use of fossil fuels such as coal and petroleum products.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the processes of the nitrogen cycle.
2. Explain the carbon cycle.
3. Explain the phosphorus cycle.
4. Explain the iron cycle and silica cycle in aquatic ecosystems.
5. Explain the sulphur cycle in aquatic ecosystems.

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UNIT 2 IMPACTS OF HUMAN ACTIVITIES ON NUTRIENT CYCLES

CONTENTS

1.0 INTRODUCTION

In this unit, we look at the effects of human activities on the nutrient cycles. These activities include shifts in the land use patterns, fertiliser use, and activities that involve energy consumption by man and animals. We also discuss the nutrient input and output processes, and the consequences of changes to the nutrient cycles.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the human impacts on the nutrient cycles
- state the nutrient input and output processes
- mention the consequences of changes to nutrient cycles.

3.0 MAIN CONTENT

3.1 Human Impacts on the Nutrient Cycles

Human activities have resulted in large-scale changes in nutrient cycles. These human impacts include:

i. Shifts in land use patterns
ii. increased fertilisation for high-yield crops

iii. lateral transfer of nutrients across ecosystem boundaries have changed the rate, pathways, and efficiency of nutrient cycling
iv. Small-scale, low-input cultivation practices cause nutrient depletion when fallow periods are short.
v. Increased demand for food, fuel, and fiber requires supplementation of the natural nutrient supply by artificial sources. This doubled the inputs and nitrogen and phosphorus to ecosystems.
vi. The regulation mechanisms in natural systems and biological controls by plants and invertebrates have been impaired, where additional inputs and tillage are used for increased food production.
vii. Atmospheric deposition of nutrients from industry, agriculture, biomass fires, and wind erosion, spreads largequantities of N, P, Fe and Si to downwind ecosystems over large regions (Brasseur *et al*. 2003).

3.2 Nutrient Input and Output Processes

Ecosystem nutrient balance is the net result of inputs minus outputs. The magnitude and duration of nutrient imbalance that can be tolerated is determined by an ecosystem's buffering capacity.Input of nutrients to ecosystems occurs through five processes:

i. Weathering of rocks produces small quantities of nutrientssuch as phosphorus, potassium, iron, aluminium, sodium, and silicon in natural ecosystems.
ii. Atmospheric input of nutrients through wet or dry deposition of elements has substantially increased through human activities.
iii. Biological processes include the fixation of atmospheric carbon (CO_2) through photosynthesis, and atmospheric nitrogen (N_2) through biological nitrogen fixation.
iv. Nutrients can be released from the biomass of dead organisms. The trade in agricultural and forest products is a major pathway of nutrient transfer globally
v. Direct anthropogenic inputs occur through fertilisation practices in intensive agriculture and the release of human sewage and livestock wastes.

The output of nutrients from ecosystems involves five processes:

i. Soil erosion transports large quantities of nutrients from terrestrial to aquatic ecosystems. Erosion is accelerated by cultivation, overgrazing, and vegetation clearance. The essential nutrients most affected by erosion are carbon, phosphorus, potassium, and nitrogen.

ii. Leaching (the vertical flow of water in the soil profile) transports large amounts of nutrients in solution from the soil into groundwater and rivers, lakes, and oceans. Leaching losses of nutrients are highest in cultivated or disturbed environments.

iii. Gaseous emissions of CO_2, CH_4, and CO etc. to the atmosphere from the decomposition of organic matter, digestion by animals, and fires. The conversion between inorganic forms of N lead to emissions of N_2, N_2O, NO, and NH_3. Phosphorus has no significant gaseous forms in most ecosystems. Anthropogenic activities like ploughing, fertilisation, fossil fuel burning, flooding, drainage, deforestation, and changes to fire regimes, have altered the amounts and proportions of emissions of nutrients to the atmosphere.

iv. The emigration of fauna or harvest of crop, forest, fish, or livestock removes nutrients. An export from one ecosystem means import of nutrients to another.

v. The effective permanent removal of nutrients from the biosphere only occurs at a slow rate and through a small number of processes.

3.3 Consequences of Changes to Nutrient Cycles

Alterations of nutrient cycling include nutrient excess, leading to eutrophication, and nutrient deficiency linked to soil exhaustion and some specific natural situations in oceans.

a. Eutrophication of Aquatic Ecosystems

Eutrophication is the fertilisation of surface waters by nutrients that were previously scarce (Carpenter *et al*. 1999). This is due to human activities causing increased inputs of urban, industrial wastewaterand agricultural runoff containing C, N, and P. Eutrophication causes many changes in the structure and function of aquatic ecosystems and the services they provide.

The symptoms of eutrophication:

i. Increase in phytoplankton, benthic, and epiphytic algae and bacterial biomass

ii. Shifts in composition to bloom-forming algae, which may be toxic or inedible

iii. Development of rooted macrophytes and macroalgae along the shores
iv. Anoxia (oxygen depletion) in deep waters
v. Increased incidence of fish and shellfish mortality
vi. Decreases in water transparency
vii. Taste, odor, and water treatment problems
viii. Coral mortality in coastal areas.

b. Marine Dead Zones

Low oxygen conditions in coastal marine waters result from enrichment in nitrogen which enhances phytoplankton growth. Dead phytoplankton sinks to the sea floor decomposition consumes oxygen. The low oxygen concentration kills most marine life leading to the designation of **‘‘marine dead zones**’’ (Brian *et al*. 2004).These have been reported off South America, Japan, China, Australia, New Zealand, and the west coast of North America.The hypoxic conditions are seasonal in some regions, such as the Gulf of Mexico. The occurrence of dead zones and their size appears to be a function of nitrogen inputs. Denitrification (which returns nitrate to the atmosphereas N_2 and N oxides) occurs only when oxygen concentrations are low and becomes effective after the dead zone phenomenon has occurred.

4.0 CONCLUSION

Human activities produce some effects on the nutrient cycles. Five input and five nutrient output processes have been identified in the nutrient cycles. The consequences of the changes that occur in the nutrient cycles include eutrophication and the formation of marine dead zones.

5.0 SUMMARY

In this unit, we discussed the human impacts on nutrient cycling, nutrient input and output processes; and the consequences of changes to the nutrient cycles.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the human impacts on the nutrient cycles.
2. Explain the nutrient input and output processes.
3. Explain the consequences of changes to nutrient cycles.

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UNIT 3 BIOLOGICAL CHARACTERISTICS OF WATER

CONTENTS

1.0 INTRODUCTION

Natural water has chemical, physical and biological characteristics. The living organisms in water also include microorganisms such as bacteria, protozoa, algae and fungi. Viruses are parasites that cannot live and reproduce outside other living cells.

2.0 OBJECTIVE

At the end of this unit, you should be able to:

- mention the different organisms that are naturally found in water.

3.0 MAIN CONTENT

3.1 Biological Characteristics of Natural water

Microorganisms that cause diseases and transmitted through water are called water borne pathogens. These include bacteria, viruses and fungi. Microorganisms of interest in water include bacteria, fungi, algae, protozoa and viruses.

3. 1. 2 Bacteria

Bacteria are among the most common microorganisms in water. They are single celled organisms, having several shapes and range in size from 0.5 to 2 microns in diameter and 1 to 10 microns in length. Bacteria have three major shapes vizrod-shaped bacteria (bacilli), spherical–shaped (cocci), and spiral–shaped. Some are single-celled; appear in pairs, chains or clusters.

Bacteria feed on plants and animals in water and land. Some bacteria can use inorganic elements such as iron as sources of energy. Growth of bacteria is faster in warm than cold temperatures. For each 10ºC increase, bacterial growth rate doubles. pH affects the growth of bacteria as bacteria grow best when it is neutral. Metal ions like copper, lead, silver and some pesticides are toxic and inhibit the growth of bacteria.

Many bacteria are aerobic and require free oxygen for growth while others are anaerobic requiring no free oxygen. Facultative bacteria can switch from aerobic to anaerobic depending on environmental conditions. Bacteria multiply by binary fission dividing into identical daughter cells. Under optimal conditions, bacteria can double in numbers every 20 -30 minutes. Some bacteria produce resistant spores which are viable structures regarded as the resting phase. The spores can survive very harsh conditions.

Water borne diseases caused by bacteria include typhoid fever (*Salmonella typhi*), gastroenteritis (*Shigella*spp, *Campylobacter*spp, Enteropathogenic*E. coli*), cholera (*Vibrio cholera*), leptospirosis (*Leptospira*spp).

3.1.3 Protozoa

Protozoa are single –celled animals which are several times larger than bacteria ranging from 4-500 microns. Protozoa are classified based on their modes of movement as:

i. Amoeba which move by gliding or streaming action and change shape as they move.
ii. Ciliates are covered with hair-like structures called cilia which beat rapidly and propel the organism. Most ciliates are free swimming, attached to floating materials or walls.
iii. Flagellates have one or more whip-like projections called flagella for movement.
iv. Suctoria are attached organisms and have tentacles rather than cilia.
v. Sporozoa are non-motile and are swept along with the current of water.

Protozoa feed mostly on bacteriaand most protozoa are aerobic or facultative. They alternate between active growth phases (trophzoites) and a resting phase called cysts (extremely resistant structures that protect the organisms from harsh environmental conditions.

3.1.4 Viruses

The viruses are several times smaller than bacteria and are very simple life forms. They range in size from 0.02-0.25 microns in diameter. They have several shapes such as geometric polyhedrals, long slender rods and elaborate irregular shapes. Viruses are intracellular parasites that must live and reproduce in host cells. A virus contains a central molecule of genetic material surrounded by a protein called capsid and sometimes an additional layer called envelope. They cannot obtain energy or reproduce on their own. Viruses invade all kinds of cells and take over host cells forcing them to produce more viruses and destroy the cell in the process.

3.1.5 Algae

Algae are aquatic plants. Many of them are microscopic cells though visible when in masses or large numbers. Some are multi-cellular e.g. kelp found in marine waters. They occur in both clean and polluted waters. Algae are capable of carrying out photosynthesis (primary production). Algae are classified according to colour as

i. Green algae-contain chlorophyll and are found mostly in freshwater.
ii. Euglenoids are single –celled, green-pigmented, resemble protozoa, contain flagella and carry out photosynthesis.
iii. Diatoms are golden-brown, single-celled, have hard silica gel.
iv. Cyanobacteria are bluish-green in colour, can carry out photosynthesis, formerly called blue-green algae but now classified as bacteria.

4.0 CONCLUSION

Apart from the chemical and physical characteristics of natural waters, living organisms also inhabit the water. These include bacteria, fungi, algae, protozoa. Viruses are obligate parasites which must live and grow in other organisms and cause diseases in the process

5.0 SUMMARY

In this unit, we have discussed the biological characteristics of natural waters. We also mentioned some characteristics of different microorganisms that are found in water

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the different classes of microorganisms that are present in water.
2. Outline the characteristics of these classes.

7.0 REFERENCE/FURTHER READING

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MODULE 3

UNIT 1 SAMPLING METHODS

CONTENTS

1.0 INTRODUCTION

In this unit, you will learn about some sampling methods used in water monitoring and aquatic biological assessment programmes. It is not always possible to study the whole aquatic environment and this makes it necessary to obtain representative samples. The types of samples obtained depend on the objectives of the study.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- mention the process of site selection
- state the different types of sampling methods
- explain the physical habitat and biological assessments.

3.0 MAIN CONTENT

3.1 Site Selection

In sampling, first determine why you are carrying out the project. This may be very simple or complicated depending on the results you aim to achieve.

Different goals determine the sampling designs, protocols to be used and sampling locations (Smiley, *et al*., 2009). Data obtained from the sites should answer questions or hypotheses that the sampling goal sought to answer. For instance, you may want to identify sources, types of contaminants in water, or the concentrations of a particular substance in the environment before a project. For site selection:

1. Identify the goals of the project, understand the working of the system before choosing locations for sampling.
2. The scale of the work will determine the number of sites to collect samples from.
3. For long-term monitoring, consider the likely future plans for the sites chosen. Choose sites with no impending modifications using aerial photographs, maps, or personal knowledge of the area, GIS software or Google earth (Benson and Dalrymple, 1984).
4. Carry out a reconnaissance survey (an initial field visit to assess the site personally) to see if the sites meet selection criteria. Sites should be easily accessible.

Water quality sampling for sediment and sediment-associated constituents is more difficult than sampling for other water chemistry variables because of temporal and spatial variability in transport. The point at which a sample is collected will influence sediment concentration data.

3.2 Sampling Methods

3.2.1 Manual Sampling

Manual grab sampling at a single location at each sampling site is the standard method for collection of base flow (discharge derived from the seepage of groundwater in combination with upstream water through-flow without significant direct contribution from surface runoff from precipitation) samples.

Advantages of grab sampling

- It is relatively safe
- It is simple
- It is inexpensive
- It can be performed at any location
- Manual grab sampling may, be the only alternative if the costs of purchasing and maintaining automatic samplers exceeds available resources (Burton and Pitt, 2002).

Disadvantages of grab sampling

i. Grab sampling provides limited information on temporal (time) variability of constituents unless frequent samples are collected.
ii. Manual sampling methods also introduce human errors due to sampling.

3.2.2 Integrated sampling

This is another manual technique that collects subsamples throughout the flow cross-section to accurately determine mean constituent concentrations. Samples are obtained at different depths across the stream to produce accurate concentration measurements even in large streams.

Disadvantages

i. This technique requires a lot of personnel time, especially for many sites.
ii. It may be difficult to collect samples throughout the range of observed discharges.
iii. If it is necessary to enter into the stream for sample collection, safety must be an important consideration.
iv. Water samples should be collected upstream from the point of entry of constituent of interest.

3.2.3 Automatic Sampling

The samplers are installed in the field and collect and record data automatically. They have the following advantages:

i. They use consistent sampling procedure and simultaneously collect samples at multiple sites.
ii. Are useful where sites are distant, hard-to-reach (e.g., steep inclines) or dangerous.
iii. They are very useful for sampling during storms because they can sample throughout runoff events of various durations and magnitudes.
iv. Disadvantage: Automatic samplers require frequent maintenance (Burton and Pitt, 2002; Harmel *et al.*, 2006a).

3.2.4 Mechanical Samplers

Mechanical samplers such as rotating slot sampler and multi-slot divisor sampler collect flow-weighted samples and estimate flow volume, allowing for the calculation of mean concentrations and mass loads. The rotating slot sampler requires minimal maintenance, no electrical power, and collects a single flow-proportional runoff sample (Parsons, 1954, 1955; Edwards *et al.*, 1976).

3.3 Physical Habitat and Biological Assessments

Physical habitat and biological assessments are parts of water quality monitoring programs that include physical habitat, biological, and traditional water chemistry and discharge assessments (USEPA, 2002).

3.3.1 Physical Habitat Assessments

Physical variables like stream cross-section area, discharge, number of riparian trees "habitat" that aquatic organisms occupy. These are the two approaches for measuring riparian habitat, geomorphology, and instream habitat.

- **Transect- based sampling methods**

  Transect-based sampling methods consist of measuring selected habitat variables at predetermined points along multiple transects within a site.

  Advantages:

  i. Transect-based habitat sampling methods result in quantitative habitat data.
  ii. Reduce observer's bias.

iii. Ensure comparability among sampling sites, time periods, and categories of interest (Simonson *et al.*, 1994; Wang *et al.*, 1996).
iv. Transect-based sampling methods are compulsory when quantitative information on water depth, water velocity, riparian characteristics, channel size, and adjacent land use is needed.

- **Visual-based habitat methods**

  This method involves estimation rather than actual measurements of a site's variables.

  Advantages:

  i. Visual habitat methods require less equipment and time than quantitative habitat measurements.
  ii. Visual-based habitat methods depend on training and skills of the observer. Scores differ among observers (Somerville and Pruitt, 2004).
  iii. Visual-based habitat sampling methods are useful for descriptive purposes and for preliminary habitat assessments intended to assist with site selection.
  iv. Visual-based methods are used to produce a habitat quality index (Barbour *et al.*, 1999) that provides an easily interpretable value representative of the physical habitat quality of the site.

3.3.2 Biological Assessments

Sampling methods for aquatic macroinvertebrates:

1. The **dipnet** is a net with a wooden handle used for sampling macro invertebrates

   Advantage
   It can sample many different types of microhabitats found within a site.

   Disadvantage
   It is a qualitative sampling technique because one cannot calculate density (number of organisms per square meter) from dipnet samples.

2. **Surber sampler** is a portable, stream bottom sampler made of two folding frames with netting fixed at right angles. For sampling, the horizontal frame is positioned in the substrate. Silt and rocks are stirred up so that the current transports bottom organisms into the net. It is used in quantitative biomonitoring studies for evaluating the effects of different disturbances in gravel bottom streams (Resh and McElravy, 1993).

   Fish sampling: Fish are sampled using hand or gill nets, hook and lines, and seines. Electro fishing method though useful for fish sampling elsewhere is not recommended in Nigeria. Record data as catch per unit time.

4.0 CONCLUSION

To study the aquatic environment, it is pertinent to obtain representative samples since it is impossible to study the whole environment at the same time. Methods of obtaining samples are discussed in this unit.

5.0 SUMMARY

In this unit we discussed the different sampling methods used in aquatic studies. The first step in designing a sampling project is to identify its goal and resources available to achieve the goal. Whether the project and its goals are very simplistic or highly complex, project design should include initial planning that considers the spatial extent of sampling, response variables to be analysed, the flow conditions of water to be sampled, and the type of technology and personnel to be used in such sampling.

6.0 TUTOR–MARKED ASSIGNMENT

1. Explain the process of site selection.
2. Explain the different types of sampling methods.
3. Explain the physical habitat and biological assessments.

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UNIT 2 SAMPLING FOR SPECIFIC WATER QUALITY PARAMETERS

CONTENTS

1.0 INTRODUCTION

Specific parameters are usually analysed in water quality studies. These specific parameters require different conditions for their determination. In this unit, we discuss the methods used in the collection of water samples and precautions needed.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the measurement of electrical conductivity
- discuss the measurement of dissolved oxygen, temperature, salinity, and pH
- explain the measurement of turbidity
- mention the sampling procedures for total and volatile suspended solids
- mention the sampling procedures for nitrogen and related nitrogen compounds
- discuss the measurement of total phosphorus cum total and organic carbon
- explain the measurement of soluble reactive silica and biochemical oxygen demand
- discuss the measurement of total water hardness and metals.

3.0 MAIN CONTENT

3.1 Methods used in Sampling and Measuring some Water Quality Parameters

- **Measurement of electrical conductivity**

  When using the hand held meter, keep it in gentle motion through the water column while taking a reading. Allow several minutes for the meter to stabilise. Take measurements about 10 cm below the water surface and about 10 cm above the sediment surface where water is deep.

  For laboratory analysis, take 125 ml unfiltered water sample in a pre-cleaned plastic container with a Teflon cover. Pre- rinse bottle three times before final collection of sample and avoid excessive agitation of water during sample collection to reduce air bubbles in the sample. Fill container to the brim to exclude air and cap tightly. Refrigerate at 1-4°C and analyse within 24 hours. Measure conductivity electrometrically with (or without) temperature compensation and calibrate against a standard solution of potassium chloride. It is better to perform this test in the field.

- **Dissolved oxygen**

  For in situ DO measurement with hand-held meter, use similar method of sample collection as for electrical conductivity and avoid excessive turbulence to minimise air bubbles in the water. Allow several minutes for the meter to stabilise before taking measurements about 10 cm below the water surface and above the sediment surface; or a mid- water column reading in shallow water.

  Record DO measurements in mg/L (dissolved oxygen concentration) or % (saturation). This in-situ DO measurement is done in the field. Winkler's method can also be used in the laboratory after fixing water samples in the field immediately after collection

- **pH**

  For *in situ* field measurement of pH using hand –held meters and laboratory analyses, same precautions are necessary as for electrical conductivity and DO. Directly collect water into sample bottle or transfer into a sample bottle from collection vessel. Fill completely to exclude air bubbles. Ensure sample bottle is pre-rinsed thrice with sample water (3 × 20mL) before final collection and do not freeze but refrigerate at 1–4°C. Analyse directly or as soon as possible after sample collection and preferably in the field, but within 6 hours if the sample is refrigerated at 1–4°C.Measure pH electrochemically using a combination electrode (glass plus reference electrode) and calibrated against two or three buffer solutions (APHA, 1998)

- **Salinity**

  Take 200 ml unfiltered water sample directly in a pre-cleaned plastic bottle with a Teflon liner or transfer into a sample bottle from a collection vessel. Pre-rinse water sample bottles thrice with sample water (3 × 20ml) before final collection. Refrigerate at 1–4°C but do not freeze. Avoid excessive turbulence during collection, fill container completely to the top to exclude air and cap tightly.

  Analyse directly or as soon as possible after sample collection, but within 24 hours. Unit of measurement for salinity is parts per thousand (ppt or ‰). It is preferable to perform this test in the field. Avoid plastic sample bottles made from low-density polyethylene (LDPE) as they leak easily. High-density polyethylene (HDPE), polypropylene, polycarbonateor a fluoropolymer (e.g. teflon) are suitable.

- **Temperature**

  Measure temperature using a thermometer with a range of 0–50°C or a suitable electronic thermometer. Place the probe in the water to be measured. Allow to stabilise before taking readings. Record temperature measurements in Degrees Celsius (°C).

- **Turbidity**

  Measurements using probes should be at least 1m below the water surface and deeper in clear waters to ensure that there is no influence from ambient light. For laboratory analysis, collect 250 ml unfiltered water sample using pre-cleaned plastic containers or glass bottles. Pre-rinse sample bottles thrice with sample water (3 × 20mL) before final collection. Do not increase the turbidity of the water while collecting a sample by disturbing the bottom or the aquatic plants.

  Store container in the dark, refrigerate at 1–4°C but do not freeze to avoid changes in turbidity. Avoid turbulence to minimise air bubbles in water and fill to just below shoulder of the bottle. Analyse directly or as soon as possible after sample collection preferably in the field, but within 24 hours. Units of measurement NTU (nephelometric turbidity units)

Secchi disk depth (For turbidity or water clarity)
The Secchi disc is used to measure the depth of light penetration or turbidity of water for comparative purposes. The disc is a circular white plate made of non-corrosive rigid material, usually with a diameter of 30 ± 1 cm. To reduce the effects of currents on the angle of view, a mass of 3.0 ± 0.5 kg is suspended below the centre of the discon a rigid rod 15 cm long. The disc is painted with quadrants in black and white waterproof paints and attached to a non-stretch rope, marked at appropriate intervals of depth with waterproof markings (10 cm in turbid water and 50 cm intervals in clearer water). Where the disc cannot be seen is where effective light penetration is extinguished.

The Secchi disk depth is a measure of the limit of vertical visibility in the upper water column and a direct function of water clarity. High Secchi depth reading simply high water clarity and light penetration while low Secchi depth readings indicate reduced water clarity, limited light penetration, primary production due to suspended particles and algal blooms. Highly coloured waters (e.g. with tannins) have low Secchi transparency, which may not indicate poor water quality. The Secchi disk is prone to error if strong flows and clouds casting shade are present. Conditions for measuring Secchi disc depth are:

a) clear sky with the sun directly overhead or the sun is at your back to minimise reflection from the sun on the water and the sampler must wear sunglasses
b) Take measurements on the protected side of the boat, with minimal waves or ripples
c) The same person should record Secchi disc depth all through a sampling day to ensure consistency.
d) If the conditions vary from this ideal situation, record any differences infield notes or the field observations form.
e) Tie the end of the rope onto a float (e.g. a bucket) to prevent accidental loss of the disc.
f) Lower the disc into the water in a position away from shadow and record the depth at which the black/white interface on the disc just disappears from sight. Raise the disc until it just becomes visible and record this depth to the nearest 10 cm,

then lower it just to the point where the disc disappears again. The depths at disappearance and reappearance are averaged and referred to as the Secchi disc depth.

- **Sampling procedures for total suspended solids**
  Take 1L unfiltered sample in a pre-cleaned bottle or plastic container directly or from a collection vessel. Pre-rinse sample bottle thrice with sample water (3 × 20 ml) before final collection. Avoid disturbing the water, aquatic weeds or increasing air bubbles in the sample during collection. Fill bottle to the shoulder and refrigerate at 1–4°C but do not freeze. Analyse sample directly or as soon as possible after collection, but within 24 hours. Do not hold samples longer than 7 days. Unit of measurement is mg total suspended solids/L.

- **Sampling procedures for volatile suspended solids**
  Use the same procedures as for total suspended solids to collect samples for volatile suspended solids. Unit of measurement is mg/L (mg volatile suspended solids/L). Volatile solids can be determined by ignition at 550°C (2540-E, APHA, 1998). VSS is determined as the weight of the lost material on ignition at 550°Ccompared to constant weight at 105°C.

- **Total nitrogen (TN)**
  Total nitrogen includes all forms of nitrogen- nitrate, nitrite, ammonia and organic nitrogen. The concentration of nitrogen can be used to assess nutrient status in waterways. Enrichment by nitrogenous compounds can cause nuisance or toxic algal blooms. Sources of nitrogen enrichment include fertilisers, animal wastes, sewage, nitrogen fixing plants, and lightning.

  Collect 200ml unfiltered water in a pre- cleaned plastic container or bottle directly or transfer from the collection vessel in a similar manner to total and volatile suspended solids. Fill to just below shoulder of the bottle. Store at 1-4°C or freeze and store in the dark. Analyse within 24 hours if sample is kept refrigerated at 1–4°C or within 30 days if kept frozen below -20°. Units of measurement mg/L (mg nitrogen/L). The method of analysis is Persulphate digestion method 4500-N C. (APHA, 1998), and the automated cadmium reduction method 4500-NO_3- F (APHA, 1998).

- **Total oxidised nitrogen**
  Total oxidised nitrogen is the sum of the nitrate (NO_3-) and nitrite (NO_2-) expressed as concentrations in mg/L nitrogen. The nitrite and nitrate species can be determined separately.

  Total oxidised nitrogen (NOx-N) = [Nitrate (NO_3-) +Nitrite (NO_2-)] **Nitrite** is an intermediate form of nitrogen and is rapidly oxidized to nitrate. **Nitrate** is an essential plant nutrient and its levels in natural waterways are typically low (less than 1 mg/L). Excessive amounts of nitrate can cause water quality problems and accelerate eutrophication, altering the densities and types of aquatic plants in affected waterways. Some bacteria convert nitrate in to gaseous nitrogen through denitrification. Nitrate is determined by the automated cadmium reduction method 4500-NO_3- F (APHA, 1998).

  Take 125 ml filtered water sample in new pre-cleaned plastic container or bottle. Collect the sample in a clean sample container prior to filtration. Place filtered sample in a different sample bottle, after rinsing thrice with filtered sample water (3 × 20 ml) before final collection. Fill to just below the shoulder of bottle. Filter the sample through 0.45µm pore diameter cellulose acetate (membrane) filter C. Analyse within 24 hours if sample is kept refrigerated at 1–4°C or within 30 days if kept frozen below -20°C. Unit of measurement is mg/L (mg oxidised nitrogen as nitrogen/L).

- **Sampling procedures for nitrogen as ammonia/ammonium**
  Ammonia nitrogen and ammonium nitrogen species are determined using the same analytical method. Ammonia and ammonium exist in equilibrium in aqueous solution. In alkaline solutions ammonia dominate species is ammonia (NH_3), while ammonium (NH_4+) predominates at lower pH. Sources of ammonia include fertilisers and decomposition of organic matter.

  Collect 125 ml filtered water sample in a pre –cleaned plastic container or bottle. You can collect the sample in a clean container prior to filtration. Filter the sample through 0.45 µm pore diameter cellulose acetate(membrane) filter C. Place filtered sample in a different sample bottle, after pre- rinsing thrice with filtered water sample (3x20ml) before final collection. Fill to just below shoulder of the bottle and refrigerate at 1–4°C or freeze and store in the dark. Analyse within 24 hours if sample is filtered and kept refrigerated at1–4°C or within 30 days if filtered and kept frozen below -20°C.

Unit of measurement mg/L (mg N/L). Analysis method is the automated phenate method 4500-NH3 G. (APHA, 1998).

- **Total organic nitrogen (TOrgN)**
  Calculate total organic nitrogen from the concentrations of total nitrogen, nitrite, nitrate and ammonium nitrogen, by subtracting the concentrations of inorganic fractions of nitrogen, namely nitrite and nitrate (NOx) and ammonium nitrogen (NH_3-N/NH_4-N) from the total nitrogen (TN) concentration:
  $TOrgN = TN – (NOx + NH_3\text{-}N/NH_4\text{-}N)$.

- **Total Kjeldahl nitrogen (TKN)**
  Kjeldahl nitrogen describes all dissolved nitrogen in the tri-negative oxidation state (e.g. ammonium, ammonia, urea, amines, amides, etc) and comprises all the dissolved nitrogen except some inorganic species (nitrite and nitrate) and organic compounds (azo-compounds, nitriles, oximes, etc). The Kjeldahl method hydrolyses all the amino nitrogen to ammonium, which is then measured by the ammonium/ammonia method.

  Assuming that the concentrations of many of the other nitrogen species are very low, the TKN concentration is therefore approximately equal to the TN concentration less the nitrite and nitrate concentrations. Or alternatively the TKN concentration is approximately equal to the sum of the total organic nitrogen and ammonia/ammonium as nitrogen concentrations. Calculate TKN (total) directly by subtracting nitrate and nitrite from total nitrogen (TN) on an unfiltered sample. The Kjeldahl determination is rarely used because it is not as precise as the persulphate digestion method used to calculate TN. It also uses mercuric sulphate–sulphuric acid digest, leaving mercury as an undesirable waste product.

- **Dissolved organic nitrogen (DOrgN)**
  Calculate dissolved organic nitrogen (DOrgN) by analysing TN in a filtered sample and subtracting the NH_3-N/NH_4-N and NOx-N (i.e. the dissolved inorganic fractions of nitrogen) from the result.

  Take 125 ml filtered sample in a pre-cleaned plastic container or bottle in a manner similar to that used for total oxidised nitrogen. Refrigerate at 1–4°C or freeze and store in the dark. Analyse within 24 hours if sample is filtered and kept refrigerated at1–4°C or within 30 days if filtered and kept frozen below -20°C. Unit of measurement is mg/L (mg DOrgN as nitrogen/L). Analysis method of Total nitrogen is by persulphate digestion method 4500-N C. (APHA, 1998) and the automated cadmium reduction method 4500-NO3- F (APHA, 1998).

- **Total phosphorus (TP)**
  Phosphorus occurs in natural waters and wastewaters as phosphates. These are classified as orthophosphates (PO_4^{3-}), condensed phosphates (pyro-, meta-, and other polyphosphates), and organically bound phosphates. They occur in solution, in particle or detritus, and bodies of aquatic organisms (APHA, 1998). Sources of phosphorus enrichment include detergents, fertilisers, animal faeces/ manure, sewage and industrial wastes. High levels of phosphorus and/or other key nutrients may lead to related problems such as nuisance or toxic algal blooms, although some waterways are naturally eutrophic (nutrient enriched).

  To sample for total phosphorus, collect 200 ml unfiltered water in pre-cleaned Teflon –capped bottle or plastic directly or from a collection vessel. Fill to just the shoulder of bottle. Ensure sample bottle is pre-rinsed thrice with sample water (3 × 20mL) before final collection. Refrigerate at 1–4°C or freeze; and store in the dark.

  Analyse immediately or within 24 hours for samples refrigerated at 1–4°C and stored in the dark. Analyse within 30 days if kept frozen below -20°C. Unit of measurement is mg/L (mg phosphorus/L). Analysis method is persulphate digestion method 4500-P B.5. (APHA, 1998), and the automated ascorbic acid reduction method 4500-P F. (APHA, 1998).

- **Total organic carbon (TOC)**
  The total organic carbon (TOC) concentration represents all the carbon covalently bonded in organic molecules and so not filtered. Total organic carbon does not take into account the oxidation state of the organic matter, and does not measure other organically bound elements, such as nitrogen, hydrogen, and inorganics that can contribute to the oxygen demand measured by biological oxygen demand (BOD). Drinking water TOC concentrations range from less than 100 µg/L to more than 25 mg/L. Wastewaters may contain very high levels of organic carbon(>100mg/L).

Take 125 ml of unfiltered sample in a new and pre-cleaned amber Teflon-lined capped bottle free from organics. The sample bottle should be pre-rinsed thrice with sample water(3 × 20 mL) before final collection. Fill the bottled completely to exclude air bubbles. Refrigerate at 1–4°C, do not freeze, store in the dark. Add 10% sulphuric acid (H_2SO_4) in the field until the pH is < 2 to acidify sample. Carry out analysis as soon as possible but maximum holding time for acidified sample is 7 days. Refrigerate at 1–4°C and store in the dark. Do not freeze. Unit of measurement is mg/L (mg carbon/L or μg non-purgeable organic carbon/L). Analysis method for total organic carbon is by high temperature combustion and IR detection, method 5310 (APHA, 1998). Inorganic carbon must be removed before analysis so volatile organic carbon will be lost. Report as non-purgeable organic carbon.

- **Dissolved organic carbon (DOC)**

  Dissolved organic carbon (DOC), represents all the soluble organic carbon (orcarbon covalently bonded in organic molecules) that can pass through a 0.45 μmpore diameter filter. Dissolved or total inorganic carbon (TIC, or DIC) represents the carbonate (CO_3^{2}), bicarbonate (HCO_3^{-}) and dissolved carbon dioxide (CO_2) present in a sample.

  Interference of DIC in the measurement of DOC is removed by acidifying the sample to a pH of less than 2 to convert all carbonates to CO_2. The CO_2 gas produced is purged from the sample before DOC analysis. Removing CO_2 purging from the sample also purges volatile organic carbon from the sample. Only non-purgeable organic carbon will be determined in the DOC measurement.

  Take 125ml of filtered sample in a pre-cleaned glass (amber or brown) container free from organics. The cap should be lined with Teflon. Filter sample through 0.45 μm pore diameter cellulose acetate(membrane) filter. Place filtered sample into sample bottle after rinsing three times with filtered water sample (3x20ml) before final collection. Fill container completely to the top to exclude air bubbles. Refrigerate at 1–4°C, do not freeze and .tore in the dark.

  Carry out test as soon as possible or analyse within 7 days if acidified, refrigerated at 1–4°C and stored in dark. Unit of measurement is mg/L (mg carbon/L or μg non-purgeable organic carbon/L). Analysis method Total organic carbon by high temperature combustion and IR detection, method 5310 (APHA, 1998). Note that:

a) samples should be filtered as soon as possible after sample collection, preferably on site. Filter paper should be washed with sample first prior to filtration. Do not re-use filter paper.

b) if the sample has high particulate matter content, it may be necessary to pre-filter using a glass fibre filter paper (GFC 1.2 µm).

- **Soluble reactive silica (SiO2-Si)**

Diatoms use silica to build their cell walls and can become a nuisance if their numbers increase rapidly and cause a bloom. Therefore, it is important to quantify the amount of soluble reactive silica in estuaries and catchments.

Collect 250 ml of filtered sample in a pre-cleaned plastic or glass bottle before filtration. Filter sample through 0.45 µm pore diameter cellulose acetate (membrane) filter C. Place filtered sample in the bottle, after rinsing three times with filtered sample water(3 × 20 ml) before final collection. Fill to the shoulder of bottle. Refrigerate at 1–4°C, do not freeze and analyse within 24 hours if sample is only kept refrigerated at 1–4°C or within 1 month for sample filtered and kept refrigerated at 1–4°C.Unit of measurement is mg/L (mg silica as silicon/L). Analysis method Automated method for molybdate-reactive silica method 4500-SiO2 D, E(APHA, 1998). Note that:

a) Samples should be filtered as soon as possible after collection, preferably on site. Wash filter paper with sample before filtration. Do not re-use filter paper.

b) Avoid plastic sample bottles made from low-density polyethylene (LDPE).Use high-density polyethylene (HDPE), polypropylene, polycarbonateor a fluoropolymer (e.g. teflon) bottles.

c) Do not pre-filter with glass fibre filter paper (GFC 1.2 µm) as these contain silica and can contaminate the sample.

- **Biochemical oxygen demand (BOD)**

Biochemical oxygen demand is a measure of the amount of biologically and/or chemically degradable organic material in water. It indicates the amount of oxygen aerobic aquatic organisms could consume in the process of metabolising all the organic matter available to them. High BOD causes low levels of dissolved oxygen in affected water.

Obtain 1L unfiltered sample in a brown or amber plastic container or glass. Use new pre-cleaned bottles only and do not pre-rinse container with sample. Collect samples directly into sample bottle or transfer into a sample bottle from collection vessel. Fill container completely to the top to exclude air. Analyse directly or as soon as possible after sample is collected or within24 hours if the sample is refrigerated at 1–4°C in the dark. Do not freeze. Analysis method is the 5-day BOD test method 5210 B (APHA, 1998). Unit of measurement is mg/L. Dark (or amber) glass bottles are preferable for samples that are low in BOD (<5 mg L-1).

Keep samples at or below 4°C during compositing. Limit compositing period to 24 hours after sample collection. To assist in preservation, refrigerate at 1–4°C and store in the dark but do not freeze. Plastic containers should be made from high-density polyethylene (HDPE), polypropylene, polycarbonateor a fluoropolymer (e.g. teflon).

- **Metals — total and dissolved metals and metalloids**
  Many metals are toxic to aquatic animals and can bioaccumulate in aquatic food chains. Metals commonly determined include aluminium (Al), silver (Ag), arsenic (As),boron (B), barium (Ba), beryllium (Be), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium(Na), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), titanium (Ti), uranium (U), vanadium (V) and zinc (Zn).

  Total metals can be analysed by digesting the sample using a concentrated nitric/hydrochloric acid added to an unfiltered water sample prior to analysis(APHA, 1998)).Dissolved metals are determined by analysing those metals in a filtered sample that passes through a 0.45 µm membrane filter (APHA,1998)]. Before analysis of a field-filtered, field-acidified sample, extra dilute acid is added to the filtered sample, to ensure dissolution of any precipitates formed after filtration. The sample must not be filtered when determining total metals (which include those metals bound to the particulate matter in the sample); otherwise, the same collection procedure is followed.

For heavy metals

a) Filter samples as soon as possible after collection preferably on site. Wash filter paper first with sample before filtration. Do not re-use filter paper.
b) Do not use plastic samples made from low density polyethylene (LDPE). Appropriate sample container plastics are high-density polyethylene (HDPE), polypropylene, polycarbonate or fluoropolymer (e.g. nalgene, teflon (polytetrafluoroethylene, PTFE)).
c) 125 ml naglene bottles are now used for heavy metals as HDPE bottles have been found to leach trace quantities of Zn over time.
d) For soluble metals analysis, if the sample has high particulate matter content, it may be necessary to pre-filter using a glass fibre filter paper (GFC 1.2 μm).
e) Acidification is not needed for the analysis of Li, K, and Na in samples because these metals in solution are stable for 1 month without acidification.

- **Total water hardness (as $CaCO_3$)**
  Water hardness is a measure of the capacity of water to precipitate soap. This is mainly due to the presence of calcium and magnesium ions in the water. Total hardness is now defined as the sum of calcium and magnesium concentrations in water, expressed as calcium carbonate equivalents in milligrams per litre according to the following formula (APHA, 1998):

  Hardness equivalent CaCO3/L = 2.497 [Ca, mg/L] + 4.118 Mg, mg/L].

  Take 125 ml of unfiltered sample in a plastic container plastic with Teflon-lined cap. Use new pre-cleaned acid rinsed bottles. Decant from collection vessel, ensuring sample bottle is pre-rinsed thrice with sample water (3 × 20 mL) before final collection. Fill to the shoulder of bottle. Samples can be stored for 7 days. Units of measurement is mg/L (mg $CaCO_3$/L).

- **Total acidity and total alkalinity (as $CaCO_3$)**
  The total *alkalinity* of water is a measure of its acid-neutralising capacity to a designated pH. It is the sum of all titratable bases-carbonates, bicarbonates, hydroxides, borates, phosphates, silicates and other bases if present. For analysis of total alkalinity (APHA,

1998) requires titration with a standard hydrochloric acid solution to an end-point pH of 3.7 (i.e. the methyl orange endpoint).

Total acidity is a quantitative measure of the capacity of water to react with a strong base. To determine total acidity APHA, 1998 requires titration with a standard sodium hydroxide solution to an end-point pH 8.3 (i.e. the phenolphthalein end-point).

Take 125 ml of unfiltered sample in new pre-cleaned bottles or plastic containers. Collect directly into sample bottle or transfer into a sample bottle from collection vessel. Pre-rinse sample bottle thrice with sample water (3×20mL) before final collection. Fill container completely to the top to exclude air and cap tightly. Refrigerate at 1–4°C but do not freeze and analyse within 1 day. Both total acidity and alkalinity are expressed as mg/L (mg $CaCO_3$/L). Both total alkalinity and total acidity require separate bottles for analysis. Analysis method acidity and alkalinity method 2310 B and 2320 B. (APHA, 1998).

- **True colour**
  Colouring water samples result from the presence of natural metallic ions (iron and manganese), humus and peat materials, plankton, weeds, and industrial wastes. True colour refers to the colour of water upon removal of suspended solids or when the sample has been filtered.

  Take 500 ml filtered water sample in pre-cleaned plastic or glass bottle with Teflon lined cap. Wash bottles in phosphate-free detergent and rinse thrice with tap water and thrice with de-ionised water. Or, collect sample in a clean sample container before filtration. Filter sample through 0.45μm pore diameter cellulose acetate(membrane) filter C. Place filtered water sample in a sample bottle, after rinsing three times three times with filtered sample water(3 × 20 mL) before final collection. Refrigerate at 1–4°C, store and transport in the dark without freezing. Fill to just below shoulder of the bottle but do not completely fill. Analyse within 2 days. Units of measurement are colour units or platinum-cobalt units (PCU, Pt/Co or Pt-Co units).

  Gilvin — colour
  Gilvin describes the natural dissolved organic carbon compounds that give water a brown colouration (absorb light in the 400–440 nm wavelength and reduce the blue region of the spectrum). Gilvin, or

soluble humic colour, is the major component absorbing light in inland waters. There are many compounds and compound classes that make up gilvin. The amount of light transmitted through the water is an important indicator of the potential for primary production within a wetland system. Measurement of colour provides information on the light climate of a wetland and its capacity for primary productivity.

Take 500 ml filtered sample in pre-cleaned plastic or glass bottle directly or transfer from collection vessel. Pre-rinse bottle thrice with sample water (3 × 20mL) before final collection. Filter sample through 0.45µm pore diameter cellulose acetate (membrane) filter B. Fill container completely to the top to exclude air, cap tightly, refrigerate at 1–4°C, store and transport in the dark but do not freeze. Analyse within 2 days. Unit of measurement is Gilvin440/m. Note that freezing may produce irreversible changes in gilvin colour.

4.0 CONCLUSION

Sampling for water quality parameters constitutes an important step before the analysis of water. This activity must be carried out carefully in order to avoid the introduction of errors to such analyses.

5.0 SUMMARY

In this unit, we discussed the methods employed in the collection of water samples for individual water quality parameters, precautions to be taken during sampling and methods used for their analyses.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the measurement of electrical conductivity.
2. Explain the measurement of dissolved oxygen, temperature, salinity, and pH.
3. Explain the measurement of turbidity.
4. Explain the sampling procedures for total and volatile suspended solids.
5. Explain the sampling procedures for nitrogen and related nitrogen compounds.
6. Explain the measurement of total phosphorus cum total and organic carbon.
7. Explain the measurement of soluble reactive silica and biochemical oxygen demand.
8. Explain the measurement of total water hardness and metals.

7.0 REFERENCES/FURTHER READING

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UNIT 3 MANAGEMENT OF SELECTED MARINE, BRACKISH AND FRESH WATERS

CONTENTS

1.0 INTRODUCTION

Water bodies are important habitats for fish, other aquatic animals and plants. Their management is important in ensuring that they remain available for growth and sustenance of aquatic animals which should also be available for human and animal consumption. The other uses of the aquatic environment also need to be sustained for future generations

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the sources of groundwater pollution
- discuss the management of groundwater pollution or contamination
- discuss the wetland management
- discuss the estuary and coastal pollution
- discuss the management and protection of continental shelf, territorial sea and claimed exclusive economic zone.

3.0 MAIN CONTENT

The effect of pollution depends on the water body it impacts. Pollution of running water, large river or meals which are natural components of water may not show may show very little impact or impacts may show where the water flows to.

3.1 Sources of Groundwater Pollution

Groundwater flows slowly beneath the earth's surface in aquifers (porous geologic formations). Sources of groundwater pollution include:

1. Water-soluble pollutants (e.g. agricultural chemicals) and the quantity of pollutant reaching the groundwater depend on soil type, pollutant characteristics and distance to the groundwater.
2. Runoff on soil surface percolates into groundwater with a portion of its pollutant load (e.g. nitrate in wastes from animal production operations).
3. Pathogens e.g. viruses, reach groundwater through sewage. Improperly treated septic systems can contaminate groundwater.
4. Improperly protected landfills can leach contaminants into groundwater including petrochemicals from leaking underground-storage tanks.
5. Groundwater can contain detectable levels of pesticides.
   Management and pollution cleanup for groundwater is very difficult and expensive. It is better to prevent it.

3.2 Management of Groundwater Pollution or Contamination

1. Use pesticides with low tendency to migrate into groundwater or apply very limited amounts to reduce run off or leaching with rain.
2. Pump-and-treat: The groundwater is pumped to the surface, treated to remove pollutants, and returned to its source. This takes a long time and may produce little changes in water quality.
3. Building underground barrier to prevent contaminants from spreading off-site. This works only for shallow water that is contaminated in a way that it can realistically be contained.
4. Groundwater can be treated *in situ*, e.g. by digging trenches, and installing tons of iron filings mixed with sand in the path of the groundwater. Contaminated groundwater flows through it and some organic pollutants like trichloroethylene react with the iron to form benign products.
5. The use of anaerobic microorganisms to degrade the contaminants.

3.3 Wetland Management

Wetlands are areas inundated by water throughout or during some part of the year. Wetlands absorb surplus nutrients, sediments, and other pollutants before they reach rivers, lakes or oceans. They also absorb and slow floodwaters, thereby reducing flood damage. Wetlands provide habitat for many species of plants and animals. They act as buffers against pollution but excess pollution can harm living organisms within wetlands.

Wetland management involves activities that can be conducted with, in and around wetlands to protect, restore, manipulate or provide for their functions and values. Natural wetlands are those that do not result from human activities. The management goal for undisturbed wetlands is to continue existing functions such as buffers for other receiving water bodies. Two main facets of managing wetlands for protection include buffering wetlands from direct human pressures and maintaining natural processes in surrounding lands that affect wetlands and may be disrupted by human activities.

Protection of wetlands through assignment of designated use: The level of protection provided should conform to the designated use established for a wetland. Factors to consider in setting the designated use and developing a management strategy for a wetland are

- Wetland type and landscape location
- Surrounding land uses
- Cumulative impacts on the wetland
- Vegetation quality
- Presence or absence of rare or endangered species
- Surface water quality
- Wildlife habitats
- Cultural values.

Pressures on wetlands created by human and other activities:

- Fragmentation of wetlands with roads or other linear facility crossings
- impacts of recreational uses
- impacts from adjacent property owners, partial or full wetland owners

- incursion of trampling , soil compaction, intense grazing and waste loading
- pest control treatments, pedestrian access, moving, landscaping waste dumping
- hydrologic alterations such as ditch construction, dewatering by redirecting contributing land area inflows, impervious surfaces
- increased sediment, nutrient, metals, pathogens and other pollutant loadings from waste water discharge
- changes in physical characteristics of inflows such as temperature, dissolved oxygen, turbidity, pH due to activities
- atmospheric deposition of pollutants
- introduction of nuisance and exotic plant and animal species
- loss of more sensitive wetland species due to changes in adjacent land uses.

Buffers and other protective measures for wetlands

A buffer consists of a band of vegetation along the perimeter of a wetland or a water body. A buffer design must consider the nature of the encroaching activity, the buffer itself, the resource to be protected and the buffering function to be performed.

Criteria for determining adequate buffer size to protect wetlands (Castelle, 1994)

- Wetland functional value-level of disturbance and sensitivity to disturbance
- Intensity of adjacent land use
- Buffer characteristics - vegetation density, structural complexity, and soil condition.
- Specific functions.

Functions of buffers

- Sediment removal
- Nutrient transformations and removal
- Metals and other pollutants’ reduction
- Storm water reduction through infiltration
- Reduction of water temperature
- Reduction of human impacts by limiting access and minimising edge effects from noise, light, temperature
- Protection of interior wetland species
- A barrier to invasion of nuisance and exotic species.

Protective Management of wetlands involves maintaining important management processes that operate on wetlands from the outside and that may be altered by human activities e.g. fire, mosquito control and construction.

3.4 Estuary and Coastal Pollution

Brackish water is found where ocean or marine water meets with freshwater from rivers such as in estuaries. An estuary is the junction where a river flows into the ocean. It is an intertidal zone containing partially fresh and salty water. Many estuaries have been modified by human activities with about 80% of the pollution in estuaries and coastal areas coming from land-based sources. Causes of pollution in estuaries or coastal areas include:

1. The large human population mainly within or close to coastal areas: a third of the world’s population lives within a hundred kilometres of a coastline.
2. Use of large quantities fertilisers that runoff surplus reactive nitrogen and phosphorus.
3. Increase in impermeable surfaces (e.g. concrete floors, tarred parking lots) promote runoff of several pollutants.
4. Destruction of coastal wetlands by filling, draining for construction reduce space for water absorption, ground water recharge and absorption of pollutants.
5. Coastal waters are stressed by pollution, fisheries and wildlife populations are affected.

3.5 Management and protection of continental shelf and territorial Sea

According to the UN Convention of the Law of the Sea, the Continental Shelf is the area of the seabed and subsoil which extends beyond the territorial sea to a distance of 200 nautical miles from the territorial sea baseline and beyond that distance to the outer edge of the continental margin. Coastal states have sovereign rights over the continental shelf (the national area of the seabed) for exploring and exploiting it; the shelf can extend at least 200 nautical miles from the shore, and more under specified circumstances.

The territorial sea is defined under the United Nations Convention on the Law of the Sea (UNCLOS) as the 12-nautical mile zone from the baseline or low-waterline along the coast. The coastal state's sovereignty extends to the territorial sea, including its sea-bed, subsoil, and air space above it.

3.6 Management and protection of Claimed Exclusive Economic Zone

Under UNCLOS, coastal States can claim sovereign rights in a 200-nautical mile exclusive economic zone (EEZ). This allows for exploration, exploitation, conservation and management of all natural resources in the seabed, its subsoil and overlaying waters. UNCLOS allows other states to navigate and fly over the EEZ, as well as to lay submarine cables and pipelines. The inner limit of the EEZ starts at the outer boundary of the territorial sea. Under UNCLOS, "land-locked and geographically disadvantaged states have the right to participate on an equitable basis in exploitation of an appropriate part of the surplus of the living resources of the EEZ's of coastal States of the same region or sub-region."

4.0 CONCLUSION

All fresh and saline water are subject to disturbances. This implies that for them to remain as useful resources, they must be properly managed and protected against human and other influences.

5.0 SUMMARY

In this unit, we have discussed the management of some aquatic habitats such as groundwater, wetlands and some coastal environments.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the sources of groundwater pollution.
2. Explain the management of groundwater pollution or contamination.
3. Explain the wetland management.
4. Explain the estuary and coastal pollution.
5. Explain the management and protection of continental shelf, territorial sea and claimed exclusive economic zone.

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MODULE 4

UNIT 1 FRAMEWORK FOR WATER POLLUTION CONTROL

CONTENTS

1.0 INTRODUCTION

Water pollution should be managed under a guiding framework. There are principles and recommendations for water resource management as recommended by UNCED, 1992. It is important to analyse, categorise and prioritise water quality problems that require solutions

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- state the principles and recommendations for sound water resources management (UNCED, 1992)
- discuss the initial analysis of water quality problems and identification of water quality problems
- explain the categorisation and prioritisation of water quality problems
- discuss the required management interventions
- define long-term and short term objectives for water pollution control
- discuss the management tools and instruments for water pollution control
- discuss the regulations, management procedures and by-laws.

3.0 MAIN CONTENT

3.1 Principles and Recommendations for Sound Water Resources Management (UNCED, 1992)

Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment. Land and water resources should be managed at the lowest appropriate levels. The government should provide an enabling role in a participatory, demand-driven approach to development.

Water should be regarded as both social and economic good. Water and land-use management should be integrated. The private sector and women have important roles in water management.

Water pollution control is an aspect of water resources management. It entails the maintenance, development of adequate quantities and quality of water. Water resources management should involve water quality aspects. A step-wise approach proposed (UNCED, 1992), comprised the following elements:

1. Identification and initial analysis of water pollution problems.
2. Definition of long- and short-term management objectives.

3. Derivation of management interventions, tools and instruments needed to fulfill the management objectives.
4. Establishment of an action plan, including an action programme and procedures for implementation, monitoring and updating of the plan.

3.2 Initial Analysis of Water Quality Problems and Identification of Water Quality Problems

Management of water pollution requires a proper definition of the problem to be managed, identify problem areas requiring intervention. Tools for analysis and prioritisation of water quality problems are important and help make the best use of the available resources. To identify water quality problems, carry out a water resources' assessment which is the determination of the sources, extent, dependability, and quality of water resources, on which is based an evaluation of the possibilities for their utilisation and control" (WMO/UNESCO, 1991). This is an integrated activity involving water pollution control and other water resources issues. The water resources assessment should form the practical basis for management of water pollution and water resources. The objective of water resources assessments include

“Ensuring the assessment and forecasting of the quantity and quality of water resources, in order to estimate the total quantity of water resources available and their future supply potential, to determine their current quality status, to predict possible conflicts between supply and demand and to provide a scientific database for rational water resources utilisation".

The assessment should identify the occurrence of both surface and groundwater quantity and their associated water quality, together with assessment of trends in water requirements and water resources development. The assessment should be based on existing data and knowledge. The objective of the assessment is to identify and list the problems, and priority areas within which more detailed investigations should be carried out.

3.3 Categorisation and Prioritisation of Water Quality Problems

Water quality problems fall into different categories requiring different management tools and interventions. For a national problem, a general effluent standard or regulation may be needed. Local problems may require a local by-law, intervention or mediation. Water quality problems may be classified as "impact issues" or "user-requirement issues".

- Impact issues come from human activities that negatively affect water quality or cause environmental degradation.
- User requirement issues result from inadequate matching of user specified water quality demand and the actual supplied water quality.

Both types of issues require intervention from a structure or institution with powers to resolve the issue. An impact issue is identified by the presence of a pollution source or human activity causing degradation of the aquatic resources (e.g. sewage dumping), user-requirement issues are identified by absence of water of adequate quality for a specific or intended use.

Priorities should be assigned to problems because resources are limited. Things to consider when assigning priority to water quality problems are:

- Economic impact
- Human health impact
- Impact on ecosystem
- Geographical extent of impact
- Duration of impact.

3.4 Required Management Interventions

For every problem identified, make an assessment of the most appropriate means for intervention, indicate the relevant administrative level(s) to be involved. Interventions may range from formulation of a national policy for an unregulated issue to the establishment of a database containing water quality monitoring results in a local monitoring unit. Examples of management interventions include:

1. Policy making, planning and co-ordination
2. Preparation/adjustment of regulations
3. Monitoring
4. Enforcement of legislation
5. Training and information dissemination.

3.5 Definition of Long-Term and Short Term Objectives for Water Pollution Control

Definition of long-term objectives includes the identification of key functions to be performed in order to achieve reasonably effective water pollution control at all administrative levels. An assessment of the full potential for development of the general level of management should form the basis for long-term objectives. The situation obtained by fulfilling the long-term objectives for water pollution control, should be satisfactory to society. The guiding principles for water resources management should be reflected in the long-term strategy. Management at the lowest appropriate level e.g. local government should be pursued through the identification of the lowest appropriate level for all identified key functions, irrespective of the present level of management.

Analysis of present capacity

The main issue in the analysis of present capacity is the identification of the potential of, and constraints upon, the present management capacity and capability in relation to carrying out the management functions defined in the long-term objectives. Factors such as suitability of institutional framework, number of staff, ability to recruit relevant new staff, staff training, educational background, and availability of financial resources should be considered. The analysis must include all relevant administrative levels. The regions or districts should be chosen with a view to selecting a representative cross-section of diversity in water quality problems and their management.

Short-term strategy

The duration of the "short-term" should be defined. A period of approximately five years is suggested, because this is roughly the planning horizon that can be controlled reasonably well and foreseen without too much dependency on future development scenarios. When defining the short-term strategy ensure that the fulfilment of the short-term objectives will significantly contribute to achieving the long-term objectives.

3.6 Management Tools and Instruments For Water Pollution Control

Tools and instruments are inputs to the overall process of achieving effective water pollution control. They are means to addressing identified problems. Appropriate tools are needed to solve water pollution problems and the selected tool(s) should be available and operational within the right institutions. Principles for selecting and combining management tools are:

1. Balance the input of resources against the severity of problem and available resources. This principle entails a reasonable input of financial, human or other resources to handle a specific problem depending on priority and severity.
2. Ensure sustainability: This principle has a bearing upon the methods and technical solutions that should be considered for the purposes of water pollution control. Technical solutions should be simple for example, the use of stabilisation ponds for wastewater treatment. Build on existing institutions rather than new ones.
3. Seek "win-win" solutions: Apply instruments that lead to improvement in water pollution control as well as in other sectors (Bartone*et al.*, 1994; Warford, 1994). Economic instruments are often in the "win-win" category.

3.7 Regulations, Management Procedures and By-laws

Regulations are the supporting rules of the relevant legislation. Regulations can be made and amended at short notice, and require the approval of the minister or cabinet to become binding. Regulations specify the current policies, priorities, standards and procedures that apply nationally.

Management procedures are guidelines and codes of practice that ensure consistent responses in problem solving and decision making. Such procedures contain more details supporting the legislation, regulations and specifying the steps to be taken in implementing particular provisions, e.g. regulation of wastewater discharge. For example, regulations and procedures pertaining to wastewater discharge would include descriptions of procedures for applying and granting a permit to discharge waste-water to a recipient, procedures for monitoring compliance with the permit, fees and tariffs to be paid by the polluter, and fines for non-compliance.

By-laws are made by legally established body, such as a district or state government and can, for example, determine the regulation and pollution of local water resources. By-laws made by lower level institutions cannot contradict those made by higher level institutions.

4.0 CONCLUSION

The framework of water pollution control consists of several steps part of which include, identification of problems, categorisation of problems which helps in allocation priorities to finding solutions to such problems. Some management tools are also employed.

5.0 SUMMARY

In this unit, we studied the framework for water pollution management - a part of Agenda 21 (UNCED, 1992) to help retain water quality in order to meet each designated use. We discussed the identification, categorisation, prioritisation of problems and management tools used to manage pollution problems.

6.0 TUTOR–MARKED ASSIGNMENT

1. Explain the principles and recommendations for sound water resources management (UNCED, 1992).
2. Explain the initial analysis of water quality problems and identification of water quality problems.
3. Explain the categorisation and prioritisation of water quality problems.
4. Explain the required management interventions.
5. Explain the definition of long-term and short term objectives for water pollution control.
6. Explain the management tools and instruments for water pollution control.
7. Explain the regulations, management procedures and by-laws.

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UNIT 2 WATER QUALITY STANDARDS

CONTENTS

1.0 INTRODUCTION

Water quality standards are numeric values or narrative descriptions of water quality parameters that are meant to sustain the designated uses of a water body. Water quality standards involve not only the actual criteria associated with water quality parameters, but how certain levels of those parameters negatively affect the use of the water for human and/or ecological purposes. Water quality standards consist of two different elements namely designated use and water quality criteria.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the fixed emission and environmental quality standard approach
- state the economic instruments and factors affecting successful implementation of economic instruments
- state the differences between regulatory and economic instruments.

3.0 MAIN CONTENT

Water quality standards are part of regulations. There are several sets of water quality standards, or guidelines for water quality standards issued by various agencies and authorities (e.g. United States Environmental Protection Agency (EPA), World Health Organisation (WHO), European Union (EU), Federal Environmental Protection Agency in 1988 (now under Federal Ministry of Environment) intended to define the maximum acceptable limit of water pollution by various pollutants. Standards for ambient water quality (quality objectives) are designated depending on the intended use of the water resource (e.g. drinking water, fishing water, spawning grounds).To establish water quality standards, identify and describe how surface waters are used and what water quality parameters should be managed. The “designated uses” of a water body are grouped into four categories:

- Agricultural and industrial water supply provides water for crop irrigation, livestock drinking, or process water for industrial activities.
- Recreation water is for human activities that involve complete immersion (swimming, diving, and water-skiing) or incomplete immersion (boating, fishing, or wading).
- Public water supply provides water for drinking and domestic use by man.
- Aquatic life includes waters that support the growth and reproduction of wildlife species (USEPA, 1994, 2007).

Effluent standards are usually based on either of the following two principles, or a combination of both:

3.1 Fixed Emission Standard Approach

This approach requires some treatment of all wastewater, regardless of its conditions and the use of the receiving water body. Standards or guidelines developed according to this approach must be very restrictive in order to protect the environment effectively. They must consider the most critical situations and locations.

Advantage: This approach requires simple administrative implications.
Disadvantages:

- Incurring unnecessary treatment costs.
- Lead to inappropriate treatment and excessive pollution, depending on the emission standards and the absorbing capacity of the receiving water body.

3.2 Environmental Quality Standard Approach

This approach involves defining the effluent standards to allow compliance with the quality objectives for the receiving water body. This allows for a more flexible administration of environmental management, and optimisation of treatment efforts and costs. The level of treatment can be tuned to the actual assimilation capacity of the receiving waters.
Problems with this approach include:

- Difficulty in practical application.
- Knowledge of the absorptive capacity requires studies of the hydraulic, dispersive, physico-chemical and biological conditions of the water body.
- Plans for future development in the area should be considered.
- The costs of applying these principles may be too high in developing countries.
- The administrative capacity to enforce high water quality standards may be lacking. Only regulations that can be enforced should be implemented. Water quality standards in developing countries should be adjusted to reflect the local economic and technological realities.

3.3 Economic Instruments

Application of economic instruments in water pollution control offers several advantages e.g. providing incentives for environmentally sound behaviour, raising revenue to finance pollution control activities and allowing the attainment of water quality objectives. The main types of economic instruments applicable in a water pollution control include (Warford, 1994):

1. Resource pricing
2. Effluent charges
3. Product charges
4. Subsidies or removal of subsidies and non-compliance fees (fines).

Successful implementation of economic instruments depends on appropriate standards, effective administrative, monitoring and enforcement capacities, institutional co-ordination and economic stability. Effluent charges, for example, require a well-established enabling environment and large institutional capacity and co-ordination while product charges are easier to administer (Warford, 1994).

3.4 Factors Affecting the Successful Implementation of Economic Instruments

1. Appropriate setting of prices and tariffs - very low fines, prices or tariffs may allow polluters to pollute and pay the fines. Low prices will not generate adequate revenues for system operation and maintenance. Prices should cover direct costs, opportunity costs and environmental costs (Nordic Freshwater Initiative, 1991).
2. Economic instruments incorporate the polluter-pays-principle to various degrees. Subsidies counter the polluter-pays-principle but may be applied for political or social reasons. Effluent charges work with the polluter-pays-principle.

3.5 Regulatory versus Economic Instruments

Compared with economic instruments, the regulatory approach to water pollution control offers a reasonable degree of predictability about the reduction of pollution, i.e. it offers control to authorities over what environmental goal scan be achieved and when they can be achieved (Bartone *et al.*, 1994). A major disadvantage of the regulatory approach is its economic inefficiency.

Economic instruments provide incentives to modify the behaviour of polluters in support of pollution control and revenue to finance pollution control activities. Economic incentives are better suited to deal with non-point sources of pollution. In developing countries, the most important criteria for balancing economic and regulatory instruments should be cost effectiveness and administrative feasibility. With highly toxic discharges, or when a drastic reduction or complete halt in the discharge is required, regulatory instruments (e.g. a ban) rather than economic instruments should be applied.

4.0 CONCLUSION

Water quality standards form an important aspect of regulation. Several approaches are used to maintain these standards. Regulatory instruments are compared with economic instruments.

5.0 SUMMARY

In this unit, we discussed the approaches used to determine water quality standards. Economic tools and factors affecting the implementation of economic tools were explained. Economic instruments were distinguished from regulatory instruments.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the fixed emission and environmental quality standard approach.
2. Explain the economic instruments and factors affecting successful implementation of economic instruments.
3. Explain the differences between regulatory and economic instruments.

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UNIT 3 WATER QUALITY MONITORING

CONTENTS

1.0 INTRODUCTION

Water quality monitoring involves the assessment, of the characteristics of a water body relative to set standards. This gives information on the adequacy of such bodies of water to serve designated purposes. Water quality monitoring programmes are carried out to meet certain pre-determined objectives.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define water quality monitoring
- discuss the design of an operational and adequate monitoring system
- state the elements to consider in the implementation and functioning of a monitoring system
- state the problems of monitoring programmes.

3.0 MAIN CONTENT

3.1 Definition of Water Quality Monitoring

Water quality monitoring is the practice of assessing the chemical, physical, and biological characteristics of water in streams, lakes, estuaries, and coastal waters and groundwater relative to set standards and providing information on whether these waters are adequate for specific uses such as drinking, swimming, irrigation, and ecosystem services. The objectives of water quality monitoring include:

- Identifying specific water quality problems that affect the health of humans and ecosystems.
- Determining long-term trends in water quality.
- Documenting effects of pollution prevention or remediation.
- Providing evidence for regulation compliance and legal disputes.

3.2 Monitoring Systems

Monitoring programmes collect data from chemical, biological analyses of water samples or field equipment. The design of an operational and adequate monitoring system must:

1. Take account of the required additional management tools to be used.
2. The complexity and size of the area to be monitored.
3. The number of pollutants monitored.
4. The frequency of monitoring.

These have to be balanced against available resources. The data obtained determine the complexity of management tools that can be supported by the monitoring system.

3.3 Elements to Consider in the Implementation and Functioning of a Monitoring System

1. Identification of decision and management information needs.
2. Assessment of capacity e.g. economic and human to maintain the monitoring system.
3. Proper design of the monitoring programme and implementation of routines according to defined objectives.
4. Data collection.
5. Data handling, registration and presentation.
6. Data interpretation for management.

3.4 Problems of Monitoring Programmes

All monitoring programmes are restricted by some factors. Some information gaps have to be filled before a rational decision about monitoring system design can be taken with respect to a specific water quality problem. There is a lack of coupling between measured concentrations and water flow or discharge measurements making quantification of pollution transport difficult.

4.0 CONCLUSION

Monitoring involves the regular watch of the environment. It is the process of assessing the chemical, physical and biological characteristics of water. We also discussed the problems associated with water quality monitoring.

5.0 SUMMARY

In this unit, we studied water quality monitoring with regards to its definition, monitoring systems, implementation and functioning of a monitoring system, and the problems of a monitoring system.

6.0 TUTOR-MARKED ASSIGNMENT

1. Give in details the definition of water quality monitoring.
2. Explain the design of an operational and adequate monitoring system.
3. Explain the elements to consider in the implementation and functioning of a monitoring system.
4. Explain the problems of monitoring programmes.

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UNIT 4 CLEAN UP AND CONTROL OF SPECIFIC POLLUTANTS

CONTENTS

3.0 Introduction
4.0 Objectives
3.0 Main Content
    3.1 Cleaning up Metal Pollution
    3.2 Bioremediation and Phytoremediation
    3.3 Reducing Pesticides through Integrated Pest Management (IPM)
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Specific measures may be required to clean up or contain specific pollutants. Such pollutants include pesticides, metals such as lead. In this unit such methods are explained.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the methods of cleaning up metal pollution
- mention the process of cleaning up metal pollution
- discuss the process of bioremediation and phyto remediation
- discuss the process of reducing pesticides through integrated pest management (IPM).

3.0 MAIN CONTENT

3.1 Cleaning up Metal Pollution

Methods of dealing with metal contamination include:

1. Excavate the soil, treat it, and place it in a landfill dedicated to hazardous wastes. This option is expensive, and simply moves the problem “away” without solving it.
2. Stabilise the metals on site by heating the soil to a temperature high enough to melt the soil into a hard mass (vitrification). Stabilised metals are less likely to leach.
3. Mixing the soil with cement and letting it solidify.
4. Metals can sometimes be removed from the soil. The method used depends on the metals involved e.g.

3.1.1 The Terra Met Process for Cleaning Lead

This method has been used to clean up lead and consists of the following steps:
Separate the contaminated soil into its components (gravel, sand, silt, and clay).Wash the gravel to remove most lead; then return it to the site. Shake the sand in water. Because lead is denser than sand, it settles to the bottom and is removed. Treat the sand itself with a chemical that dissolves the remaining lead. Return the cleaned sand to the site. Treat the chemical solution to precipitate the lead from it; recover the lead for recycling. Treat the silt and clay using methods similar to those for sand, and return these to the site.

3.2 Bioremediation and Phytoremediation

Some trees such as the poplar and willow trees can accumulate organic solvents. Other living organisms can be used to remediate hazardous waste sites contaminated with oil or ammunitions, or to clean up contaminated water or sediments. The microorganisms and plants used must concentrate the contaminant of concern, but not be poisoned by it. To use bioremediation successfully, investigate the site to know the pollutants, the characteristics of its soil and water, and microorganisms naturally present. Site microbes are adapted to degrade organic wastes.

Microbial actions work faster with provision of fertiliser for the microbes. At metal- contaminated sites, microorganisms cannot destroy metals, but can convert them to less hazardous forms or lead to metal stabilisation e.g. in the conversion of suphate to sulphide by microorganisms, sulphide reacts with metal contaminants to produce metal suphides which are insoluble (metal immobilisation).Microbes have also been able to concentrate plutonium, a (radioactive element) and natural microbes are used in remediation projects, while bioengineered organisms can degrade specific chemicals.

Phytoremediation is an aspect of bioremediation. Several plants can accumulate metals from soil or water. Plants that can accumulate high concentrations without adverse effects are hyperaccumulators. Some can accumulate metals up to 40% of their weight. They are harvested and burnt to recover the metals. Sunflower and some ferns have been used to accumulate some metals.

Advantages

Plants and microbes have large potentials for remediating chemicals. It is cheaper than most other methods and work with natural systems though bioremediation cannot degrade or take up all the contaminant in the soil or water. Microorganisms use the organic chemicals they degrade as sources of nutrients for their growth. Low concentrations of the chemicals reduce available nutrients for growth of microbes.

3.3 Reducing Pesticides through Integrated Pest Management (IPM)

Integrated pest management, is an effective and environmentally sensitive approach to pest management that relies on a combination of common - sense practices.IPM programmes use current, comprehensive information on the life cycles of pests and their interactions with the environment. This information, in combination with available pest control methods, is used to manage by the most economic way, and with the least possible hazard to people, property and the environment. The IPM approach can be applied to agricultural and non- agricultural activities. IPM takes advantage of all appropriate pest management options including but not limited to the use of pesticides. In contrast, organic food production applies many of the same concepts as IPM but limits the use of pesticides to those that are produced from natural sources, as opposed to synthetic chemicals.

How does IPM work?

IPM is not a single pest control method but a series of pest management evaluations, decisions and controls. In practicing IPM follows a four-tiered approach.

- Set action thresholds
  Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. The level at which pests will become an economic threat is critical to guide future pest control decisions.

- Monitor and identify pests
  Not all insects, weeds and other living organisms require control. Many organisms are innocuous and some are beneficial. IPM programmes monitor pests and identify them so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification allow pesticide use only when needed and the right kind of pesticide will be used.

- Prevention
  As a first line of pest control, IPM programmes work to manage the crop, to prevent pests from becoming a threat using cultural methods such as crop rotation, selecting pest –resistant varieties and planting pest-free rootstock. These control methods can be very effective, cost efficient and present little to no risk to people or the environment.

- Control
  When monitoring, identification and action thresholds indicate that pest control is required and preventive methods are no longer adequate or available, IPM programmes evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are used first including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identifications and action thresholds indicate that less risky controls are not working, the additional pest controls would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific insecticides is a last resort.

Other methods are the use of biological control e.g. natural enemies of pests (e.g. parasitic insect that preys on the pest (e.g. praying mantis). Large numbers of a pest's eggs can be hatched, raised to adulthood, sterilised, and released. The sterilised pests mate with normal insects, but with no offspring are produced or ensuring that enough habitat exists to allow a pest's natural enemies to grow. An exotic enemy may be imported from a distant location.

4.0 CONCLUSION

Specific methods for cleaning up or reducing pollutants include bioremediation, integrated pest management for reducing the use of pesticides.

5.0 SUMMARY

The different methods of cleaning or remediating specific pollutants have been explained in this unit.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the methods of cleaning up metal pollution.
2. Explain the process of cleaning up metal pollution.
3. Explain the process of bioremediation and phytoremediation.
4. Explain the process of reducing pesticides through integrated pest management (IPM).

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MODULE 5

Unit 1	Chemical, Mechanical and Biological Methods of Improving Water Quality
Unit 2	Biological and Ecological Characteristics of Polluted Waters
Unit 3	Effects of Pollutants on Fish, Plankton, Benthic Macro Invertebrates, Algae and Water Quality

UNIT 1 CHEMICAL, MECHANICAL AND BIOLOGICAL METHODS OF IMPROVING WATER QUALITY

CONTENTS

1.0 INTRODUCTION

It is necessary to promote efforts aimed at improving water quality so as to ensure availability of water in quantity and quality for future use. Methods of improving water quality help to ensure this availability. Similar methods are used for both wastewater and drinking water purification. These methods combine mechanical, chemical and biological processes.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- mention the procedure of waste water treatment
- state the methods of improving drinking water quality
- discuss the process of re-using wastewater or reducing its volume
- explain the construction of wetlands
- discuss the method of reducing nonpoint sources of water pollution
- discuss the method of reducing nonpoint source runoff from other activities

3.0 MAIN CONTENT

3.1 Wastewater Treatment

Wastewater is tap water after it has been used in homes and institutions for drinking, bathing, flushing toilets, and other purposes.

- **Primary treatment**
  Primary treatment removes large objects, trash and smaller solids such as sand and small stones. Suspended solids in the wastewater are settled out by chemical treatment. Most BOD and many pathogenic organisms settle out with the suspended solids. Reactive nitrogen and phosphorus are only partially removed in this process. The settled solids – primary sludge – are removed leaving the wastewater to move on to secondary treatment. Most groundwater does not need screening.

- **Secondary treatment**
  Soluble organic contaminants in the wastewater are digested by bacteria which multiply rapidly during this process. These settle out from the secondary wastewater, and are recovered as secondary sludge. The final step is to disinfect the water with chlorine before discharge. Standard wastewater treatment removes only a portion of the nutrients – reactive nitrogen and phosphorus which can be detrimental to receiving waters. Advanced treatment is necessary for nutrient removal. Non-conventional contaminants such as excessive colour may also need to be removed from some wastewaters.

- **Tertiary treatment**
  This involves the use of further filtration or chemicals to destroy pathogens and remove chemicals (discussed in the next section)

3.2 Methods of Improving Drinking Water Quality

Screening removes large debris that may interfere with other treatment steps. Storage of water obtained from rivers and other sources in reservoirs for some time (days to months) may allow natural biological purification of the water to occur. This is important when using slow sand filters.

Adjustment of pH

Pure water has a pH close to 7 but fresh water can vary in pH depending on the geology of the drainage basin or aquifer and the presence of contaminants. If water is acidic, lime, soda ash or sodium hydroxide can be added to increase the pH during water purification. The addition of lime increases the calcium ion concentration thereby raising the water hardness. For very acidic waters, degasifiers can be used to raise the pH of the water by removing dissolved carbon dioxide from the water.

Making the water alkaline helps coagulation and flocculation processes, minimises the risk of lead dissolving from pipes into drinking water. Acid may be added to alkaline waters to reduce alkalinity or pH.

Coagulation and flocculation

Coagulation entails the addition of chemicals to reduce suspended particles in water (e.g clay, silt, algae, bacteria, viruses, protozoa and organic matter). Organic and inorganic particles contribute to the turbidity and colour of water. Addition of inorganic coagulants (e.g aluminum sulphate -alum or iron III salts e.g. iron III chloride cause many reactions among particles in water. Inorganic coagulants neutralise negative charges and precipitate metal hydroxides (iron and aluminum).

Flocculation refers to the formation of large amorphous metal hydroxides e.g. iron III and aluminum which adsorb and enmesh particles in suspension and allow their removal by sedimentation and filtration.

Sedimentation or clarification

Water from the flocculation process enters sedimentation basin where there is low water velocity which allows the floc to settle to the bottom. The sedimentation basin depth must be of sufficient depth so that water currents do not disturb the sludge and settled particle interactions are promoted.

The settled particles form asludge at the bottom of the sedimentation basin which must be removed and treated.

Filtration

After removing the sludge, the water is filtered to remove the remaining suspended particles and unsettled floc. Types of filters include rapid sand filters, pressure filters, slow sand filters and membrane filtration.

- Rapid sand filters
  This is the most common type of filter and contains activated carbon or anthracite coal above the sand. It removes organic compounds that produce taste and colour but cannot remove smaller particles. Some particles block the pores spaces or adhere to sand particles. This requires back flushing, back washing or air scouring to clear the pores.

- Pressure filters
  The pressure filters work on the same principle as sand filters but differ in that their medium is enclosed in a steel vessel and water is forced though it under pressure. They can filter smaller particles than paper and sand filters; they are thin and liquids flow through them rapidly; they can withstand high pressures and they can be cleaned and reused.

- Slow sand filters
  These filters are useful where there is sufficient space and land since water must pass through the pores very slowly. They rely on biological treatment processes rather than physical filtration. They are constructed with graded layers of sand with gravel at the bottom and fine sand at the top. Another type of slow filtration is **bank filtration** in which natural sediments on the river bank filter out contaminants from incoming water.

- Membrane Filtration
  This method is widely used for drinking water and sewage. For drinking water, membrane filters can remove all particles larger than 0.2µm. They are an effective part of tertiary treatment when the water is to be reused in industry, for some domestic purposes or before discharge into streams. No filtration can effectively remove dissolved substances like phosphorus, nitrates and heavy metal ions.

- Removal of ions and dissolved metals
  Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that filter out dissolved substances without the use of coagulants. **Ion exchange systems** use ion exchange ion resin or zeolite – packed columns to replace

unwanted ions e.g. the removal of Ca^{2+} and Mg^{2+} ions replacing them with Na^+ and K^+ (removal of water hardness). This method is also used to remove toxic ions like nitrite, lead, mercury, arsenic etc.

- Precipitative softening
  Water rich in hardness (calcium and magnesium ions) is treated with lime (calcium oxide) and/ or calcium carbonate to precipitate calcium carbonate out of solution using the **common ion effect**.

- Electrodeionisation
  Water is passed between a positive and a negative electrode. Ion exchange membranes allow positive ions to migrate from the treated water towards the negative electrode and negative ions towards positive electrodes. Complete removal of ions from water is called **electrodialysis**.

Disinfection

This is accomplished by filtering out micro-organisms and by adding disinfectants to kill pathogens which remain after filtration. Disinfected water is allowed to stand for some time before use.

- Chlorine disinfection
  Chlorine or its compounds such as chloramine or chlorine dioxide are used. Chlorine is a strong oxidant and rapidly kills many harmful microbes. But chlorine is a toxic gas which should be used with care. Sodium hypochlorite when used does not release chlorine gas. Chlorine is ineffective against protozoa that form cysts in water such as *Giardia* spp and *Cryptosporidium* spp.

- Ozone disinfection
  Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidising agent which is toxic to most water borne organisms. It is a very strong broad spectrum disinfectant which can inactivate cyst-forming protozoa. It also works against many other pathogens but leaves no residual in water.

- Ultraviolet disinfection
  This very effective at inactivating cysts in low turbidity water but its power decreases with increasing turbidity of the water. It leaves no residual in water. Residual disinfectant can be provided by adding chloramines

- Solar water disinfection can be used in remote areas and has a lower impact on the environment.

3.3 Re-using Wastewater or Reducing its Volume

- **Reusing sewage indirectly for drinking water**
  In places where clean water is scarce, sewage can be treated and reused for drinking water. For example, in the space station urine is purified for drinking, food preparation, and washing. Recycled wastewater is also used in Israel, Singapore, and parts of Europe.

- **Reducing the volume of wastewater**
  Grey water describes all wastewater except that flushed down toilets. Grey water usually goes down the drains to the sewage line but some water-scarce areas recover it and using to flush toilets, wash cars, or irrigate plants. Wastewater reclamation is important in arid areas with large populations. Treated wastewater is used as cooling and process water for commercial washing, ornamental fountains, fire fighting, golf course irrigation, creation of artificial wetlands, and groundwater recharge. The major concern when using reclaimed water is surviving pathogens.

3.4 Construction of Wetlands

Wetlands can be constructed to treat wastewater. The wetlands remove nutrients, reduce suspended solids and BOD. The effluent can be used for plant irrigation, flushing toilets, and for groundwater recharge. Mature plants grown in the greenhouse can be sold.

3.5 Reducing Nonpoint Sources of Water Pollution

Agriculture is a major cause of non-point source runoff of soil, pesticides, fertilisers, and animal wastes into rivers, lakes, and other water bodies. Steps to reduce runoff from non- point sources include:

1. Plant grass or trees as buffer strips next to water bodies to absorb the runoff.
2. When possible, use zero-tillage in which crop residues are not tilled into the ground, but left on soil to limit soil erosion and runoff.

3. Fertilisers should only be applied when and where necessary. Excess application as runs off into surface water or infiltrate down into groundwater as surplus.
4. Contour strip-cropping (planting rows of different crops) helps to lower both chemical runoff and soil erosion.
5. Use integrated pest management to reduce pesticide use.
6. Choose chemicals that are needed in small amounts to kill weeds or use herbicides are that are less water soluble and bind more tightly to soil.
7. In Livestock feed lots, methods exist to minimise runoff, but large operations may allow animal waste solids to settle out in detention ponds.
8. Practice crop rotation e.g. between maize and legumes, apply less fertiliser, and apply fertiliser with less runoff.

3.6 Reducing Nonpoint Source Runoff from other Activities

- Provide buffer zones of grass or trees near water bodies onto which runoff can flow.
- Build detention ponds or constructed wetlands into which runoff can flow for natural treatment.
- Seal off any open mine that is the source of runoff.
- For large construction sites, reduce runoff by laying out the sites to makes use of or modify the land’s natural contours.

4.0 CONCLUSION

Several methods are used to improve water quality for use in the home and industry. These methods usually combine mechanical (sedimentation, filtration, storage in reservoirs, etc.) with chemical methods (addition of chemicals) and biological methods (the use of beneficial microbes). Some of these methods have been explained in this unit.

5.0 SUMMARY

In this unit, you learnt about the chemical, mechanical and biological methods of improving water quality .We also discussed the different methods of water treatment, reusing of reclaimed water, wetland construction and methods of reducing non point sources of pollution.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the procedure of waste water treatment.
2. Explain the methods of improving drinking water quality.

3. Explain the process of re-using wastewater or reducing its volume.
4. Explain the construction of wetlands.
5. Explain the method of reducing nonpoint sources of water pollution.
6. Explain the method of reducing nonpoint source runoff from other activities.

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UNIT 2 BIOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF POLLUTED WATERS

CONTENTS

1.0 INTRODUCTION

Polluted water usually differs from pure water and exhibit different biological and ecological characteristics. Some natural constituents and chemistry of water can change with the introduction of pollutants or contaminants. In this unit, you will learn about some of the biological and ecological changes that are associated with polluted water.

2.0 OBJECTIVE

At the end of this unit, you should be able to:

- discuss the characteristics of polluted water.

3.0 MAIN CONTENT

3.1 Characteristics of Polluted Water

Pollution can cause several changes in water quality such as:

- **Eutrophication**
  Eutrophication is defined as an increase in the rate of supply of organic matter into an ecosystem (Nixon, 1995). It is also the process by which a body of water acquires a high concentration of nutrients especially phosphates and nitrates which promote excessive algal growth. The algae die, decompose and high levels of decomposing organic matter deplete the water of available oxygen killing other organisms. It is a natural slow aging process for a water body (Art, 1993). Eutrophication is promoted by

anthropogenic wastes and nitrification of ground water. Surface and groundwater can equally be affected by nutrient enrichment through percolation. Eutrophication causes:

  - Excessive algal bloom and fish death, increased abundance of cyanobacteria.
  - Changes in aquatic fauna e.g. disappearance of species with high oxygen requirements compromise the biodiversity of the aquatic communities (Boatman *et al*, 1999).
  - Bad taste and odour occur due to water enrichment
  - Toxin production by algae (e.g. Cyanobacteria), infilling or clogging of canals with aquatic weeds, loss of recreational use due to slime, weed infestation, and loss of targeted species.
  - High nitrate in water causes blue baby syndrome.

- **Acidification**

  Acidification of water is caused by air pollution, mine drainage, industrial effluents and atmospheric emissions of sulphur and nitrogen oxides. Surface waters have pH 6-8.5.Fish, shellfish, aquatic insects have different tolerance levels to acidic waters. Species diversity decreases with acidification and young organisms are more sensitive. Effects of acidity include:

  - Mobilisation of metals that can cause toxicity, e.g. aluminium.
  - Affected animals can suffer toxicity, stress, impaired feeding and reduced survival. (Mohan and Kumar, 1998).
  - Industrial effluents alter the chemistry of receiving waters and make them more susceptible to acidification.

- **Salinisation**

  Agriculture, urbanisation and industrial activities can cause salinisation. Toxic conditions occur when the composition and of receiving waters are out of range of physiological tolerance of organisms. Effects of salinity include:

  - Increased salinity encourages halo-tolerant species.
  - Saline toxicity occurs with high levels of ions though some effluents contain low levels of ions creating de-ionised conditions.

- **Trace metals and mercury**
  Trace metals and mercury result from agriculture, urbanisation, impoundments, mining and industrial effluents. Effects mainly are due to long range transport:

  - They are harmful e.g. reduced growth rates, direct toxicity.
  - Can magnify and accumulate along food chains (biomagnification).

- **Pesticides and oil spills**
  Pesticides form by-products some of which are toxic. Non-metallic toxins e.g. dioxins, furans, polycyclic aromatic hydrocarbonsare formed mostly through incineration of wastes. Effects of pesticides are diverse (DEFRA, 2004). Oil spills cause hydrocarbon contamination. Long range transport of pollutant also cause water degradation

- **Sedimentation**
  This occurs from agriculture, forestry, urbanisation, mining and some industrial activities. Effects of sedimentation include:

  - High turbidity decreases the amount of sunlight and production of algae, plants and macrophytes. Turbid waters irritate, scour gills or reduce success of visual predators.
  - Fish habitat degradation e.g. filling of spawning gravel beds restricts oxygen from buried eggs.
  - Very fine sediments (<63µm) are chemically active. Many toxic organic contaminants e.g. pesticides or their by-products are strongly associated with silt, clay and organic carbon.
  - High sediment loads in water increase thermal pollution by increasing the absorption of light; impair navigation and water retention facilities by silting (Owens, 2005).

- **Temperature**
  Aquatic organisms have a narrow range of temperature tolerance. Water bodies can buffer against atmospheric temperature extremes. Thermal pollution is a direct impact e.g. the discharge of industrial cooling water into aquatic environment, removal of vegetation on the riverbanks or creating impoundments on the water bodies. Heated waters scour habitats and change the characteristics of receiving water bodies. Temperature affects

physical, chemical and biological processes. Changes in temperature can eliminate species adapted to the natural fluctuations of water temperature in free flowing streams. Increases in temperature also affect the levels of dissolved oxygen in the water column (Canon and Rajaram, 2001).

- **Dissolved oxygen and Biological oxygen demand**

  Dissolved oxygen is needed for aerobic activities of organisms and influences chemical reactions. High concentrations of oxygen indicate good water quality. The amount of dissolved oxygen in water is inversely proportional to the temperature and salinity of the water. High algal blooms in surface water can deplete DO leading to death and decomposition of organisms which cause further oxygen depletion. Biological oxygen demand refers to microbial consumption of oxygen. BOD increases with water temperature. High water temperature increases growth rates and species abundance forming algal blooms (Lackly and McArthur, 2000).

- **pH and alkalinity**

  The pH of an aquatic system is closely linked to biological productivity. pH of 6.5-8.5 usually indicates good water quality. Rain water is slightly acidic because of the carbon dioxide dissolved in it. The H^+ ions entering a river basin in rain water are neutralised by carbonate and silicate minerals as water percolates through soils. This neutralisation determines whether or not acid precipitation will cause water quality impacts in receiving water bodies. Where rocks have low buffering abilities e.g. hard igneous rocks, the water will be acidic. Areas downstream of peat bogs and wetlands produce acidic black waters with very little hardness, mineral content and low biological productivity.

- **Turbidity and suspended solids**

  The greater the suspended solids in water, the higher the turbidity. The major source of turbidity in open water is phytoplankton growth, but closer to shores, particulates - clays, silts, re-suspended bottom sediments and organic detritus dominate. Suspended solids result from sediments carried by water. These sediments arise from activities like erosion and runoff, industrial effluents and phytoplankton blooms. High water transparency values indicate good water quality. Waste discharges can contribute ions to receiving water bodies or contain poor conductors (organic compounds) which change the conductivity of receiving waters.

- **Major ions and nutrients**
  Human activities alter the discharge regimes, transport of particulate matter, the chemical composition of surface run off and atmospheric deposition of solutes through wet and dry deposition. Ionic composition of surface water is relatively stable and insensitive to biological processes within a water body. Magnesium, sodium and potassium concentrations are not greatly influenced by metabolic activities of aquatic organisms but calcium ion shows marked seasonal and spatial changes due to biological activity. Sulphate and inorganic carbon (carbonate and bicarbonate) are influenced by production and respiration cycles of living organisms.

  High nutrient levels kill some aquatic organisms and encourage rapid algal growth thereby reducing the oxygen level of the water. Some algae produce toxins. Clear water increases photosynthesis. Reservoirs with a high level of organic pollution provide an ideal habitat for the breeding of mosquitoes.

- **Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs)**
  The polychlorinated biphenyls have a low solubility in water. Their concentrations in sediments are highest in contaminated estuaries and lower in coastal waters. They are mostly concentrated in top predators with high fat deposits where the compounds accumulate. High PCBs cause infertility and disruption of endocrine activities.

  Polychlorinated aromatic hydrocarbons are of concern for two reasons: The smaller and more water –soluble PAHs are toxic to animals while some of the larger ones are carcinogenic to both fish and man. They may affect reproduction in humans and fish. PAHs like PCBs do not have a high water solubility and tend to settle in sediments. Direct toxicities of PAHs increase with ultra violet radiation.

4.0 CONCLUSION

Polluted waters exhibit characteristics not usually associated with clean water such as eutrophication, high nutrient contents, low dissolved oxygen, high biological oxygen demand among others. The characteristics influence water quality and produce different biological and ecological characteristics

5.0 SUMMARY

In this unit, we discussed the biological and ecological characteristics of polluted waters such as eutrophication, acidification, salinisation, and several water quality changes observed under such situations.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the characteristics of polluted water.

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UNIT 3 EFFECTS OF POLLUTANTS ON FISH, PLANKTON, BENTHIC MACRO INVERTEBRATES, ALGAE AND WATER QUALITY

CONTENTS

1.0 INTRODUCTION

Pollution affects different living organisms in the aquatic environment differently. This has made it necessary to discuss the effect of different pollutants on fish, plankton, benthic macro invertebrates, algae and water quality.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- the effects of pollution on fish
- the effects of pollution on algae and zooplankton
- the effects of pollutants on benthic organisms
- the effects of pollution on water quality.

3.0 MAIN CONTENT

3.1 Effects of Pollution on Fish

Fish are sensitive to many pollutants and are often used as indicator organisms in bioassays. They can move out of polluted areas under natural conditions. Fish are indirectly affected by organic matter through the reduction of oxygen in water and direct exposure to various toxic organic pollutants. Low dissolved oxygen can kill fish. Most fish require at least 5mg/l D.O. but some fish survive about 2mg/l of minimum dissolved oxygen in water. Examples of toxic substances in water are:

a) Ammonia is a pollutant and its toxicity depends on pH of the water. It can be lethal to most species of fish at concentrations above 0.1ppm at alkaline pH levels.
b) Cyanide is extremely toxic to fish with LC_{50} values (concentration at which 50% of test population die) below 1mg/l for most fishes.
c) Pesticides affect growth and reproduction of many species of fish and small quantities of pesticides can prevent eggs of fish from hatching. Chlorinated pesticides are more toxic than others. Toxic concentrations of some pesticides to fish are aldrin (0.02), chlordane (1.0 ppm), dieldrin (0.025), and endrin (0.0003) ppm.
d) Fish are sensitive to different detergents as they damage gill epithelium of fish. Fishes have LC_{50} for detergents between 1-10ppm.
e) Most heavy metals (mercury, cadmium, chromium, arsenic and copper) are toxic to fish and exposure may induce respiratory distress. For instance lead and cadmium can kill fish at 0.33ppm and 0.06mg/l respectively.
f) Thermal pollution lowers the disease resistance of fish and pollutants are more toxic at higher temperatures. Fish may be unable to capture food at elevated temperatures and thermal death can occur.
g) Polychlorinated biphenyls (PCBs) are common pollutants in rivers and other surface waters. They are extremely toxic to fish at very low concentrations of 0.005ppm. At sub-lethal concentrations, they can cause premature hatching of eggs.
h) Phenols can also cause death of fish but are more toxic at lower temperature.

3.1 Effects of Pollution on Algae

Heavy metals are highly toxic to algae. For instance, copper can kill all species of algae at low concentrations of 0.5mg/l. Mercury in the range of 0.01ppm can damage algal growth with *Chlorophyceae* being more sensitive than others. Concentrations of heavy metals within safe limits for fish may be toxic to several algal species.

Marine oil pollution can affect the phytoplankton with algal cell division and photosynthesis inhibited at oil concentrations as low as 0.01ppm - 0.02ppm. In freshwater, *Chlorophyceae* is the most susceptible to petroleum oils. Thermal pollution of waters for extended periods can replace diatoms with green algae and later by blue green algae. PCBs reduce the rate of cell division in many phytoplankton.

3.3 Effects of Pollution on Zooplankton

Zooplankton consume algae and changes in algal communities affect zooplankton species depending on their food preferences e.g. some zooplanktons species do not eat blue green algae and are replaced by those that eat them. Pollution decreases zooplankton diversity. Some important effects of pollution on zooplankton are:

- In severe oxygen limitation, protozoa can replace other zooplankton.
- The important tolerant species of zooplankton are *Hexotrichia caudate, Glaucoma scintillans, Metopusspp,Vorticella spp, Colpidiumcolpoda, Saprodiniummicrostoma* and *Uronemamarium* etc. which can replace sensitive species.
- Thermal pollution has a lethal effect on most zooplankton with high temperatures increasing the toxicity of many chemicals many times to zooplankton.
- Low oxygen levels enhance the toxicity of hydrogen sulphide and other pollutants to several zooplankton.
- At high concentrations, pollutants can kill most zooplankton. Cladocera, Diptera and Daphnia are very sensitive to toxic metals. Copper is extremely toxic to most zooplankton.

3.4 Effects of Pollutants on Benthic Organisms

Benthic organisms are bottom – dwelling organisms of the aquatic environment. Fish and other motile organisms can move out of polluted areas but macro invertebrates cannot and are impacted by pollution. For this reason they are widely used as indicator organisms for aquatic studies. Many sensitive species are replaced by highly tolerant species. Sensitivity to pollution decreases in the order:

Stoneflies (*Plecoptera*) >mayflies (*Ephemeroptera*)>caddisfly (*Tricoptera*)>Amphipods >Isopods>midges (*Diptera*) >Oligochaetes.

In highly polluted waters, most macro invertebrates are eliminated but leach, sludge worms (*Tubificidae*), bloodworms (*Chironomus* larvae), sewage fly and rat-tailed maggot dominate. *Tubificidae* are more tolerant to pollution than other insects. Some members can tolerate moderate levels of pollution e.g. black fly larvae, scud, fingernail clam, snail, damsel fly nymph, and dragonfly nymph. The most severely affected bottom organisms in polluted conditions are stonefly nymph, mayfly naid and caddisfly larvae.

3.5 Effects of Pollution on Water Quality

Water quality describes the chemical, physical, and biological characteristics of water which affect its suitability for human consumption (drinking, irrigation, industrial use) and ecosystem health. The chemical constituents of water are substances that dissolve in water, including gases (e.g. oxygen, carbon dioxide), metals (e.g., iron, lead), nutrients (e.g. nitrogen, phosphorus), pesticides (e.g., atrazine, endosulfan), and other organic compounds (e.g., polychlorinated biphenyls). The most common physical characteristics of water are colour, odour, temperature, taste, and turbidity, while biological constituents of water are living organisms including bacteria (e.g., *Escherichia coli),* viruses, protozoans (e.g., *Cryptosporidiosis*), phytoplankton, zooplankton, insects, plants, and fish.

Water quality is termed as “good” or “poor” depending on the designated use of the water. For example, high nitrate content in drinking water causes a blood disorder in infants, methemoglobinemia (blue-baby syndrome) and not suitable for drinking. It is designated “poor” for drinking but when used for irrigation, would promote crop growth and is “good” water quality for this use.

Reclaimed water must meet disinfection standards to reduce the concentrations of constituents that may affect public health and/or limit human contact with reclaimed water. Water intended for reuse should:

- have biochemical oxygen demand (BOD) and total suspended solids levels of < 30 mg/L
- receive additional disinfection by chlorination or other chemical disinfectants

Pathogens in water may survive for short periods, while others (e.g., *Cryptosporidium*) may survive for months and when consumed in drinking water, may cause illness (Crittenden *et al*., 2005).

4.0 CONCLUSION

The effects of pollution in water are experienced by all aspects of the aquatic environment including fish, phytoplankton (primary producers), zooplankton (consumers), benthos and water quality. The sediments serve as reservoirs for pollutants and may recycle such depending on prevailing environmental conditions.

5.0 SUMMARY

In this unit, we discussed the effects of pollution on the aquatic environment with reference to fish, planktons (phytoplankton), zooplankton, benthic macro invertebrates, and water quality.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the general effect of water pollution on algae.
2. Give the names of important sensitive and tolerant algal species.
3. Why benthic macro invertebrates are often considered good biological indicators of water pollution. Name the groups which more tolerant to water pollution.
4. Discuss the general effects of pollution on fish. Why are they commonly used in bioassay tests?

7.0 REFERENCES/FURTHER READING

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