NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE : ESM 322

COURSE TITLE : WATER AND WASTEWATER MANAGEMENT

COURSE GUIDE

ESM322
WATER AND WASTEWATER MANAGEMENT

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Published By:
National Open University of Nigeria

First Printed 2010

ISBN: 978-058-848-5

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Introduction

Water and Wastewater Management (ESM322) is a second semester course at the National Open University of Nigeria programme's 300 Degree Level. It is a 2- credit degree course available to all students offering Bachelor of Science (B.Sc.) in Environmental Management (ESM).

Water and Wastewater Management is a specialised area in Environmental Management. The practitioner is primarily an environmentalist or a specialist in an allied discipline, including geographers, hydrologists, environmental engineers, chemists and soil scientists who may have received similar training and work using the same methods with colleagues who are specialists in other areas. It will not be advisable to work through this course without first taking ESM 223, i.e. water resources evaluation, so I encourage you to revise it once again if you have forgotten what you learnt therein.

No student is likely to be lost in the study of water and wastewater management because it comprises what you do on a daily basis. For example, all of us must excrete, or at least once a day, we visit the toilet, imagine if that excreta of yours has to be in your sitting room! God forbid, I hear you say…yes, it is better not imagined. Then, imagine what happens when your sewerage leaks or the municipal systems leak; imagine a situation where everybody dies of cholera because wastewater is not properly take care of. This is to let you know how important the knowledge of this course will be in your training as an environmentalist.

What You Will Learn in this Course

The course consists of a guide and modules which are divided into units. The course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully.

It gives you guidance in respect of your Tutor–Marked Assignments which will be made available in the assignment file. There will be regular tutorial classes that are related to your course. It is advisable that you attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of water and wastewater management.

Course Aim

The aim of the course is simple. It is to provide you with an understanding of water and wastewater management, and associated issues.

Course Objectives

To achieve the above aim, the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after the completion of each unit. By doing so, you would have followed the instructions in the unit.

Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you would have achieved the aim of the course. The objectives are as stated below. Thus, after going through this course, you should be able to:

- explain water quality and the processes of water contamination, and the effects on man.
- identify the procedure of standard water treatment and household processes of water treatment.
- explain wastewater constituents, types and the various ways of its treatment.
- compare the several treatment approaches and identify factors that could facilitate or hinder the adoption of each of the approaches.
- explain recycle and reuse of wastewater and account for the motivating factors.

Working through this Course

To complete this course you are required to go through each study unit, read the textbooks and other materials that the National Open University of Nigeria has provided. Each unit contains Tutor-Marked Assignment which will be required to be submitted at some point for assessment purposes. At the end of the course, there is a final examination. The course should take you about a total of 17 weeks to complete. Below you will find listed all the components of the course, which you have to do in order to complete the course on time and successfully.

This course entails that you spend a lot of time to read and think. I will advise that you avail yourself of the opportunity of comparing your knowledge with that of other people.

Course Materials

The main components of the course are:

- The Course Guide
- Modules and Study Units
- References/Further Reading
- Assignments
- Presentation Schedule

Study Units

The modules and study units in this course are as follows:

Module 1 introduces you to the basic definition and characterisation of water and wastewater. Here, the problem that has necessitated water and wastewater treatment is brought out within the available units. The first unit focuses on providing the background information on the justification for water and wastewater management. The second and third units deal with the general classification and the sources of wastewater and water contaminants. Module 2 in its two units elucidates the global water quality condition and examines waste recycle and reuse as adoptable option for waste management. Module 3 is all about the principles of water and wastewater management. Its unit 1 emphasises the available guidelines for treatment of water. Units 2 and 3 deal with the treatment options that are available for potable water and illustration of typical municipal wastewater systems. Module Four is concerned with wastewater treatment. Its unit 1 considers the available options, while units 2 and 3 are concerned with more specific items.

Each unit consists of one or two weeks work and includes an introduction, objectives, reading materials, conclusion, summary, Tutor-Marked Assignments (TMAs), References and Further Reading.. The unit directs you to work on exercises related to the required reading. In general, these exercises test you on the materials that you have just covered or required to apply in some way and thereby assisting you to evaluate your progress and to reinforce your comprehension of the course. Together with the TMAs, these exercises will help you to achieve the stated learning objectives.

Presentation Schedule

Your course materials have important dates for the early and timely completion and submission of your TMAs and attendance at tutorials. You should remember that you are required to submit all your assignments by the stipulated time and date.

Assessment

There are three aspects to the assessment of the course. First, is made up of self-assessment exercises, second, consists of the Tutor-Marked Assignments and third, is the written examination/end of course examination.

You are advised to do the exercises. In tackling the assignments, you are expected to apply information, knowledge and techniques that you gathered during the course. The assignments must be submitted to your facilitator for formal assessment in accordance with the deadlines stated in the presentation schedule and the assignment file. The work you submit to your tutor for assessment will count for 30% of your total course work. At the end of the course you will need to sit for a final or end of course examination of about three hour duration. This examination will count for 70% of your total course mark.

Tutor-Marked Assignment

The TMA is a continuous assessment component of your course. It accounts for 30% of the total score. You will be given four (4) TMAs to answer. Three of these must be answered before you are allowed to sit for the end of course examination. The TMAs would be given to you by your facilitator and returned after you have done the assignment. Assignment questions for the units in this course are contained in the assignment file. You will be able to complete your assignment from the information and material contained in your reading, references and study units. However, it is desirable in all degree level of education to demonstrate that you have read and researched more into your references, which will give you a wider view and may provide you with a deeper understanding of the subject.

Make sure that each assignment reaches your facilitator on or before the deadline given in the presentation schedule and assignment file. If for any reason you cannot complete your work on time, contact your facilitator before the assignment is due to discuss the possibility of an extension. Extension will not be granted after due date unless there are exceptional circumstances.

Final Examination and Grading

The end of course examination for Water and Wastewater Management will be for about 2 hours and it has a value of 70% of the total course work. The examination will consist of questions, which will reflect the type of self testing, practice exercise and tutor-marked assignment problems you have previously encountered. All areas of the course will be assessed.

Use the time between finishing the last unit and sitting for the examination to revise the whole course; you might find it useful to review your self-test, TMAs and comments on them before the examination. The end of course examination covers information from all parts of the course.

Course Marking Scheme

Assignment	Marks
Assignments 1 – 4	Four assignments, best three marks of the four count at 10% EACH, = 30% of course marks
End of course examination	70% of overall marks
Total	100% of course materials

Facilitators/ Tutors and Tutorials

There are 16 hours of tutorials provided in support of this course. You will be notified of the date, time and location of these tutorials as well as the name and phone number of your facilitator, as soon as you are allocated a tutorial group.

Your facilitator will mark and comment on your assignments, keep a close watch on your progress and any difficulties you might face and provide assistance to you during the course. You are expected to mail your TMAs to your facilitator before the scheduled date (at least 2 working days are required). They will be marked by your tutor and returned to you as soon as possible.

Do not delay to contact your facilitator by telephone or e-mail if you need further assistance.

The following might be circumstances in which you would find assistance necessary, hence you would have to contact your facilitator if:

- You do not understand any part of the study or the assigned readings
- You have difficulty with self-tests
- You have a question or problem with an assignment or with the grading of an assignment.

You should endeavour to attend tutorials. This is the only chance to have face to face contact with your course facilitator and to ask questions which may be answered instantly. You can raise any problem encountered in the course of study.

To derive any benefit from course tutorials, prepare a question list before attending them. You will learn a lot from participating actively in discussions.

Summary

Water and Wastewater Management is a course that provides a well balanced theoretical and field based information for intending rural and urban managers. Upon completing this course, you should be equipped with the knowledge of water quality assessment, wastewater management practices, water and wastewater treatment options. In addition, you should be able to answer the following questions:

- Highlight the common wastewater management practices in your surrounding and identify the effects of such on the environment.

- Identify the different stages of water treatment practices and their objectives.
- Is wastewater wasted water? Support your answer with justifications.
- When should a community reuse her wastewater and where has such happened?
- Sketch a typical water treatment plant.

Of course, the list of questions is not limited to the list above. To gain the most from this course you should endeavour to apply the principles that you have learnt to your daily life.

I wish you success in this course and I do hope that you will find learning the course exciting, challenging and interesting. Good luck.

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MODULE 1 INTRODUCTION TO WATER AND WASTEWATER MANAGEMENT

UNIT 1 FRESHWATER AND THE NEED FOR ITS MANAGEMENT

CONTENTS

1.0 INTRODUCTION

You are very much welcome to another programme in Water Science within the context of Environmental Sustenance and Management. Your experience while learning ESM 223 (Water Resources Evaluation) and Introduction to Instrumentation in Environmental Science is quite useful in this regard. While, we will not repeat what you have learnt in these previous courses, it is with joy that I inform you that this present one will complement your knowledge of water science in environmental sustainability and management, successfully. A journey of a thousand kilometres starts with a step. It is based on this that I encourage you to take the bold step of taking your learning further from this unit. The unit examines the issue of freshwater and its attributes.

2.0 OBJECTIVES

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

- define freshwater
- highlight some causes of freshwater pollution
- identify some potential risks of human activities on water resources
- analyse the need for water and waste management and
- describe some properties of a water body.

3.0 MAIN CONTENT

3.1 Constituents of Freshwater

Freshwater is the non-saline (i.e. contains very little percentage of salt chemicals) part of the planet-wide water cycle. The water cycle has been defined in ESM 223; you are advised to read it if you have not. Lakes, rivers, precipitation (ice, snow or rain), ponds, reservoir, springs and groundwater (wells and boreholes) are major sources of freshwater while oceans, seas, and many inland lakes are usually saline and are not freshwater sources. Figure 1 shows that the freshwater sources contain only 2.5 per cent of the global water resources (i.e. 32, 000 out of 1385990.8 cubic kilometers).

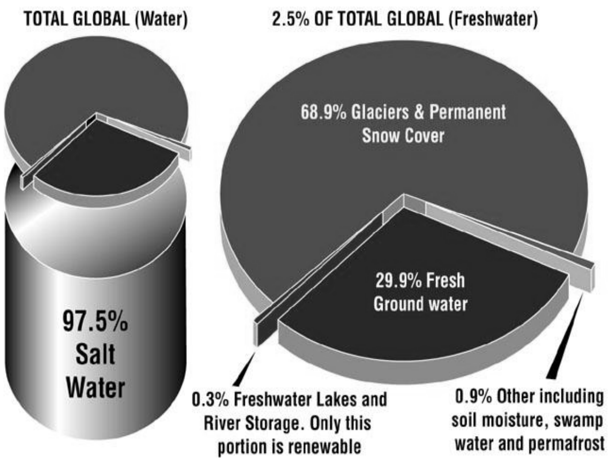


Fig. 1: Freshwater Content in the Global Water System

Source: http://www.cyber-nook.com/water/concerns.html

3.2 Causes of Freshwater Pollution

Causes of freshwater pollution are many. This course material will highlight the pollutants of water and their sources. As water travels over the surface of the land or through the ground, it dissolves naturally occurring as minerals and, in some cases, radioactive material. It can also pick up substances resulting from the presence of animals or human activity. Pollutants that may be present in water include:

- **Microbial Pollutants**: These include viruses and bacteria that may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife.
- **Inorganic Pollutants**: These are salts and metals that can naturally occur or result from urban storm water runoff, industrial or domestic wastewater discharges, oil and gas production, mining or farming.
- **Pesticides and Herbicides**: These may come from a variety of sources such as agriculture, urban storm water runoff, and residential uses.
- **Organic Chemical Pollutants**: These include synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and can also come from gas stations, urban storm water runoff, and septic systems.
- **Radioactive Pollutants**: These can naturally occur or result from oil and gas production and mining activities.

3.3 Freshwater and Potential Risk of Human Activities

The environment has a natural absorptive, self-cleansing capacity. However, if this is exceeded, biodiversity is lost, livelihoods are affected, natural food sources (e.g. fish) are damaged and high clean-up costs result. Environmental damage is leading to increased natural disasters, with floods increasing where deforestation and soil erosion are preventing natural water attenuation.

Table 1 summarises the pressures to which freshwater ecosystems are subjected and the potential impacts on systems at risk.

Table 1: Pressures of Freshwater Ecosystem

Human activity	Potential impact	Function at risk
Population and consumption growth	Increases water abstraction and acquisition of cultivated land through wetland drainage; increases requirement for all other activities with consequent risks	Virtually all ecosystem functions including habitat, production and regulation functions
Infrastructure development (dams, dikes, levees, diversions etc.)	Loss of integrity alters timing and quantity of river flows, water temperature, nutrient and sediment transport and thus delta replenishment, blocks fish migrations	Water quantity and quality, habitats, floodplain fertility, fisheries, delta economies
Land conversion	Eliminates key components of aquatic environment; loss of functions; integrity; habitat and biodiversity; alters runoff patterns; inhibits natural recharge, fills water bodies with silt	Natural flood control, habitats for fisheries and waterfowl, recreation, water supply, water quantity and quality
Overharvesting and exploitation	Depletes living resources, ecosystem functions and biodiversity (groundwater depletion, collapse of fisheries)	Food production, water supply, water quality and water quantity
Introduction of exotic species	Competition from introduced species; alters production and nutrient cycling; and causes loss of biodiversity among native species	Food production, wildlife habitat, recreation
Release of pollutants to land, air or water	Pollution of water bodies alters chemistry and ecology of rivers, lakes and wetlands; greenhouse gas emissions produce dramatic changes in runoff and rainfall patterns	Water supply, habitat, water quality, food production; climate change may also impact hydropower, dilution capacity, transport, flood control

Source: IUCN, 2000

3.4 Why Water and Waste Management?

Water has always played a prominent role in human civilisation. When people first began settling in one place and growing crops for sustenance, it was invariably near water sources like rivers, lakes, or groundwater springs. Water was needed for drinking, preparing food, bathing, cleaning, irrigating crops, and a variety of other tasks, so it was important to have ready access to this resource. The following are the reasons to justify water and waste management:

- Water abstraction for domestic use, agricultural production, mining, industrial production, power generation, and forestry practices can lead to deterioration in water quality and quantity that impact not only the aquatic ecosystem (i.e., the assemblage of organisms living and interacting together within an aquatic environment), but also the availability of safe water for human consumption.

- The water sources used for supplying water are not always clean and treating drinking water to improve smell, taste, clarity, or to remove disease-causing pathogens has occurred in one form or another throughout recorded history.
- Providing safe and secure water to people around the world, and promoting sustainable use of water resources are fundamental objectives of the Millennium Development Goals.
- The preservation of aquatic resources for ecosystem and human health and well-being is a paramount concern worldwide and it has become evident that approaches to managing aquatic resources must be undertaken within the context of ecosystem dynamics in order that their exploitation for human uses remains sustainable.
- 80% of sickness in the world is caused by inadequate water supply or sanitation.
- 40% of the world population does not have access to safe drinking water.
- It is estimated that water-borne diseases kill 25,000 people per day.
- In many populated areas of the world, water-borne diseases represent the leading cause of death.

3.5 Chemical and Physical Properties of a Water Body

Water bodies, both freshwater and saline water can be generally characterised with a number of attributes. In this section are a number of some of these attributes and brief descriptions of them.

Temperature*:* Temperature affects the speed of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents. Temperature is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen (DO) and other materials in the water column (e.g., ammonia). Water temperatures fluctuate naturally both daily and seasonally. The maximum daily temperature is usually several hours after noon and the minimum is around daybreak. Water temperature varies seasonally with air temperature.

Vertical gradients in temperature can often be measured in deeper systems, especially in lakes where thermal stratification is common. A warm upper layer, called the *epilimnion*, often develops during summer months in temperate regions, while a cool bottom layer, the *hypolimnion*, can be detected below the *thermo cline*. Exceptions to this pattern can be found in ice covered systems, where an inverse temperature gradient may be set up and the upper layer of water is cooler than the bottom layer.

Dissolved Oxygen: Oxygen dissolved in the water column, is one of the most important components of aquatic systems. Oxygen is required for the metabolism of aerobic organisms, and it influences inorganic chemical reactions. Oxygen is often used as an indicator of water quality, such that high concentrations of oxygen usually indicate good water quality. Oxygen enters water through diffusion across the water's surface, by rapid movement such as waterfalls or ripples in streams (aeration), or as a by-product of photosynthesis. The amount of dissolved oxygen gas depends highly on temperature and somewhat on atmospheric pressure. Salinity also influences dissolved oxygen concentrations, such that oxygen is low in highly saline waters and vice versa. The amount of any gas, including oxygen, dissolved in water is inversely proportional to the temperature of the water; as temperature increases, the amount of dissolved oxygen (gas) decreases.

pH and Alkalinity: In water, a small number of water (H_2O) molecules dissociate and form hydrogen (H^+) and hydroxyl (OH^-) ions. If the relative proportion of the hydrogen ions is greater than the hydroxyl ions, then the water is defined as being acidic. If the hydroxyl ions dominate, then the water is defined as being alkaline. The relative proportion of hydrogen and hydroxyl ions is measured on a negative logarithmic scale from 1 (acidic) to 14 (alkaline): 7 being neutral.

Alkalinity, on the other hand, is a related concept that is commonly used to indicate a system's capacity to buffer against acid impacts. Buffering capacity is the ability of a body of water to resist or dampen changes in pH. Alkaline compounds in water such as bicarbonates, carbonates, and hydroxides remove H^+ ions and lower the acidity of the water (i.e., increase pH).

Turbidity and Suspended Solids: Turbidity refers to water clarity. The greater the amount of suspended solids in the water, the murkier it appears, and the higher the measured turbidity. The major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also include clays and silts from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or water discharges. Suspended solids in streams are often the result of sediments carried by the water. The source of these sediments includes natural and anthropogenic (human) activities in the watershed, such as natural or excessive soil erosion from agriculture, forestry or construction, urban runoff, industrial effluents, or excess phytoplankton growth.

Turbidity is often expressed as total suspended solids (TSS). Water transparency and Secchi disk depth are also commonly-used measures of water quality that quantify the depth of light penetration in a body of water. Water bodies that have high transparency values typically have good water quality.

Salinity and Specific Conductance: Salinity is an indication of the concentration of dissolved salts in a body of water. The ions responsible for salinity include the major cations (calcium, Ca^{2+}; magnesium, Mg^{2+}, sodium, Na^{+}; and potassium, K^{+}) and the major anions (carbonates, CO_3^{-} and HCO_3^{2-}; sulphate, SO_4^{2-}; and chloride, Cl^{-}). The level of salinity in aquatic systems is important to aquatic plants and animals as species can survive only within certain salinity ranges. Although some species are well-adapted to surviving in saline environments, growth and reproduction of many species can be hindered by increases in salinity.

Salinity is measured by comparing the dissolved solids in a water sample with a standardised solution. The dissolved solids can be estimated using total dissolved solids (see: turbidity) or by measuring the specific conductance. Specific conductance, or conductivity, measures how well the water conducts an electrical current, a property that is proportional to the concentration of ions in solution. Conductivity is often used as a surrogate of salinity measurements and is considerably higher in saline systems than in non-saline systems.

Major Ions: The ionic composition of surface and ground waters is governed by exchanges with the underlying geology of the drainage basin and with atmospheric deposition. Human activities within the drainage basin also influence the ionic composition, by altering discharge regimes and transport of particulate matter across the landscape, and by changing the chemical composition of surface runoff and atmospheric deposition of solutes through wet and dry precipitation.

Global average concentrations of the four major cations (calcium, magnesium, sodium, and potassium) and the four major anions (bicarbonate, carbonate, sulphate, and chloride) in surface water tend to approach patterns in which calcium concentrations dominate the cations and bicarbonate and/or carbonate concentrations dominate the anions. However, as Table 2 shows, there is considerable variability in the patterns for ca tions in rivers on a global scale.

Table 2: Median Composition of Major Cations in Rivers and Lakes around the World

Region		Cations (MgL^{-1})		
	Calcium	Magnesium	Sodium	Potassium
Africa	13	5	18	4
Americas	22	6	8	1
Asia	20	9	11	2
Europe	45	6	10	2
Oceania	8	2	6	1

Source: UN GEMS/Water Programme (2006)

The ionic composition of surface waters is usually considered to be relatively stable and insensitive to biological processes occurring within a body of water. Magnesium, sodium and potassium concentrations tend not to be heavily influenced by metabolic activities of aquatic organisms, whereas calcium can exhibit marked seasonal and spatial dynamics as a result of biological activity. Similarly, chloride concentrations are not heavily influenced by biological activity, whereas sulphate and inorganic carbon (carbonate and bicarbonate) concentrations can be driven by production and respiration cycles of the aquatic biota. External forces such as climatic events that govern evaporation and discharge regimes and anthropogenic inputs can also drive patterns in ionic concentrations. Such forces are probably most responsible for long-term changes in the ionic composition of lakes and rivers.

Nutrients: Nutrients are elements essential to life. The major nutrients, or macronutrients, required for metabolism and growth of organisms include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, magnesium, and calcium. In aquatic systems, nitrogen and phosphorus are the two nutrients that most commonly limit maximum biomass of algae and aquatic plants (primary producers), which occurs when concentrations in the surrounding environment are below requirements for optimal growth of algae, plants and bacteria. There are many micronutrients also required for metabolism and growth of organisms, but for the most part, cellular demands for these nutrients do not exceed supply.

For example, elements such as iron (Fe) and manganese (Mn) are essential cellular constituents but are required in relatively low concentrations in relation to their availability in fresh waters.

Metals: Metals occur naturally and become integrated into aquatic organisms through food and water. Trace metals such as mercury, copper, selenium, and zinc are essential metabolic components in low concentrations. However, metals tend to bioaccumulation in tissues and prolonged exposure or exposure at higher concentrations can lead to illness. Elevated concentrations of trace metals can have negative consequences for both wildlife and humans. Human activities such as mining and heavy industry can result in higher concentrations than those that would be found naturally.

Metals tend to be strongly associated with sediments in rivers, lakes, and reservoirs and their release to the surrounding water is largely a function of pH, oxidation-reduction state, and organic matter content of the water (and the same is also true for nutrient and organic compounds). Thus, water quality monitoring for metals should also examine sediment concentrations, so as not to overlook a potential source of metal contamination to surface waters.

Organic Matter: Organic matter is important in the cycling of nutrients, carbon and energy between producers and consumers and back again in aquatic ecosystems. The decomposition of organic matter by bacteria and fungi in aquatic ecosystems, inefficient grazing by zooplankton and waste excretion by aquatic animals, release stored energy, carbon, and nutrients, thereby making these newly available to primary producers and bacteria for metabolism. External subsidies of organic matter that enter aquatic ecosystems from a drainage basin through point sources such as effluent outfalls, or non-point sources such as runoff from agricultural areas, can enhance microbial respiration and invertebrate production of aquatic ecosystems.

Organic matter affects the biological availability of minerals and elements, and has important protective effects in many aquatic ecosystems, by influencing the degree of light penetration that can enter.

Biological components: Organisms, populations, and communities composed of different species make up the biological diversity of aquatic ecosystems. From single-celled microbes such as viruses, bacteria, protists, and fungi, to multi-cellular organisms such as vascular plants, aquatic invertebrates, fish and wildfowl, the community of organisms that reside within and near aquatic ecosystems simultaneously plays a vital role in regulating biogeochemical fluxes in their surrounding environment and is influenced by these same biogeochemical fluxes. Aquatic organisms, often considered ‘engineers’ of aquatic ecosystems, not only react to physical and chemical changes in their environment, but also they can drive such changes and have important roles in cleansing and detoxifying their environment.

The entire biological diversity of aquatic environments ensures that ecosystems can continue to function normally: shifts in species composition through species losses or biological invasions can lead to physical and chemical changes in the environment that may have detrimental effects on both the community of organisms residing within the ecosystem and on humans that rely upon the system for water supply and other activities. The diversity of aquatic ecosystems can also be influenced by physical and chemical changes in the environment.

Biochemical Oxygen Demand and Chemical Oxygen Demand:
Many aquatic ecosystems rely heavily on external subsidies of organic matter to sustain production. However, excess inputs of organic matter from the drainage basin, such as those that may occur downstream of a sewage outfall, can upset the production balance of an aquatic system and lead to excessive bacterial production and consumption of dissolved oxygen that could compromise the integrity of the ecosystem and lead to favourable conditions for growth of less than ideal species.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are two common measures of water quality that reflect the degree of organic matter pollution of a water body. BOD is a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements during the breakdown of organic matter, and systems with high BOD tend to have low dissolved oxygen concentrations.

COD is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant, such as dichromate.

Although BOD and COD are usually at or near analytical limits of detection in relatively undisturbed systems, water samples taken near points of organic matter pollution often yield very high observations.

3.6 Effects of Contaminated Water on Man

Sometimes, we ask ourselves questions such as what are the contaminates in water, what are their concentration levels, and do they pose short or long term health risks at those levels?

Finding answers to these questions is not easy. The answers depend on where you live (country, city, surrounding land use, etc.), the primary source of drinking water (confined or unconfined aquifer or surface water), water supplier (private or community well, small or large municipal water system), and what is happening at any moment as water travels from its source through the treatment/distribution system to the faucet.

Specific effects of contaminated water are described below.

- **Nitrate** – is a common pollutant in water in the agricultural regions. High levels of nitrites or nitrates in the water supply can interfere with infants' ability to absorb oxygen and can lead to "blue-baby" syndrome (methemoglobinemia), which can result in death.
  Exposure during pregnancy is possibly linked to neural tube defects, although studies have not ruled out other causes.
- **Arsenic -** May cause low birth weights, spontaneous abortions, and other problems. Other compounds like lead, mercury; DDT, etc. have also been implicated as having harmful effects on the developing fetus in pregnant women.
- **Pesticides -** Malignancies (in children) linked to pesticides in case reports or case-control studies include leukemia, neuroblastoma, Wilms' tumor, soft-tissue sarcoma, Ewing's sarcoma, non-Hodgkin's lymphoma, and cancers of the brain, colorectum, and testes. Although these studies have been limited by nonspecific pesticide exposure information, small numbers of exposed subjects, and the potential for case-response bias, it is noteworthy that many of the reported increased risks are of greater magnitude than those observed in studies of pesticide-exposed adults, suggesting that children may be particularly sensitive to the carcinogenic effects of pesticides.
- **Biological Contaminants -** *Escherichia coli (E. coli)*, giardia and cryptosporidia cysts can all cause gastro-intestinal problems where dehydration from diarrhea and vomiting may be more severe and rapid than in adults. These contaminants can cause death. In some people, particularly children under 5 years of age and the elderly, E. coli infection can also cause a complication called hemolytic uremic syndrome, in which the red blood cells are destroyed and the kidneys fail.

4.0 CONCLUSION

Water is an essential part of human life, but which must be used in a sustainable way. Introducing a material which could alter the property / attribute of water is an attempt to pollute it. This will have negative effects on mankind.

5.0 SUMMARY

In this unit, we have learnt that:

- Freshwater is the non-saline part of the planet-wide water cycle.
- Water pollutants can be classified into microbial, inorganic, pesticides and herbicides, organic chemical and radioactive pollutants'
- Water management is desired because water is very important for human survival.
- The physiochemical properties of water include pH, alkalinity, cations, anions, turbidity, transparency, nutrients, biological components, etc.
- Polluted water can cause health problems to man.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight 5 physiochemical properties of water.
2. State 5 sources of freshwater.
3. Mention 2 sources of saline water.
4. Discuss 3 effects of polluted water on man.

7.0 REFERENCES/FURTHER READING

UN GEMS/Water Programme (2006). *Water Quality for Ecosystem and Human Health*. http://www.gemswater.org/.

Jones, A. A. A. (1997). *Global Hydrology: Processes, Resources and Environmental Management.* London: Longman.

UNIT 2 DEFINITIONS AND CHARACTERISTICS OF WASTEWATERS

CONTENTS

1.0 INTRODUCTION

When water is desired to sustain and support life, it is required in adequate quantity and desirable quality. You should have learnt about the desirable quality parameters in the previous units. One of the main reasons why water is often not in desired quality is due to contamination from various sources, especially wastes. Wastes generally could be in solid, liquid or gaseous form. Our concern here is the liquid form otherwise known as wastewaters. Please enjoy your study.

2.0 OBJECTIVES

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

- define wastewaters
- highlight the different sources of wastewaters and
- categorise wastewaters according to their sources.

3.0 MAIN CONTENT

3.1 What is Wastewater?

Wastewater is water containing dissolved and suspended solids from municipal or industrial sources. All the water used in the home that goes down the drains or into the sewage collection system is wastewater. This includes water from baths, showers, sinks, dishwashers, washing machines, and toilets.

Small businesses and industries often contribute large amounts of wastewater to sewage collection systems; others operate their own wastewater treatment systems. In combined municipal sewage systems, water from storm drains is also added to the municipal wastewater stream.

Wastewater is about 99 percent water by weight and is generally referred to as influent as it enters the wastewater treatment facility.

Wastewaters come from homes (domestic wastewaters), institutions, commercial outfits, industries, farms (agricultural) and from urban areas after rain (storm runoff). The term ‘wastewater’ is more or less a replacement of the older, more restrictive term ‘sewage’. These sources are described briefly in the next section.

3.2 Sources of Wastewaters

Ogedengbe (1998) grouped the different sources of wastewaters into the following:

- **Domestic Wastewaters**: These come from homes (residences) and consist of wastes from kitchens, toilets, bathrooms, etc. As they are derived from food wastes and fecal matter, they are highly decomposable, consisting of carbohydrates, proteins and fats in varying stages of digestion. The strengths of such wastes are measured in terms of BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), suspended solids concentration, dissolved solids, ammonia concentrations, etc. The BOD of typical domestic wastewaters in Nigeria is not much different from the BOD of wastewaters elsewhere and may range from about 200 to 500mg/l. Ammonia concentration ranges from 10 to 50mg/l and suspended solids concentration should also be about 200 to 500mg/l.

- **Institutional Wastewaters**: These come from institutions such as schools, prisons, clinics/hospitals, etc. as can be expected, these wastewaters should be similar to domestic ones except that hospital wastes may contain in addition, clinical wastes (e.g. germs, human blood, x-ray wastes, etc). A study by Ademoroti (1989) showed that the wastewaters from the University College Hospital community in Ibadan arises from the residences of the medical students, staff and student nurses, house officers, resident doctors, domestic servants and also from the hospital laboratories, wards and clinics. Raw wastewaters from the institution at a time was characterised by 26 – 28^{0}C as temperature, 6.9 – 7.4 as pH and 106 – 222mg/l, 206 – 385 mg/l and (3.5 – 3.9) x 10^7, respectively as suspended solids, BOD and Total coliforms per 100ml sample.

- **Commercial Wastewaters**: These come from hotels, restaurants, cafeteria, "bukataria," markets, cottage industries and similar places. The wastes are also, by and large, domestic in character. Levels of BOD, COD, and suspended solids may be higher than those of domestic wastewater due to special inputs from the handling of milk, ice cream, sweets, etc. A study on a medium sized market in Ile-Ife showed that the wastewaters from the market is characterized by 30.9^0C, 5.7, 9.4mg/l and 340.2mg/l, respectively as temperature, pH, BOD and Dissolved Solids (Eludoyin, *et al.*, 2008).

- **Industrial Wastewaters**: These come from industries. Common wastewater generating industries include breweries, beverages, bottling, textiles, pulp and paper, pharmaceutics, meat packing, dairies, paint, metal finishing, etc. These wastewaters may be direct by-products of wet processes or may arise from equipment and floor washings. Thermal power plants (e.g. Egbin Thermal station) discharge hot water which on its own is a potent wastewater.

  Industrial wastewaters, as a class of wastewater, are by far more complex than domestic wastewaters. This is because, in addition to having, possibly, the characteristics of domestic wastewaters as earlier described, they may contain other complex organic matter, toxic chemicals, and heavy metals, depending on the type of industries. Table 3 for example, shows the groups of industries in Nigeria, such that their by-products could be envisaged. It could easily be deduced that groups 1, 2, 3, 4 would be particularly involved in wastewater generation.

- **Agricultural Wastewaters**: Apart from the domestic wastewaters generated on agricultural lands, runoffs from farmlands may be laden with dissolved agrochemicals (fertilizers, herbicides, and pesticides), animal dung, sand and silt which as non-point sources pollute aquatic environments.

- **Storm Runoff**: Runoff from rain in urban areas may be laden with organic and inorganic dirt (depending on how dirty the community is) and may contain also sand, silt, etc.

Table 3: The Groups of Industries in Nigeria as Classified by the Manufacturers Association of Nigeria (MAN)

S/N	Group	Subgroups
1	Food, Beverages and Tobacco	Beer, starch, flavouring, soft drinks and carbonated water, flour and grain milling, meat/poultry/ fish, tea/coffee, dairy products, fruit juices, tobacco, biscuits and bakery products, animal feeds, sugar distillery and blending of spirit, cocoa/chocolate, confectionery.
2	Chemicals and Pharmaceuticals	Paints/vanishes, industrial/medical/special gases, soap/detergent, agro-chemicals, pharmaceuticals, foam manufacturers, safety matches, domestic insecticide aerosol, dry cell battery, petroleum refineries, gramophone/musical tape manufacturers, candle manufacturers, printing ink manufacturers, toiletries/cosmetics, basic industrial chemicals, automotive battery.
3	Domestic and Industrial Plastic and Rubber	Rubber products, domestic/industrial plastics
4	Basic Metal, Iron and Steel and Fabricated Metal Products	Steel Pipe Manufacturers Association, metal packaging manufacturers, foundry, metal manufacturers and fabricators, aluminum products, enamel wares/welding electrode manufacturers, galvanized iron sheets manufacturers, nail and wire manufacturers group, steel manufacturers.
5	Pulp, paper and paper products, Printing and Publishing	Chemical /stationery manufacturers, printing and publishing, pulp and paper products
6.	Electrical and Electronics	Electronics, refrigerators and air conditioning/ domestic appliances, electric bulbs/lamps/accessories/fittings, electric power control/distribution equipment, cable/wire
7	Textile, Wearing Apparel and Leather	Textile/wearing apparel manufacturers, leather products/carpets and rug/footwear manufacturers, cordage / rope/twine manufacturers
8.	Wood and wood products including furniture	Wood products and furniture (excluding metal furniture), plywood and particle board manufacturers
9.	Non-metallic mineral products	Glass/ceramics/asbestos manufacturers, school chalk and crayon, cement manufacturers
10	Motor vehicle and miscellaneous	Boat/ship building, automotive components manufacturers, electric generator assemblers,

	assembly	miscellaneous, horological, motor vehicle assemblers.

Source: Ogedengbe, 1998

4.0 CONCLUSION

An appreciation of the sources and character of different forms of wastewater as briefly presented is essential towards taking decisions as to the techniques that can be used to treat them.

5.0 SUMMARY

In this unit, we have learnt that:

- Wastewater is water containing dissolved and suspended solids from municipal or industrial sources. Wastewaters come from homes (domestic wastewaters), institutions, commercial outfits, industries, farms (agricultural) and from urban areas after rain (storm runoff)
- Wastewater used to be known as sewage, which is restrictive; and
- Different types of wastewater exist, based on different sources and characteristics.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define wastewaters.
2. Describe 5 types of wastewaters.

7.0 REFERENCES/FURTHER READING

Ogedengbe, M.O. (1998). *Technologies for Industrial Waste Management*, Lecture note Delivered at a Short Certificate Course Workshop on Environmentally Sound Technologies for Management of Wastes held November / December, 1998 under the Auspices of the Institute of Ecology and Environmental Studies and the UNIFECS.

WHO/ UNICEF Joint Monitoring Programme for Water and Sanitation (2005). *Water for Life: Making it Happen*, World Health Organisation and UNICEF, Switzerland, http://www.unicef.org/wes/files/JMP_2005.pdf.

UNIT 3 CLASSES AND SOURCES OF WATER POLLUTANTS

CONTENTS

1.0 INTRODUCTION

Man is using more water in more and more ways. Although lakes, rivers and oceans have considerable ability to purify themselves by biological action, the quantities of waste discharged into water by man now frequently exceed this self-cleansing natural ability. In addition, industry and agriculture now contribute large amounts of non-degradable pollutants. About half the population of the developed countries use sewers and the rest of the people discharge their wastes directly into septic tanks or directly into the ground or water. Of the wastes carried in domestic waters, one tenth is discharged raw and one quarter after only primary treatment. The situation in the less developed countries is quite deplorable without the sewers or the water control technology of the developed countries. This unit highlights some classes of water pollutants and their effects on water quality.

2.0 OBJECTIVES

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

- the objectives of this unit are to: highlight some classes of water pollutants and
- the sources of water pollutants.

3.0 MAIN CONTENT

3.1 Classes of Water Pollutants

Water pollution is a relative term. Water is considered polluted when its composition or state is directly or indirectly modified by human activity to such an extent, that it is less suitable for purposes it could have served in its natural state. Water pollution takes many forms. Some of these are:

- **Diseases–Causing Organisms**: specifically parasites, bacteria and viruses which often enter water with human sewage
- **Synthetic Organic Compounds**: in the form of industrial, household and agricultural chemicals, as well as water treatment chemicals added deliberately and the products formed by reaction of these with other contaminants
- **Inorganic Compound and Mineral Substances**: including acids, mineral fibres such as asbestos and heavy metals discharged directly into water by certain mining and industrial operations and also entering water as fallout or in precipitation from the atmosphere.
- **Radioactive Substances**: from commercial and military applications of nucleus energy
- **Oxygen – Demanding Wastes**: namely organic compounds contained in sewage and some industrial effluents, whose biological or chemical degradation depletes dissolved oxygen
- **Plant Nutrient**: such as nitrogen and phosphorous, from sewage and agriculture runoff
- **Sediments**: from erosion caused by agriculture or construction
- **Thermal Discharge**: from power plants and certain industrial facilities.

3.2 Sources of Water Pollutants

- Most water pollution problems originate from land–based activities carried out within drainage basins, and not from water based activities such as shipping, boating and swimming. Even without human activity to pollute the streams, stream water is never absolutely pure, because natural pollution is at work in form of soil erosion, deposition of leaves and animal waste, solution of minerals, etc. over a long stretch of time, a lake can die a natural death because of such pollution. The natural process of eutrophication of environment with nutrients encourages the growth of algae and other plants, slowly turning a lake into a bog.

- Agriculture and Drainage Basins: Agricultural areas contribute to the degradation of water quality in several ways. Excessive soil erosion increases a river's sediments load. Pesticides, fertilizers and animal wastes from fields and orchards, run off into streams or seep into groundwater. Regions from which contaminants are washed in this way are referred to as **non-point sources of pollutants**, since the contaminants they contribute come from many places but not from one or two concentrated sources. In contrast to point sources, concentrated wastes from sewage treatment plants and industry – pollutants from non-point sources are especially difficult and expensive to control, because the concentration of pollutants is relatively low and the volumes enormous.

- Urban-Industrial Areas and Drainage Basins: These basins contain the greatest number of point sources of pollutants. In the developed countries, the multitudes of wastes from such areas are no longer dumped directly into waterways. Nevertheless, modern day sewer systems are very important contributors to surface water pollution. In cities, concretes, asphalt, and buildings render a large part of the urban surface impermeable to rainwater thereby increasing the volume of runoff. To prevent flooding, large storm sewer pipes lying under city streets channel this runoff, usually directly to the nearest river, lake or ocean. During a rainstorm, the air and streets are washed, and many pollutants, e.g. hydraulic fluid, dirt, oil, radiator coolant, road salt, etc are carried into surface waters by storm sewer systems. In the less developed countries, control of surface runoff is virtually nil and this has caused several hardships to life and properties in many urban areas.

In the developed countries, smaller sewer pipes called sanitary sewers carry wastewaters from homes and commercial areas to treatment plants where it is treated and discharged into the nearest surface water. Some sewer systems employ a single pipe to transport both urban runoff and sewage to the treatment plant. Such is called combined sewer. The treatment plant receives only domestic water during the dry weather. Dry heavy rains, however, could increase the volume of water flowing the sewer which is often exceeded by a hundred times amount that can be processed by the treatment plant. As a consequence, only a fraction of the sewage water is treated and the overflow – containing raw sewage – is bypassed and discharged directly into surface waters.

The wastewater of some industries is so toxic that municipal treatment plants are prohibited from treating it. Industries that do send their wastewater to municipal treatment must limit the level of potentially toxic substances. Other factories install specialised water treatment systems that are designed to remove the particular type of pollutants in their effluent or liquid wastes. With the tightening of air and water quality standards, industries and municipalities have been forced to dispose more of the wastes in landfill sites. These disposal systems do protect surface waters, but they do pose a potential threat to groundwater quality.

Industry also produces an increasingly important pollutant of an entirely different kind – heat. Power generation and some manufacturing processes use great quantities of water for cooling, and it goes back into streams warmer than it came out. Power plants disgorging great masses of hot water can raise the stream temperature by ten or twenty degrees in the immediate vicinity of the plant. Warmer water absorbs less oxygen and this slows down decomposition of organic matter, fish being cold blooded, cannot regulate their body temperatures and the additional heat upsets their life cycles; for example fish-eggs my hatch too soon.

4.0 CONCLUSION

This unit has introduced you to:

- The subject of managing polluted water and wastewater.

5.0 SUMMARY

In this unit, you have learnt that:

- Water pollutants are variedly classified
- Sources of water pollutants are urban, agricultural, industrial, etc
- Sources of water pollutants can also be divided into point and non-point sources

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight 5 classes of water pollutants.
2. Mention 5 sources of water pollutants.

7.0 REFERENCES/FURTHER READING

UN GEMS/Water Programme (2006). *Water Quality for Ecosystem and Human Health*, http://www.gemswater.org/.

Osunade, M. A. A., Ekanade, O. Jeje, L. K. and Tengbe, P. B. (2004). *Man in His Environment*, (A Publication of the Department of Geography), Obafemi Awolowo University, Ile-Ife.

MODULE 2 GLOBAL WATER CONDITION AND MANAGEMENT EFFORTS

UNIT 1 GLOBAL WATER QUALITY CONDITIONS

CONTENTS

1.0 INTRODUCTION

From **ESM 223** (**Water Resources Evaluation**), you have read that water resources include surface, groundwater and precipitation water systems – all being collectively known as the water system. Water quality in this system is essential for maintaining viable, abundant and diverse communities of organisms. People have specific water quality requirements for drinking water, recreation, agriculture and industry; although the specific water quality requirements vary by sector. Degradation of water quality erodes the availability of water for humans and ecosystems, increasing financial costs for human users, and decreasing species diversity and abundance of resident communities. These changes in environmental quality can be associated with changes in water quality parameters such as sediment load, nutrient concentrations, temperature, dissolved oxygen levels, and pH. The addition of excessive levels of naturally occurring or synthetic compounds, such as oil and grease, pesticides, mercury and other trace metals, and non-metallic toxins can harm wildlife and people that depend on these aquatic resources.

This unit outlines how water quality is affected by different processes and the ways in which human activities in different economic sectors influence these processes.

2.0 OBJECTIVES

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

- describe the condition of water quality in Africa with respect to the rest of the World and
- discuss some processes leading to deterioration in water quality and their effects.

3.0 MAIN CONTENT

3.1 Condition of Water Quality in the World

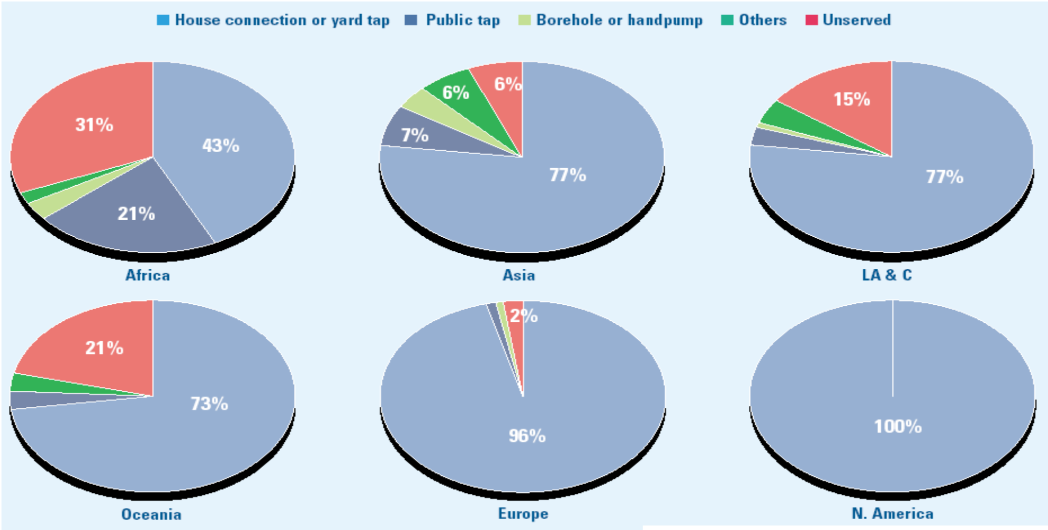
Table 4 shows the generally identified causes of degradation of water quality in many water resources in the world, and their sources.

Table 4: Sources and Causes of Water Contamination in Many Parts of the World

	Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Causes	Pathogens (Bacteria)	Nutrients	Metals (Primarily mercury)
	Siltation (Sedimentation)	Metals (Primarily mercury)	Pesticides
	Habitat Alterations	Siltation (Sedimentation)	Oxygen-Depleting Substances
Sources	Agriculture	Agriculture	Municipal Point Sources
	Hydrologic Modifications	Hydrologic Modifications	Urban Runoff/Storm Sewers
	Habitat Modifications	Urban Runoff/Storm Sewers	Industrial Discharges

Source: USEPA National Water Quality Inventory 2000 Report

Figures 2 – 3 show that Africa has the least percentage of cities served by good water supply in the world while the highest population in the continent either do not have modern toilet facilities or do have the local variety and it is of low quality.



Latin America and Caribbean countries

Fig. 2: **Water Supply in the Largest Cities: Mean Percentage of the Population and each Type of Service by Region**

Source: WHO and UNICEF "Global Water Supply and Sanitation Assessment 2000 Report

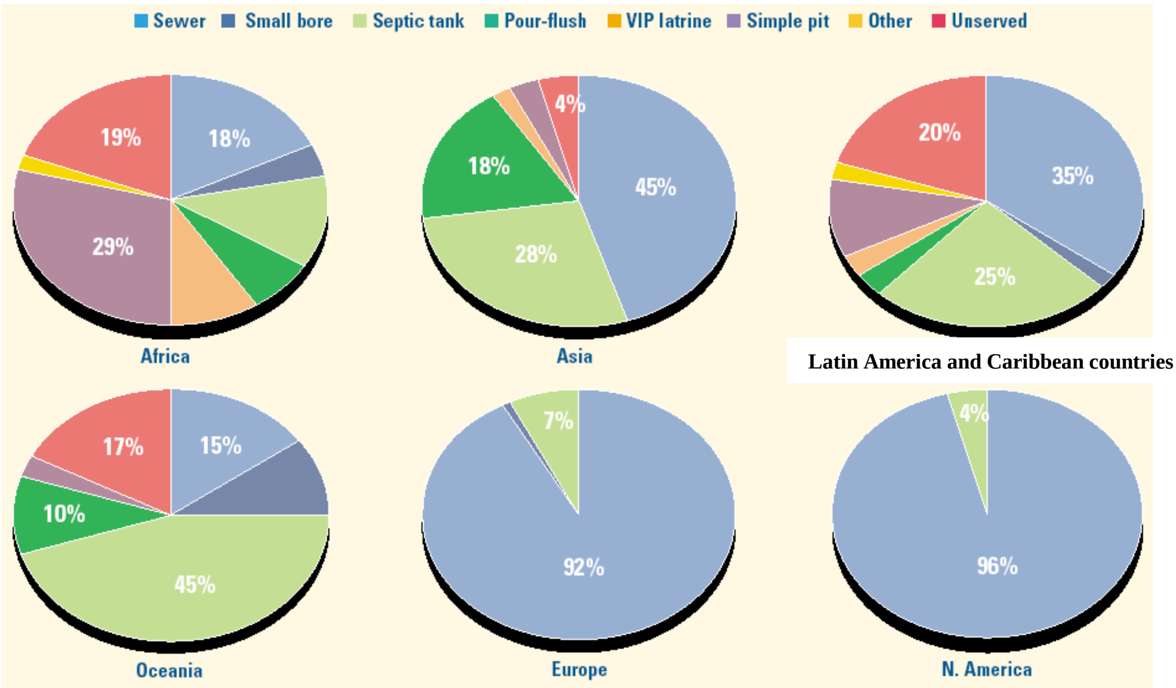


Fig. 3: **Sanitation in the Largest Cities: mean Percentage with each Type of Facility, by Region**

Source: WHO and UNICEF "Global Water Supply and Sanitation Assessment 2000 Report"

Africa also has the highest percentage of contaminated drinking water available for her population. See Figure 4.

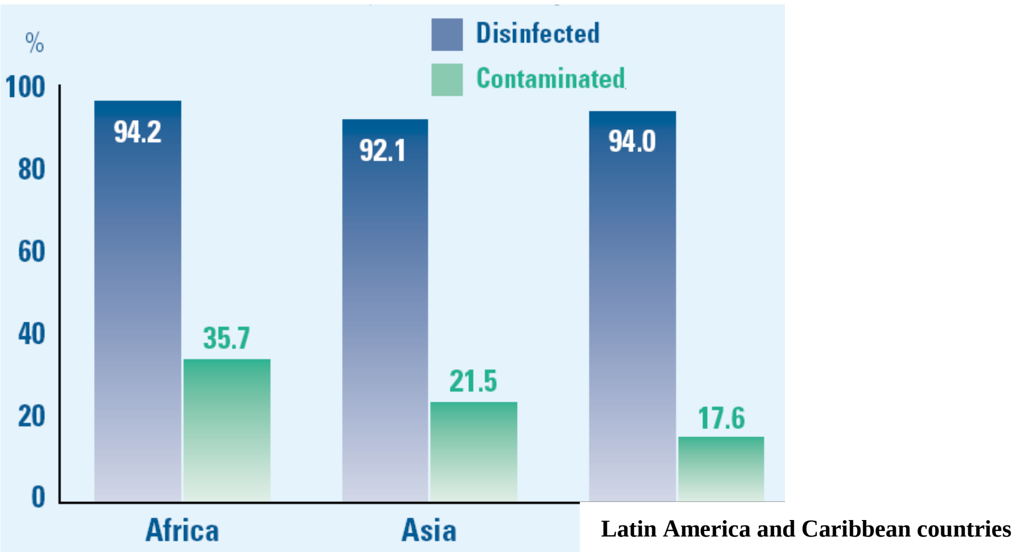


Fig. 4: **Percentage of Water Supply which is effectively Disinfected (Free Residual Chlorine over 0.1 mg/l), and Percentage of Drinking Water Quality Test results that Violate National Standards (Microbiological, Chemical, Physical, Aesthetic)**

Source: WHO and UNICEF "Global Water Supply and Sanitation Assessment 2000 Report"

3.2 Processes Leading to Deterioration in Water Quality

The following are processes that cause degradation of the quality of water from natural sources:

3.2.1 Sedimentation

Sediments transported into aquatic systems are from almost all human land use and industrial activities, including agriculture, forestry, urbanisation, mining and some industrial activities. Increases in sediment transport to aquatic systems are typically observed as bank side vegetation is degraded or removed, rivers are channelised to enable development closer to stream banks, and natural land cover is removed or replaced by human-built land cover (e.g., roads and buildings). The construction of impoundments also generates sediments and alters the natural sedimentation regime of many water courses. Sediments tend to accumulate in reservoirs and ecosystems downstream of reservoirs are often depleted of natural sediment fluxes and riverbank scouring is increased.

- **Effects**: The transport of sediments into surface waters has both physical and chemical consequences for water quality and aquatic ecosystem health.

- High turbidity can decrease the amount of available sunlight, limiting the production of algae and macrophytes. Fish habitat can be degraded as spawning gravel becomes filled with fine particles, restricting the oxygen available for buried eggs. Turbid waters may also damage fish directly by irritating or scouring their gills, or by reducing the success of visual predators. The scouring action of turbid waters may also harm some benthic macro-invertebrates.

- Very fine sediment (less than 63µm) is often chemically active. Phosphorus and metals tend to be highly attracted to the ionic exchange sites associated with iron and manganese coatings that occur on small particles. Many toxic organic contaminants, such as pesticides or their breakdown products, are strongly associated with silt, clay and organic carbon transported by rivers. Thus, sediments act as an agent in the process of eutrophication and toxicity in aquatic organisms.

- High sediment loads in surface waters can also increase thermal pollution by increasing the absorption of light, thereby increasing water temperatures.

- High sediment loads can also impair navigation and water retention facilities by silting in watercourses and filling in reservoirs thereby needing costly dredging or shortening their useful life. Dredging of reservoirs and lakes also has serious implications for the ecology of these systems.

3.2.2 Eutrophication

Causes of nutrient loading, or eutrophication, of aquatic ecosystems can be attributed to agriculture, urbanization, forestry, impoundments, and industrial effluents. Surface and ground water may be equally affected by nutrient enrichment, as nutrient enriched water on the surface may percolate into groundwater supplies. Increased rates of primary production typical of eutrophic ecosystems is often manifest as excessive growth of algae and the depletion of oxygen (increased BOD), which can result in the death of fish and other animals. Nutrient enrichment can also increase the abundance of cyan bacteria (blue-green algae), which produce toxins.

- **Effects**:

- Eutrophication can lead to changes in the composition of aquatic fauna, particularly the disappearance of species with high oxygen requirements; thus, biodiversity of aquatic communities is often compromised in nutrient-enriched environments.

- The consequences of eutrophication for humans are bad taste and odour in public water supplies, production of cyan bacterial toxins that can threaten animal and human health, infilling or clogging of irrigation canals with aquatic weeds, loss of recreation due to slime, weed infestations and noxious odours, and economic losses due to the disappearance of species targeted in commercial and sport fisheries.

- In addition, nitrate in drinking water has been linked to human health problems such as methaemoglobinaemia (blue-baby syndrome), stomach cancer and negative reproductive outcomes. High nitrate concentrations have also been linked to lower productivity in livestock.

3.2.3 Thermal Pollution

Urbanisation, forestry, agriculture, impoundments, and industrial effluents can cause changes in surface water temperatures. Probably the most pronounced changes in temperature regimes in aquatic ecosystems can be documented downstream of coal and nuclear electrical power generating plants, where heated water is discharged into receiving environments on a continual basis. The heated water can increase local water temperatures by tens of degrees, and in temperate systems may prevent the formation of ice on a system during the winter months. Heated effluents from power generating plants often are combined with increased discharges of water to small systems that can scour native habitats and alter the physical structure of the receiving environment.

- **Effects**

- Temperature is very important to living organisms as it affects some of the basic physical and chemical processes necessary for life. For example, temperature affects the movement of molecules, fluid dynamics, and saturation concentrations of dissolved gasses in water, and the metabolic rate of organisms. Aquatic ecosystems experience daily and annual fluctuations in temperatures. This thermal regimen is crucial for aquatic fauna, as many life history traits, such as reproduction and growth, are regulated by temperature. Therefore, unseasonable changes in temperatures can eliminate species that are adapted to the natural cycle of water temperatures found in free-flowing systems.

- Increases in temperature will also affect the levels of dissolved oxygen in the water column, which is inversely proportional to temperature, reducing the chances of survival of oxygen sensitive species.

- Microbial consumption of oxygen, measured as BOD, tends to increase with water temperature. Higher water temperatures affect plant life by increasing growth rates, resulting in a shorter lifespan and species overabundance (i.e., algal blooms). Increases in algae and macrophyte abundance further reduce oxygen saturation in the water column. The loss of oxygen-sensitive but highly valued trophy species like trout and the aesthetic degradation caused by ‘weedy’ receiving waters can impact the use of the system as a recreational resource.

- Aquatic ecosystems that have received thermal effluent are able to recover from disturbance once the thermal effluent is removed. However, the degree of recovery depends on the degree of impact and the length of time the system was impacted. That is, systems that received thermal effluents with extreme temperature differences for decades can be expected to take longer to recover to natural conditions than systems that received thermal effluents for shorter periods with smaller temperature differences do.

3.2.4 Acidification

Acid mine drainage, industrial effluent, and atmospheric emissions of sulphur and nitrogen oxides are largely responsible for the acidification of surface waters. Most surface waters have a pH between 6 and 8.5, and values below six can be hazardous to aquatic life. Industrial effluent has the potential to alter the chemistry of receiving waters and make them more susceptible to acidification. For example, a study on Periyar River, India, showed that alkalinity downstream of a rare earth metals processing plant declined significantly in the early 1980s; this decline was accompanied by an increase in the overall variability of pH. Water quality at that monitoring station also tended to have much higher hardness, conductivity, chloride, sulphate and nitrate concentrations than a baseline, upstream monitoring station.

- **Effects:**

- Fish, shellfish and aquatic insects have different levels of tolerance to acidic waters and species diversity will decrease along with increased acidification. Young organisms tend to be more sensitive to acidic waters: for example, at a pH of 5, most fish eggs cannot hatch, while only some adult fish will be affected.

- Trophic level effects may cause indirect survival challenges in instances where prey species are eliminated. Acidic waters also mobilise metals that can be toxic to aquatic species (e.g., aluminum). Metal toxicity can cause reduced chances of survival in fish through chronic stress, which impairs health and decreases the affected individuals' ability to secure food, shelter, or reproductive partners.

- While acid mine drainage tends to affect individual systems and be fairly localized in its impact, industrial emissions of sulphur and nitrogen oxides to the atmosphere have affected large areas and many ecosystems.

3.2.5 Microbial Contamination

Microbial pollution in inland waters originates primarily from agriculture and urban land uses and although contamination of a water body may occur at any time, the survival of microbial contaminants depends largely on the physical and chemical conditions of the water. Thus, microbial contamination in a water body often appears to be episodic, coinciding with periods that are favourable to microbial growth.

Surface and ground water can be infected with a variety of pathogens, yet testing and monitoring for all pathogens is unrealistic, mainly because of analytical costs and technical difficulties in detecting organisms at low concentrations in chemically complex environments such as surface waters. Instead, indicator organisms are typically used to detect the presence of fecal contaminants in the water resource.

In particular, either total coliforms or fecal coli forms (a subset of total coliforms) are measured as indicators of pathogenic microbes. However, testing for *Escherichia coli* alone is becoming more prominent as *E. coli* indicates the presence of only fecal contaminants, while total or fecal coli form tests may give positive results for non-fecal, naturally occurring bacterial species. In general, fecal coli form bacteria in surface waters increase with population size of cities located upstream of a sampling station.

Although many cities have advanced wastewater treatment facilities that effectively reduce microbial contaminant loads to near zero values, there remains a very large proportion of the world's population, primarily in developing countries, without access to improved sanitation facilities, where wastewaters are discharged directly to the environment without treatment. In fact, an estimated 2.6 billion people lacked access to improved sanitation facilities in 2002.

- **Effects:**

- The largest concern about microbial pollution is the risk of illness or premature death to humans and livestock after exposure to contaminated water. Communities downstream of intensively farmed areas or municipal sewage outfalls, people working or recreating in infected waters, such as commercial or sport fishers, or agricultural workers labouring in fields treated with manure are at the highest risk of illness due to microbial pathogens.

- The risk of contamination increases the cost of treatment and in some instances the loss of the ecosystem resource (e.g., holiday beach tourism or shellfish harvesting). In addition, the treatment of farm waste on site can increase the cost associated with farm produce, increasing the cost of food for the average consumer.

- Infection agents: water is a significant vehicle in the transmission of diseases when it contains water borne pathogens, or diseases producing organisms. These pathogens which can be viruses, bacteria, protozoa (single-celled animal) and parasitic worms cause such diseases as dysentery, typhoid fever, cholera and infectious hepatitis. Some of the more common water diseases and their characteristics are as shown in Table 5.

Table 5: Water- Borne Diseases Transmitted through Drinking Water and Food

Disease	Type of organism	Symptoms and comments
Cholera	Bacteria	Severe vomiting, diarrhea and dehydration, often fatal if untreated; primary causes water-borne; secondary causes carried by contact with food and flies
Typhoid fever	Bacteria	Severe vomiting, diarrhea, inflamed intestine; enlarged spleen; often

		fatal if untreated; primarily transmitted by water and food
Bacteria dysentery	Several species of bacteria	Diarrhea; rarely fatal; transmitted through water contaminated with fecal material or by direct contact through milk, food and flies
Paratyphoid	Several species of bacteria	Severe vomiting and diarrhea; rarely fatal; transmitted through water contaminated with fecal material
Infectious hepatitis	Virus	Yellow jaundiced, enlarged liver, vomiting and abdominal pain, often permanent liver damage; transmitted through water and food including shellfish foods
Amoebic dysentery	Protozoa	Diarrhea possibly prolonged; transmitted through food, including shellfish

Source: Osunade, *et al.* (2004)

3.2.6 Salinisation

Anthropogenic increases in salinity and electrical conductivity in surface waters are largely due to agriculture, urbanisation and industrial activities. Increased salinity in aquatic ecosystems will encourage halo tolerant (i.e., tolerant of saline conditions) species at the expense of halo sensitive (i.e., intolerant of saline conditions) species. Saline toxicity is most often associated with high levels of ions, but there are situations in which effluents contain low levels of ions, creating de-ionized environments.

- **Effects:**

- The loss of biodiversity due to changes in salinity can affect invertebrates, vertebrates, aquatic plants, and riparian vegetation alike.

- There are economic losses associated with the diminished value of water that could otherwise be used for domestic, agricultural and industrial needs and in some instances countries incur direct costs associated with the salinisation of inland waters

3.2.7 Trace Metals and Mercury

Elevated levels of trace metals in aquatic systems have resulted from a number of land use activities including agriculture, urbanisation, impoundments, mining, and industrial activities. The effects of trace metal deposition are not always detected near the original source of contamination. Long range transport of contaminants to remote areas has led to concerns regarding trace metals (and other contaminants such as pesticides and other synthetic organic compounds) in, for example, arctic environments. Trace metals can be harmful to aquatic organisms. Industrial effluents and atmospheric emissions, impoundments, and mining are also known anthropogenic sources of mercury in aquatic environments. Inorganic mercury is transformed to organic methyl mercury by micro-organisms. Methyl mercury is absorbed easily and bioaccumulates in exposed organisms; mercury then biomagnifies as it is transported in the food chain.

- **Effects:**

- Causes reduced growth rates, impaired reproduction, and sometimes death. Acute or chronic toxicity will influence species numbers and diversity, altering community structure and function.

- Bioconcentration and bioaccumulation of these substances in the food chain can put terrestrial consumers, including humans, at risk. Contaminated food webs can have health and economic disadvantages for people as contaminated commercial, sport, and sustenance fisheries become restricted or closed due to high metal burdens in fish.

- Exposure to mercury can cause acute toxicity as well as neurological and reproductive problems in wildlife. Effects are more pronounced at higher strophic levels. Of particular concern are species that consume large amounts of fish such as river otters and fish eating birds. In humans, prenatal exposure to high mercury levels, particularly in fish-eating populations, has been associated with developmental problems related to the central nervous system. Loss of sustenance and commercial fisheries has been associated with high mercury concentrations in piscivorous fish species such as whitefish and northern pike.

3.2.8 Pesticides

Pesticides are frequently applied in agricultural, forestry, and urban settings. There are tens of thousands of pesticides in use, many of which are synthetically produced. Pesticides will break down in the environment forming by-products, some of which are toxic whereas others are relatively non-toxic. Many pesticides have been linked to health problems in humans and animals. Direct exposure can occur during the preparation and application of pesticides to crops. More frequently, exposure occurs when ingesting these agrochemicals while consuming contaminated foods. People are exposed to pesticides through aquatic systems either by ingesting fish or shellfish that have stored these compounds in their tissues or directly by drinking contaminated water. Concerns over health effects of certain compounds in humans and animals have lead to bans of certain pesticides in different parts of the world.

- **Effects:**

- Acute (immediate) toxic effects can influence the survival or reproduction of aquatic species leading to the disruption of predator-prey relationships and a loss of biodiversity. If aquatic organisms are not harmed immediately, they may concentrate chemicals from their environment into their tissues. This bioconcentration can lead to biomagnifications, a process in which the concentration of pesticides and other chemicals is increasingly magnified in tissues and other organs as they are transferred up the food chain.

- The chronic effects of these substances on aquatic organisms include health repercussions such as cancers, tumours, lesions, reproductive inhibition or failure, suppressed immune systems, disruption of the endocrine (hormone) system, cellular and DNA damage, and deformities. Terrestrial predators that feed on aquatic species may also be affected.

- Pesticide exposure has been linked to cancer, neurological damage, immune system deficiencies, and problems with the endocrine system.

3.2.8 Other Non-Metallic Toxins

Atmospheric emission resulting from incomplete combustion of materials during manufacturing processes, incineration of wastes or accidental fires produces toxic chemicals such as dioxins and furans. There are many types (hundreds to thousands) of these toxins released into the environment and they can have acute or chronic effects on the health and well-being of aquatic organisms. These substances can be widely dispersed, either in the atmosphere or by adhering to particles carried along in rivers. They are persistent, meaning that they are resistant to decomposition, and bioaccumulations, which has led to their classification as 'Persistent Organic Pollutants' or POPs. There is a tendency to associate oil spills as the primary source of hydrocarbon contamination of aquatic ecosystems. However, only 35 percent of oil contamination of land and water originates from transportation spills. Much of the rest comes from industrial effluents and as a result of urban runoff.

- **Effects:**

- The effects of individual substances are diverse but include cancer, endocrine disruption, immunotoxicity, development toxicity, dermatological ailments, cardiovascular difficulties, diabetes, heritable genetic damage, neurological conditions and reproductive inhibition.

4.0 CONCLUSION

This unit concludes that water quality is a function of land use around water supply unit, the sophistication of the treatment given to water pre-use and the nature of the intended use. It also concludes that people in developing countries suffer more from poor sanitation and consumption of water of poor quality than their counterparts in the developed countries.

5.0 SUMMARY

In this unit, we have learnt that:

- Africa has the least percentage of cities served by good water supply in the world.
- A high population in the continent either does not have modern toilet facilities or do have the local variety which is of low quality.
- Processes leading to degradation of water quality include eutrophication, salinisation, thermal pollution, etc.
- Effects of these processes include death of the consumers.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight four processes affecting water degradation in natural waters.
2. Describe two effects of each of the highlighted processes.

7.0 REFERENCES/FURTHER READING

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UNIT 2 RECYCLES AND REUSE OF WASTEWATERS

CONTENTS

1.0 INTRODUCTION

Reuse of wastewater for domestic and agricultural purposes has been occurring since historical times. However, planned reuse has gained importance only two or three decades ago, as the demands for water dramatically increased due to technological advancement, population growth, and urbanisation, which put great stress on the natural water cycle. Reuse of wastewater for water-demanding activities, which, so far consumed limited freshwater resources is, in effect, imitating the natural water cycle through engineered processes. Several pioneering studies have provided the technological confidence for the safe reuse of reclaimed water for beneficial uses. While initial emphasis was mainly on reuse for agricultural and non-potable the recent trends prove that there are direct reuse opportunities to applications closer to the point of generation. There are also many projects that have proved to be successful for indirect or direct potable reuse. All the case studies presented in this unit point towards the fact that wastewater could serve as a viable alternative source of water in future.

2.0 OBJECTIVES

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

- describe different forms of which wastewater could be reused
- highlight some motivating factors for wastewater reuse
- illustrate some issues of concern in wastewater reuse and
- discuss the future of water reuse.

4.0 MAIN CONTENT

3.1 Types of Wastewater

Wastewater can be recycled/reused as a source of water for a multitude of water-demanding activities such as agriculture, aquifer recharge, aquaculture, fire fighting, flushing of toilets, snow melting, industrial cooling, parks and golf course watering, formation of wetlands for wildlife habitats, recreational impoundments, and essentially for several other non-potable requirements. Potential reuse of wastewater depends on the hydraulic and biochemical characteristics of wastewater, which determine the methods and degree of treatment required. While, agricultural irrigation reuses, in general, require lower quality levels of treatment, domestic reuse options (direct or indirect potable and non-potable) reuses need the highest treatment level. Level of treatment for other reuse options lie between these two extremes.

(i) Reuse for Irrigation

Agricultural irrigation has, by far, been the largest reported reuse of wastewater. About 41 percent of recycled water in Japan, 60% in California, USA, and 15% in Tunisia are used for this purpose. In developing countries, application on land has always been the predominant means of disposing municipal wastewater as well as meeting irrigation needs. In China, for example, at least 1.33 million hectares of agricultural land are irrigated with untreated or partially treated wastewaters from cities. In Mexico City, Mexico, more than 70 000 hectares of cropland outside the city are irrigated with reclaimed wastewater. Reuse has advantages as well as disadvantages at each level.

Irrigation reuse of wastewater can be for application on agricultural crops, woodlots and pastures, or landscape and recreational areas. The choice of type of irrigation application generally depends upon the location and quantity of wastewater available for reuse. Potential constraints in this type of application are:

- surface and groundwater pollution, if poorly planned and managed
- marketability of crops and public acceptance
- effect of water quality on soil, and crops and
- public health concerns related to pathogens.

However, many research studies have shown that in addition to providing a low-cost water source, other side benefits of using wastewater for irrigation include increase in crop yields, decreased reliance on chemical fertilizers, and increased protection against frost damage in the ice region.

Modern reuse for irrigation of agricultural purposes in developed countries was the result of two pioneering studies that were conducted in California during the 1970s and 1980s. The Pomona virus study and the Monterey wastewater reclamation study for agriculture. The Pomona virus study was conducted in Los Angeles in an effort to determine the degree of treatment necessary to minimise potential transmission of waterborne diseases via surface water. The study concluded that complete virus removal is possible through tertiary treatment of wastewater by either direct filtration or activated carbon followed by adequate disinfection, thus proving the possibility for reclamation of "microbiologically risk free" water from wastewater. The results of this study have opened up the possibilities of wastewater reuse for various applications. Since the virus removal through treatment has been established by Pomona study, investigations of Monterey study concentrated on virus survival on crops and in soils in the field.

(ii) Irrigation of Landscape and Recreational Area

Application of reclaimed wastewater for landscape irrigation includes use in public parks, golf courses, urban green belts, freeway medians, cemeteries, and residential lawns. This type of application is one of the most common applications of wastewater reuse worldwide. Examples of such uses can be found in USA, Australia, Japan, Mexico and Saudi Arabia among others. These schemes have been operating successfully in many countries for many years without attracting adverse comments. This type of application has the potential to improve the amenity of the urban environment. However, such schemes must be carefully run to avoid problems with community health.

Because the water is used in areas that are open to public, there is potential for human contact, so reuse water must be treated to a high level to avoid risk of spreading diseases. Other potential problems of application for landscape irrigation concern aesthetics such as odour, insects, and problems deriving from build-up of nutrients

(iii) Domestic and Industrial Reuse

Reuse of wastewater for purposes other than irrigation may be either for:

- industrial reuse
- non-potable purposes
- indirect potable purposes or
- direct potable purposes.

(iv) Industrial Reuse

Industrial reuse of reclaimed wastewater represents major reuse next only to irrigation in both developed and developing countries. Reclaimed wastewater is ideal for many industrial purposes, which do not require water of high quality. Often industries are located near populated areas where centralised treatment facilities already generate reclaimed water. Depending on the type of industry, reclaimed water can be utilised for cooling water make-up, boiler feed water, process water etc. Cooling water make-up in a majority of industrial operations represents the single largest water usage. Compared to other purposes such as boiler feed and process water, the water quality requirements for industrial cooling is not generally high. Consequently, cooling water make-up presents a single largest opportunity for reuse. In Australia, considered the "driest continent" on earth, cooling water make-up would be attractive from the viewpoint of substantially lessening the demand for potable water by power stations. Operational problems encountered in cooling water recirculation systems are irrespective of the quality of make-up water used. They are scaling, corrosion, biological growth, and fouling.

A major problem associated with reuse of wastewater will be biofilm growth in the recirculation system. Presence of microorganisms (pathogens or otherwise) with nutrients such as nitrogen and phosphorus, in warm and well-aerated conditions, as found in cooling water towers, create ideal environments for biological growth.

(v) Non-Potable Domestic Reuse

Adequately treated wastewater meeting strict quality criteria, can be planned for reuse for many non-potable purposes. Non-potable reuse leads to reduction of water for consumption from other sources, and a reduction in wastewater flow rate. So, non-potable reuse schemes can avoid adverse environmental consequences associated with conventional water sources and wastewater disposal systems. Non-potable domestic reuse can be planned either within single households/building, or on a larger-scale use through a reticulation system meant only for use for non-potable purpose.

- *Systems for individual households/buildings/facilities:*

In many parts of the world, it has become apparent that it may not be possible to provide a centralised sewage collection facility for all the households, due to both geographic and economic reasons. Wastewater from individual dwellings and community facilities in such unsewered locations is usually managed by on-site treatment and disposal systems. Although a variety of onsite systems have been used, the most common system consists of a septic tank for the partial treatment of wastewater, and a subsurface disposal field for final treatment and disposal.

By segregating the “gray” sullage from “black” toilet wastes, potential for reuse with minimal treatment within the household enhances manifold. There are several different schemes for reusing gray water at the household levels. Where the gray water is not separated from toilet wastes, improvements in the quality of treated wastewater can be brought about by many alternative systems. One of the alternatives includes intermittent and re-circulating granular-medium filters. The effluent from a re-circulating filter has been found to be of such high quality, it can be used in a variety of applications, including drip irrigation. In Japan, the major in-house gray water reuse system is the hand basin toilets, which uses a hand basin set on the top of the cistern, so the water from hand washing forms part of the refill volume for toilet flushing. Hand basin toilets are reportedly installed in most new houses in Japan.

- *Large-scale non-potable reuse through a dual reticulation system:*

A dual reticulation system is the wastewater reuse concept for urban areas where a centralised sewage collection system is in place, on a large scale. This system supplies treated wastewater to houses, and commercial/official/shopping complexes through a separate water supply network, to be used primarily for toilet flushing, and irrigation of lawns. Thus, households will have two water supply lines, one for potable and human-contact use purposes, and the second for non-potable, non-contact uses such as toilet flushing, use in the yards and gardens etc., hence the name “dual reticulation system.”

(vi) Indirect Potable Reuse

Indirect potable reuse of treated wastewater may occur unintentionally, when wastewater is disposed into a receiving body of water that is used as a source of potable water supply. It can also be through planned schemes, such as that of Cerro del la Estrella sewage treatment plant in Mexico City. Here, treated wastewater which meets the criteria for potable reuse except for total dissolved solids, is diluted by water from other sources to meet these criteria, and used for potable purposes. Another planned indirect potable reuse can be through groundwater recharge of treated wastewater.

One of the earliest indirect reuse of treated wastewater can be traced back to a pilot study of the 1930s, in the city of Los Angeles. The study reported that secondary treated wastewater treated in a long chain of tertiary treatment processes including super chlorination, ferric chloride coagulation, sedimentation, sand filtration, and activated carbon filtration, has been infiltrated into ground up to 7–5 m above groundwater table in a dry river bed 2–5 km upstream from collection galleries for the municipal water system. In Arizona, USA, many cities and towns recharge their aquifers with urban wastewater to obtain “recharge credits,” which allows them to continue pumping their groundwater wells for municipal water supplies. Recharged water is recovered for use in drinking, irrigation and industrial purposes.

(vii) Direct Potable Reuse

Direct potable reuse means adding treated wastewater directly into the normal drinking water distribution system. Though the idea of such a wastewater reuse may be repugnant to many, technologically, direct potable reuse of treated wastewater has been feasible for many years. A classic example of wastewater reuse for direct potable purposes in an emergency happened in the 1950s in the town of Chanute, Kansas, USA. The Neosho River in eastern Kansas served as the sole water source of Chanute. Due to continuous drought for five years, surface flow of the river ceased in 1956. After considering all other alternatives, the river was dammed just below the town’s sewage outfall, and the treated wastewater was used to fill the potable water intake pool.

For five months, the city reused its sewage, circulating it some eight to fifteen times. Thanks to the elaborate sewage treatment as well as raw water, the bacteriological qualities were met. An epidemiological survey showed fewer cases of stomach and intestinal illness during recycle than in the following winter when Chanute was back to use as river water. Another famous example widely quoted for direct potable reuse of reclaimed water is the reclamation scheme adopted in Windhoek, capital city of Namibia, which was initiated in 1968. The city of Windhoek approached the limits of its conventional drinking water sources during the 1960s due to severe water shortage, as groundwater and surface water sources in the vicinity of the city had been fully harnessed. Therefore, in 1968, the city adopted a water reclamation scheme from domestic wastewater to supplement the potable water to the city. The scheme was well publicised and there has been no public opposition. The reclamation scheme was founded on the three basic premises for reclamation to succeed: diversion of industrial and other potentially toxic wastewater from the main wastewater stream, wastewater treatment to produce an effluent of adequate and consistent quality, and effluent treatment to produce acceptable potable water. In addition, it was considered that it is of utmost importance to develop a multi-barrier treatment sequence as a safeguard against pathogens.

The industrial wastewaters were diverted to be treated in separate small treatment plants, and only the industries that do not generate wastewater were allowed in areas were effluents merged with domestic sewage. The system went through a succession of modifications and improvements over the year. The wastewater is treated in two separate, consecutive treatment plants to potable standard. The first is the conventional biological treatment plant (activated sludge process) at Gammas to treat raw wastewater. This wastewater is discharged into a series of maturation ponds, from where the effluent gravitates directly to the water reclamation plant at Goreangab. The water reclamation plant consists of alum coagulation, dissolved air floatation, lime dosing, sedimentation, sand filtration, breakpoint chlorination, activated carbon filtration, and final chlorination.

(viii) Wastewater Sludge Reuse

Wastewater sludge is the solid/semi-solid substance, concentrated form of mainly organic, and some inorganic impurities (pollutants), generated as a result of treatment of wastewater. For any growing modern city, it is necessary to expand its sewage collection system to cater to the needs of the growing urban areas and its population. With the expansion of sewerage system comes the ever-increasing problem of how best the sludge generated in wastewater treatment facilities can be disposed. Disposal methods once used for sludge management, such as ocean disposal, are not environmentally appropriate. Though it is traditionally suggested that the sludge can be applied on land as soil conditioner and as fertilizer, there are many issues involved in handling and transportation, and odour nuisance, which are of concern.

Exprience in Europe and the USA have shown that land application/reuse of sludge options are the most promising ones that benefit the society. Sludge can be reused to reclaim parched land by application as soil conditioner, and also as a fertilizer in agriculture. Deteriorated land areas, which cannot support the plant vegetation due to lack of nutrients, soil organic matter, low pH and low water holding capacity, can be reclaimed and improved by the application of sludge. Sewage sludge has a pH buffering capacity resulting from an alkalinity that is beneficial in the reclamation of acidic sites, like acid mine spoils, and acidic coal refuse materials. Netherlands, Sweden, and Spain in Europe use more than 60% of sludge for agricultural purposes. Their experience shows that by following regulations and strict adherence to standards, adverse environmental effects of sludge application for agricultural purpose could be reduced to a minimum, thereby giving confidence to those who rely on them.

3.2 Motivational Factors for Recycling and Reuse

Major among the motivational factors for wastewater recycle/reuse are:

- Opportunities to augment limited primary water sources
- Prevention of excessive diversion of water from alternative uses, including the natural environment
- Possibilities to manage *in situ* water sources
- Minimisation of infrastructure costs, including total treatment and discharge costs
- Reduction and elimination of discharges of wastewater (treated or untreated) into receiving environment
- Scope to overcome political, community and institutional constraints.

Reuse of wastewater can be a supplementary source to existing water sources, especially in arid/semi-arid climatic regions. Most large-scale reuse schemes are in Israel, South Africa, and arid areas of USA, where alternative sources of water are limited. Even in regions where rainfall is adequate, because of its spatial and temporal variability, water shortages are created. For example, Florida, USA is not a dry area, has limited options for water storage, and suffers from water shortages during dry spells. For this reason wastewater reuse schemes form an important supplement to the water resource of this region.

Costs associated with water supply or wastewater disposal may also make reuse of wastewater an attractive option. Positive influences on treatment costs of wastewater and water supplies, and scopes for reduction in costs of head works and distribution systems, for both water supply and wastewater systems has been the motivation behind many reuse schemes in countries like Japan.

Reuse is frequently practiced as a method of water resources management. For example, depleted aquifers may be “topped-up” by injection of highly treated water, thus restoring aquifer yields or preventing saltwater intrusion (in coastal zones).

Avoidance of environmental problems arising due to discharge of treated/untreated wastewater to the environment is another factor that encourages reuse. While the nutrients in wastewater can assist plant growth when reused for irrigation, their disposal, in extreme cases, is detrimental to ecosystems of the receiving environment. In addition, there may be concerns about the levels of other toxic pollutants in wastewater.

Concern about water supply or environmental pollution may emerge as a political or institutional issue. Community concern about the quality of wastewater disposed to sensitive environments may lead to political pressures on the water industry to treat wastewater to a higher level before discharge that can be avoided through reuse of wastewater. Institutional structures may also provide incentives for reuse. Because responsibility for different parts of water use and disposal system may rest with different organisations, a water utility may also be faced with standards of service set in agreements with other industry bodies.

3.3 Issues in Wastewater Reuse and Recycling

- Despite a long history of wastewater reuse in many parts of the world, the question of safety of wastewater reuse still remains contentious mainly because of the quality of reuse water. There always have been controversies among the researchers and proponents of extensive wastewater reuse, on the quality the wastewater is to meet. In general, public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilisation, especially *long term impact of reuse practices*. It is difficult to delineate acceptable health risks and is a matter that is still hotly debated.

- Issues other than quality of reuse water include socioeconomic considerations, and hydro-geologic conditions. The socio-economic considerations include community perceptions, and the costs of reuse systems. Wide community level surveys in various States of Australia during early 1990s indicated that in general, public is not reluctant to the concept of wastewater recycling within the community. In one of such surveys, however, less than 15% readily agreed for potable reuse.

- Wastewater reuse has not been implicated as the cause of any infectious disease outbreaks. A more specific study of the city of St. Petersburg, Florida to estimate the potential risk to the exposed population concluded that:

- There is no evidence of increased enteric diseases in urban regions housing areas irrigated with treated reclaimed wastewater, and
- There is no evidence of significant risks of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water.

However, the study recommended that adequate treatment schemes must always be designed to eliminate, or at least minimize the potential risks of disease transmission.

- The economic considerations are necessary because, when "first-hand" water is available at a cheaper price, it may not be worthwhile to reuse wastewater, unless there are other special conditions. Consideration of hydro-geologic conditions helps to compare the reuse water quality and the quality of alternative sources intended for the same kind of use.
  Irrigation, for example is the highest water consuming activity in any country, and hence is the first option considered in any reuse planning. For example, 90 percent of available water supply in the Indian subcontinent, and a staggering 98 percent in Egypt, is used in irrigation.

3.4 Future of Water Reuse

As of now, major emphasis of wastewater reuse has been for non-potable applications. In spite of developing sound technological approaches to producing water of any desired quality from reclaimed wastewater, it has generally been too expensive to be taken seriously as a potable supply option. There are several other key issues that include evaluation of health risks associated with trace organic and inorganic contaminants in reclaimed water, application of membrane treatment processes in production of high quality reclaimed water, optimisation of treatment trains for wastewater reclamation projects to be cost-effective, that require additional research and demonstration for progress in reclaimed water reuse applications. There also is a psychological threshold that is keeping us at bay for reuse in portable applications, even when there are no other viable long-term options. If water reuse projects are to succeed, efforts to generate greater community awareness to judge water by its quality and not by its history and seeking their increased participation in such schemes will also be needed.

4.0 CONCLUSION

This unit concludes that though wastewater is spent water, it could still be recycled, reclaimed and reused.

5.0 SUMMARY

In this unit, we have learnt that:

- Wastewater can be reused
- Certain factors have necessitated the need to reclaim and reuse the spent water, and
- That there are issues to consider if and when wastewater will be reused.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe three ways by which wastewater can be reused.
2. State four motivating factors for wastewater reclamation and reuse.

7.0 REFERENCE/FURTHER READING

Vigneswaran, S. and Sundaravadivel, M. (2004). Recycle and Reuse of Domestic Wastewater, in Saravanamuthu V (Ed). *Encyclopedia of Life Support Systems (EOLSS),* UNESCO, Oxford: EOLSS Publishers, UK, http://www.eolss.net.

MODULE 3 PRINCIPLES OF WASTEWATER TREATMENT AND MANAGEMENT

UNIT 1 WASTEWATER TREATMENT AND GUIDELINE STANDARDS

CONTENTS

1.0 INTRODUCTION

With what you have learnt in the previous modules, l hope that you now have a little understanding of the need for adequate management of water – perhaps not for wastewater now; that will be treated later. This is better summarised by the statement that the *water sources are not always clean, and treating water to improve smell, taste, clarity, or to remove disease-causing pathogens in one form or another is often desired.* It is therefore the aim of this unit to take you into some water treatment issues that will provoke your thoughts. Meanwhile, it is very desirable that you begin by reviewing the history of drinking water treatment.

2.0 OBJECTIVES

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

- highlight some important historical events in water treatment
- evaluate some frequently used standards and guidelines for water use, and
- identify some methods of water treatment.

3.0 MAIN CONTENT

3.1 History of Water Treatment

It is not my wish to bother you with details of the history here. Nonetheless, I need you to understand the highlights below, with the intention of understanding why the need for water management, and how this was achieved in history. The information given here is as summarised from the USEPA Report in February 2000 obtained from www.epa.gov/safewater/sdwa25/sdwa.html.

- Ancient civilisations established themselves around water sources. While the importance of ample water *quantity* for drinking and other purposes was apparent to our ancestors, an understanding of water *quality* was not well known or documented.
- Although historical records have long mentioned aesthetic problems (an unpleasant appearance, taste or smell) with regard to drinking water, it took thousands of years for people to recognise that their senses alone were not accurate judges of water quality.
- Water treatment originally focused on improving the aesthetic qualities of drinking water. Methods to improve the taste and odour of drinking water were recorded as early as 4000 B.C. Ancient Sanskrit and Greek writings recommended water treatment methods such as filtering through charcoal, exposing to sunlight, boiling, and straining.
- Visible cloudiness (later termed turbidity) was the driving force behind the earliest water treatments, as many source waters contained particles that had an objectionable taste and appearance.
- To achieve water quality, the Egyptians reportedly used the chemical alum as early as 1500 B.C. to cause suspended particles to settle out of water. During the 1700s, filtration was established as an effective means of removing particles from water, although the degree of clarity achieved was not measurable at that time.
- By the early 1800s, slow sand filtration was beginning to be used regularly in Europe. During the mid to late 1800s, scientists gained a greater understanding of the sources and effects of drinking water contaminants, especially those that were not visible to the naked eye.
- In 1855, epidemiologist Dr. John Snow proved that cholera was a waterborne disease by linking an outbreak of illness in London to a public well that was contaminated by sewage. In the late 1880s, Louis Pasteur demonstrated the “germ theory” of disease, which

explained how microscopic organisms (microbes) could transmit disease through media like water.

- During the late nineteenth and early twentieth century's, concerns regarding drinking water quality continued to focus mostly on disease-causing microbes (pathogens) in public water supplies. Scientists discovered that turbidity was not only an aesthetic problem; particles in source water, such as fecal matter, could harbour pathogens. As a result, the design of most drinking water treatment systems built during the early 1900s was driven by the need to reduce turbidity, thereby removing microbial contaminants that were causing typhoid, dysentery, and cholera epidemics. To reduce turbidity, some water systems began to use slow sand filtration.
- While filtration was a fairly effective treatment method for reducing turbidity, it was disinfectants like chlorine that played the biggest role in reducing the number of waterborne disease outbreaks in the early 1900s. In 1908, chlorine was used for the first time as a primary disinfectant of drinking water in Jersey City, New Jersey, USA. The use of other disinfectants such as ozone also began in Europe around this time.
- Federal regulation of drinking water quality began in 1914, when the U.S. Public Health Service set standards for the bacteriological quality of drinking water. The standards applied only to water systems which provided drinking water to interstate carriers like ships and trains, and only applied to contaminants capable of causing contagious disease. The 1962 standards, regulating 28 substances, were the most comprehensive Federal drinking water standards in existence before the Safe Drinking Water Act of 1974.
- By the late 1960s it became apparent that the aesthetic problems, pathogens, and chemicals were not the only drinking water quality concerns. Industrial and agricultural advances and the creation of new man-made chemicals also had negative impacts on the environment and public health. Many of these new chemicals were finding their way into water supplies through factory discharges, street and farm field runoff, and leaking underground storage and disposal tanks. Although treatment techniques such as aeration, flocculation, and granular activated carbon adsorption (for removal of organic contaminants) existed at the time, they were either underutilised by water systems or ineffective at removing some new contaminants.

3.2 Guidelines and Standards for Water Quality

Typically, water quality is assessed by comparisons of water samples to water quality guidelines or standards. These guidelines and standards provide for the protection of human health, by ensuring that clean and safe water is available for human consumption.

There is a distinction between the two terms, *guidelines* and *standards*. The World Health Organisation's (WHO) Water Quality Guidelines provide international norms on water quality and human health that are used as the basis for regulation and standard setting, in developing and developed countries world-wide. These guidelines are adopted by many countries as national guidelines to follow, even if they are not necessarily enforceable by law. In contrast, drinking water quality standards are primarily set by nation states and can be enforceable by law. For example, the Environmental Protection Agency (EPA) of the United States of America has two sets of standards: the Primary Standards, that directly link human safety to drinking water and are enforceable by law, and the Secondary Standards, that relate to cosmetic and aesthetic effects and are not legally required.

Another example of binding standards is the Water Framework Directive set out by the European Union. Under Council Directive 98/83/EU, the Union provides Drinking Water parameters which include an obligation for EU member countries to inform the consumer on drinking water quality and measures that they can take to comply with the requirements of the Water Directive. EU members have agreed to comply with these parameters.

Many countries set drinking water quality guidelines based on the WHO guidelines but may modify these based on what is achievable in-country. For example, the financial requirements and infrastructure needed to monitor and assess drinking water quality can be limiting in some developing countries. For these and other reasons, the guidelines may also vary between rural areas and urban centres within a country.

3.3 Water Treatment Technology

Water treatment is used in many commercial operations, including food services, laundries, laboratories, pharmacies, and car washes. The type of treatment depends upon the application and the required water purity.

Treatment ranges from simple cartridge filtration to sophisticated systems that produce extremely pure water. For example, ice machines often have cartridge sediment and carbon filters installed on the make-up water, such that the ice is free of particles and chlorine taste. Some laboratories and the pharmaceutical and electronics industries, however, require "ultrapure water," which has had all but a few parts per billion of minerals, organics, and other substances removed through a train of treatment, including filtration, carbon filtration, softening, reverse osmosis, and strong acid/base ion exchange, followed by microfiltration and ultraviolet-light disinfection. Table 6 compares various treatments found in commercial operations.

Table 6: Different Water Treatment Options

	Treatment Process						
	Sediment Filtration	Carbon Filtration	Softening and Ion Exchange	Membrane Process	Distillation	Disinfection	Other Treatment Processes
All food service	X	X	X	X			X
All laundry & dry cleaning	X		X				
Hospital & Laboratory	X	X	X	X	X	X	X
Car Wash	X		X	X			
Beverage Manufacturing	X	X	X	X		X	
Metal Plating	X	X	X	X		X	X
Cooling Tower & Boiler	X		X	X		X	X
Pool, Spa & Water Feature	X					X	
Office & Non – Process	X	X	X			X	X

Source: www.bobvilla.com/howto_library

Each treatment technology offers unique opportunities for water conservation, as described below:

- **Sediment filtration** is one of the most common treatment techniques. Swimming pools, water feeds to commercial ice machines, cooling-tower side-streams, drinking- water and water-using medical equipment are but a few examples where sediment filters are found (e.g. Figure 5). They remove particles down to a few microns in size. The two basic designs use disposable cartridges or granular filter media.

By their nature, cartridge filters are usually not designed for very large flows. Sample uses include pre-filters for ice machines, smaller medical equipment, and smaller swimming pools and spas. Filter material varies from tightly wound fibers to ceramics, fused powdered-metals, or other materials. Such filters are left in place until the sediment buildup causes a predetermined increased pressure drop across the filter, at which time the filter is replaced, backwashed, or removed and cleaned for reuse.

The second type of sediment filter is often found where larger volumes of water must be processed or higher levels of sediment must be removed. These include granular media such as sand, coated media (cellulose, and perlite), and mixed-bed filters. All of these must be backwashed. The backwash water is generally discharged to the sanitary sewer. In some larger applications, however, the sediment can be allowed to settle out and the clarified water can be reintroduced at the head of the filtration process. Common applications include swimming pools, industrial water treatment, and side-stream filtration for cooling towers.

Fig. 5: An Example of Sediment Filter: A Culligan Heavy-Duty Whole House Filter
(Source: www.bobvila.com/howto_library)

- *Carbon filtration* removes chlorine, taste, odour, and a variety of organic and heavy-metal compounds from water by adsorption. Activated carbon, which has an enormous surface area per unit volume, attaches to the unwanted materials and holds them on its surfaces. Restaurants and food service providers for hospitals and other institutional operations often use activated carbon for drinking water and ice-machine feed water. It is also used in the beverage industry for taste and odour control. Activated carbon is also used to remove pollutants in the metal-finishing industry and other operations where pretreatment to remove metals or organics is needed. These systems can employ either disposable cartridges or packed columns, where the activated carbon can be removed and sent for recharge. With both cartridge and packed-column systems, water simply pass through the carbon medium until its adsorptive capacity is used up.

- *Water softening* employs zeolites or ion exchange resins, where calcium and magnesium ions are exchanged for sodium or potassium ion. Softening removes hardness to control scale, improves water for washing, and prevents "hard water" spots. Recharge is done with a salt solution containing sodium or potassium cations, the most common being sodium chloride (table salt). Water is used in the recharging process to make up the brine solutions and to purge the softener of brine prior to being returned to service. All softener systems should be equipped with controllers that are activated based upon the volume treated, not on timers. (e.g. Figure 6) They should either be adjusted for the hardness of the water supply or be equipped with a hardness controller that actually measures the hardness and volume treated, if the hardness of the feed water varies.

Softeners are commonly found where hardness interferes with water use or where scale formed by hard water could be detrimental. Laundries, car wash, boiler feed-water, laboratory water, hot-water systems for restaurants and food-service establishments, and metal-plating operations commonly employ softening. It is used occasionally for cooling-tower feed-water or in a process called side-stream softening, which helps extend the usefulness of cooling-tower water. Deionization also employs exchange resins, but it is different from softening. Strong acid/base ion-exchange resins, known as deionization resins, are used to produce extremely pure water for laboratory analysis, kidney dialysis, and feed-water for a number of industrial processes. Water use is similar to that for recharging softening systems, but the discharge water can be much more corrosive. Controls should be based upon the chemistry of the feed water and volume treated, not on timers. Ion-removal systems operate similarly to ion-exchange systems and have similar water-use patterns. Ion exchange resins can also remove a variety of ionic contaminants, such as arsenic or fluoride.

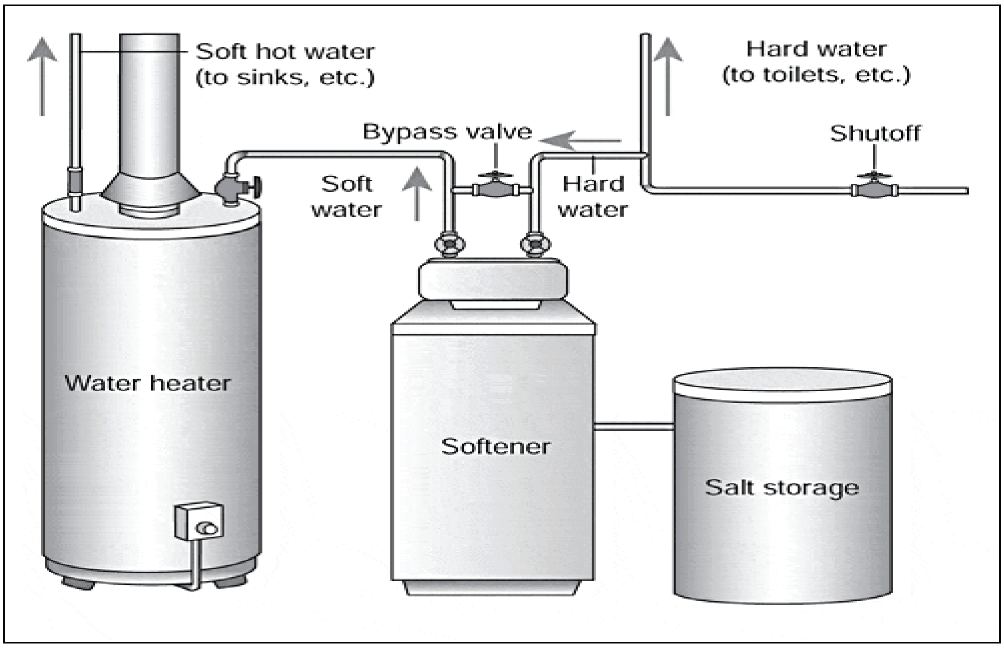

Fig. 6: A Water Softening System
(Source: www.bobvila.com/howto_library)

- *Membrane processes* include several water-treatment methods. A membrane, usually composed of a polymer material, is used to remove contaminates. All membrane processes have three things in common:

- There is a feed stream, a retentate or waste stream, and products called permeate. The type of membrane process used depends upon the size or type of contaminant one wishes to remove.

- Microfiltration employs membranes that remove particles of 0.1 to 10 microns in size or larger. It is used in municipal water treatment to remove bacterial and *Giardia lamblia* cysts, and *Cryptosporidium* oocysts. Water is forced through the membrane until the pressure drop reaches a set point. The filter is then backwashed. The membranes also require periodic chemical cleaning. Both the backwash and cleaning processes use water. Retentate or waste volumes are usually a small percentage of the total feed volume. The retentate is often reticulated and only a small stream of "bleed water" is discharged as wastewater. Some ceramic filters can also filter in this range.

- Ultra filtration operates at higher pressures than microfiltration and removes materials that are much smaller, including viruses and proteins. It is often used to separate milk and whey. These filters must be backwashed and cleaned in a manner similar to microfiltration membranes.

- Nanofiltration membranes have pore sizes midway between those of ultra filtration and reverse osmosis. Nanofilters are often referred to as "softening" filters, since they are effective in removing multivalent cations such as calcium and magnesium.

- Reverse osmosis (RO) removes salts from a water stream (Figure 7). It finds use wherever very pure water is needed, such as laboratories, medical uses including kidney dialysis, metal plating, boiler feed-water, and a number of related applications. Typically, RO will reject 90 to 95 percent of the salts. RO is also used before strong acid/base deionization for the production of ultrapure water for laboratory, pharmaceutical, and microelectronics manufacturing operations.

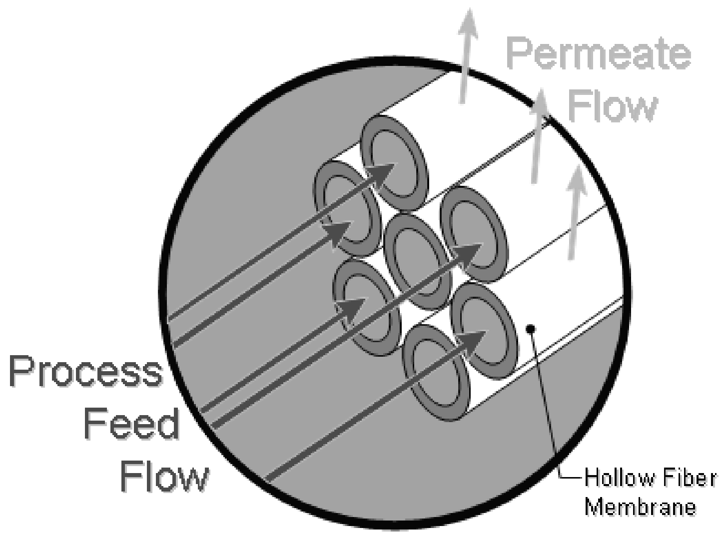

Fig. 7: Permeate/Feed-Stream/ Retentate Diagram

Source: www.kochmembrane.com

- *Distillation*, a process once in common use to make water for laboratory applications, is still found in many laboratories. Electric or gas stills are used. Production quantity depends upon the size of the still. Smaller stills often use once-through condenser water and can waste huge volumes of water to produce a single gallon of distillate. Small and medium size stills use air to cool the coils and have no discharge. These are the most water-efficient stills. Some larger stills have reject streams to prevent scale buildup. These typically dump 15 to 25 percent of the water entering the still.

- *Disinfection and other technologies* can consume small amounts of water, if chemicals are fed in a liquid or slurry form. Chemical disinfection technologies include use of chlorine compounds, ozone, and hydrogen peroxide, as well as pH control with acids and bases and the addition of antiscalants and sequestrates such as sodium hexameter phosphate. Ultraviolet light, heat, and extreme mechanical sheer are among other technologies in use. It is important to examine disinfection requirements. Ultraviolet light, heat, and mechanical sheer processes do not use water. Other processes use water to make up the solutions, but this becomes part of the product water and is not lost. However, cleaning chemical storage areas does consume water. The potential for water savings by choosing among disinfection technologies is not great; however, the potential to waste water in cleaning the equipment and storage vessels is a concern which use of waterless methods can lessen

4.0 CONCLUSION

Contaminated water is not desirable for consumption but could be treated to make it consumable. A number of approaches have been discussed.

5.0 SUMMARY

In this unit, we have learnt that:

- Methods to improve the taste and odour of drinking water were recorded as early as 4000 B.C.
- Water quality is assessed by comparisons of water samples to water quality guidelines or standards
- Water treatment is used in many commercial operations, including food services, laundries, laboratories, pharmacies, and car washes.
- Water treatment ranges from simple cartridge filtration to sophisticated systems that produce extremely pure water.

6.0 TUTOR-MARKED ASSIGNMENT

1. Draw a well labeled diagram of a water softening system.
2. Highlight five historical events in water treatment to date.
3. Differentiate between water standards and guidelines.

7.0 REFERENCES/FURTHER READING

Klenck, T. (2009). *How Softeners Work*. Ahdorma Water Filters Purification and Treatment www.thewatersite.com/how_they_Work_Water_softeners.htm.

APS Water Services Corporation (2009). www.apswater.com

UNIT 2 POTABLE WATER PARAMETERS AND TREATMENT SYSTEMS

CONTENTS

1.0 INTRODUCTION

If your home water comes from a public water supply, it has been tested and meets the Environmental Protection Agency standards for drinking water. If you use a private well, however, you are responsible for assuring that the water is safe to drink. This means that you should periodically have your water tested, make sure your well is in proper condition without faulty well caps or seals, and identify and remove potential sources of contamination to your well such as leaking septic systems or surface contamination. With a private well, you are also responsible for any treatment your water may need if it contains harmful pollutants or contaminants that affect the taste, odour, corrosiveness or hardness of the water.

2.0 OBJECTIVES

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

- define potable water
- differentiate between palatable and potable water
- identify the characteristics of potable water.

5.0 MAIN CONTENT

3.1 What is Potable Water?

According to Academics Dictionary of Geography (Lohda, 2007), potable water is water of quality acceptable for human consumption and initially free from, or treated to remove tastes and odour, dissolved solids, suspended solids and pathogens.

3.2 Difference between Palatable Water and Potable Water

The goal of municipal water treatment is to provide water that is both palatable and potable. Palatability of water is usually regulated under the Secondary Maximum Contaminant Levels (SMCLs) (Table 8) of the US Safe Drinking Water Act while portability is usually regulated under Primary Maximum Contaminant Levels (MCLs) (Table 9)

Potable water should be safe to drink, but not necessarily aesthetically pleasing. Portability could also be affected by microbial (e.g. Giardia, Cryptosporidium), organic chemicals (e.g., alachor, chlordane, cis-1, 2-dichloroethylene, and disinfection by-products), inorganic chemicals (e.g., cadmium, copper, lead, mercury), and radionuclide.

Palatable water should be aesthetically pleasing. It considers the presence of chemicals that do not pose a threat to human health. Palatability of water is usually affected by chloride, colour, corrosivity, iron, manganese, taste and odour, total dissolved solids, turbidity.

Table 7: Secondary Maximum Contaminant Levels (SMCLs)

Contaminant	Level	Contaminant effects
Aluminum	0.05–0.2 mg/L	Water discoloration
Chloride	250 mg/L	Taste, pipe corrosion
Color	15 color units	Aesthetic
Copper	1 mg/L	Taste, porcelain staining
Corrosivity	Noncorrosive	Pipe leaching of lead
Fluoride	2.0 mg/L	Dental fluorosis
Foaming agents	0.5 mg/L	Aesthetic
Iron	0.3 mg/L	Taste, laundry staining
Manganese	0.05 mg/L	Taste, laundry staining
Odor	3 threshold odor number	Aesthetic
pH	6.5–8.5	Corrosive
Silver	0.1 mg/L	Skin discoloration
Sulfate	250 mg/L	Taste, laxative effects
Total dissolved solids	500 mg/L	Taste, corrosivity, detergents
Zinc	5 mg/L	Taste

Table 8: Primary Maximum Contaminant Levels (PMCLs)

Inorganic Chemicals

Arsenic	0.05	Mercury	0.002
Barium	2.	Nickel	0.1
Cadium	0.005	Nitrate (as N)	10.
Chromium (total)	0.1	Nitrite (as N)	1.
Copper	TT	Nitrate + nitrite	10.
Fluoride	4.0	Selemium	0.05
Lead	TT	Thallium	0.002
Asbestos	7 million fibers/liter (longer than (10 μm)		

Volatile Organic Chemicals

Benzene	0.005	Ethylbenzene	0.7
Carbon tetrachloride	0.005	Monochlorobenzene	0.1
p-Dichlorobenzene	0.075	Tetrachloroethylene	0.005
o-Dichlorobenzene	0.6	1,2,4-Trichlorobenzene	0.07
1,2-Dichloroethane	0.005	1,1,1-Trichloroethane	0.2
1,1-Dichloroethylene	0.007	1,1,2-Trichloroethane	0.005
cis-1,2-Dichloroethylene	0.07	Trichloroethylene	0.005
trans-1,2-Dichloroethylene	0.1	Vinyl chloride	0.002
1,2-Dichloropropane	0.005		

Synthetic Organic Chemicals

Acrylamide	TT	Glyphosate	0.7
Adipate (diethylhexyl)	0.4	Heptachlor	0.0004
Alachlor	0.002	Heptachlor epoxide	0.0002
Atrazine	0.003	Hexachlorobenzene	0.001
Benzo-a-pyrene	0.0002	Hexachlorocyclopentadiene	0.05
Carbofuran	0.04	Lindane	0.0002
Chlordane	0.002	Methoxychlor	0.04
Dalapon	0.2	Oxylamyl (Vydate)	0.2
Dibromochloropropane	0.0002	Pentachlorophenol	0.001
Di(ethylhexyl)adipate	0.4	Picloram	0.5
Di(ethylhexyl)phthlate	0.006	Polychlorinated byphenyls	0.0005
Dichloro-methane	0.005	Simazine	0.004
Dinoseb	0.007	Styrene	0.1
Diquat	0.02	Toluene	1.
Endothall	0.1	Toxaphene	0.003
Endrin	0.002	Xylenes (total)	10.
Epichlorohydrin	TT	2,4-D	0.07
Ethylene dibromide	0.00005	2,4,5-TP (Silvex)	0.05
2,3,7,8-TCDD (Dioxin)	0.00000003		

Disinfection By-Products (interim)

Total trihalomethanes	0.10

Radionuclides

Radium 226	20 pCi/L	Beta particle and photon radioactivity	4 mrem/yr
Radium 228	20 pCi/L	Radon	300 pCi/L
Gross alpha particle activity	15 pCi/L	Uranium	20 μg/L

3.3 Properties of Potable Water

Table 9 details some international set of guidelines or standards (i.e. WHO, EU and US guidelines) for potable water. Any water or source of water that contains these properties above the recommended limits is considered unsafe for consumption. Table 10 contains some standards for different stage of consideration for potable water treatment.

Table 9: Some Water Quality Guidelines and Standards

Standards	WHO	US	European Standards
	(MgL^{-1} except otherwise stated)		
Parameters			
Alkalinity			
Calcium			
Arsenic	0.01	0	0.01
Cadmium	0.003	0.005	0.005
Chloride	250	250	250
Chromium	0.05	0.1	0.05
Cadmium	0.003	0.005	0.005
Conductivity	250 µS cm^{-1}		250 µS cm^{-1}
Copper	2	1.3	2
Cyanide	0.07	0.2	0.05
E. Coli		0/250ml	
Fluoride	1.5	2	1.5
Iron		0.3	0.2
Lead	0.01	0	0.01
Magnesium			
Manganese	0.5	0.005	0.005
Mercury	0.001		0.001
Nitrate		50	10
Nitrite		1	0.5
pH		6.5 – 8.5	
Sodium	200		200
Sulphate	500	250	250
Salinity			
TDS		500	
TSS			
Turbidity			
Zinc	3	5	

Columns not filled are either not available or unknown
Source: UNEP GEMS/Water Programme (2006)

Table 10: Limitation Guidelines for Different Treatment of Potable Water

Parameters	*Class A*	*Class B*	*Class C*
DO (mg/L)	50% > 9	50%>9	50% > 8
BOD(mg/L)	<3	<5	<7
Phosphate(mg/L)	<10	<20	<50
Sulphate (mg/L)	<150	<150	<150
Chloride (mg/L)	<150	<150	<150
Nitrate (mg/L)	<5	<5	<5
Lead (mg/L)	<5	<10	<25
Zinc (mg/L)	<5	<5	<10
Ph	6.5 – 8.5	6.5 – 8.5	6 -9
Conductivity (uScm/m)	<1000	<1000	<1000

Class A: *drinking water supply requiring simple physical treatment and disinfection*

Class B: *drinking water supply requiring normal physical treatment and disinfections*

Class C: *drinking water supply requiring physical and intensive chemical treatment, extended treatment and disinfection*

Source: Chiaudani and Premazzi (1988)

4.0 CONCLUSION

You have learnt in this unit about what the raw water undergoes before it becomes potable, i.e. consumable.

5.0 SUMMARY

In this unit, we have learnt that:

- Potable water is water of the quality acceptable for human consumption and initially free from, or treated to remove tastes and odour, dissolved solids, suspended solids and pathogens
- A set of guidelines exist internationally to guide the chemical content of water for potable use

6.0 TUTOR-MARKED ASSIGNMENT

1. Define potable water and give the standard limits of some of its chemical properties.
2. Differentiate between class A and class B water sources based on given guidelines and standards

7.0 REFERENCES/FURTHER READING

USEPA (2000). *Drinking Water Treatment, A Detailed Examination of Municipal Drinking Water Treatment Methods*, United States Environmental Protection Agency, USA. www.epa.gov/safewater/faq/treatment.pdf

USEPA (2000). *Drinking Water and Health: What You Need to Know, Overview of Potential Contaminants in Drinking Water and Related Health Effects*, United States Environmental Protection Agency, USA., http://www.epa.gov/safewater/dwh/dw-health.pdf

UNIT 3 STRUCTURE OF A TYPICAL WATER TREATMENT PLANT

CONTENTS

1.0 INTRODUCTION

The sources of water have been treated earlier, in ESM 223, Water Resources Evaluation, as including surface, ground and atmospheric water sources. Although some of these water sources are expected to be pristine but they are not. Therefore, disinfection of the water is recommended; the reasons for this have been highlighted in the first module, you may need to revise them. This unit does not intend to re-emphasise the fact that untreated water is both aesthetically and hygienically unacceptable in any part of the world. Instead, it emphasises some expectations of a typical water treatment plant.

2.0 OBJECTIVES

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

- describe the water treatment system or cycle
- sketch and describe a typical water treatment plant
- highlight the objectives of water treatment
- discuss some water treatment processes.

3.0 MAIN CONTENT

3.1 Water Treatment System or Cycle

Figure 8 shows the water treatment system. From the surface and groundwater sources to water treatment plants, the water is made useful. The useful potable and palatable water is distributed to houses, industries and institutions for use. Wastewaters are later generated and this has to be disposed, recycled or reused before the effluent is discharged back into the stream to continue the system. This is known as the water treatment system or cycle.

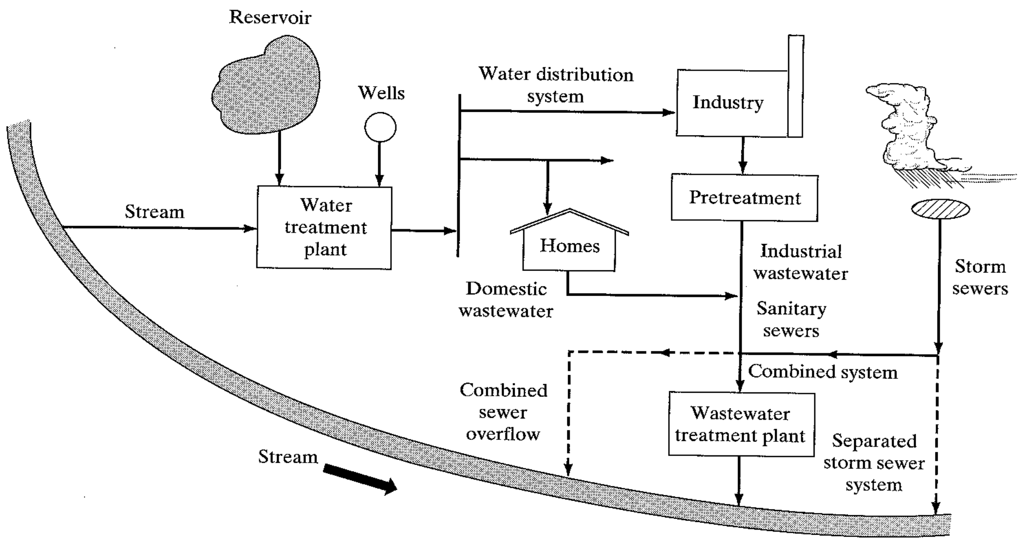

Fig. 8: Water Treatment System or Cycle

3.2 A Typical Water Treatment Plant

Figure 9 shows the configuration of a typical water treatment plant.

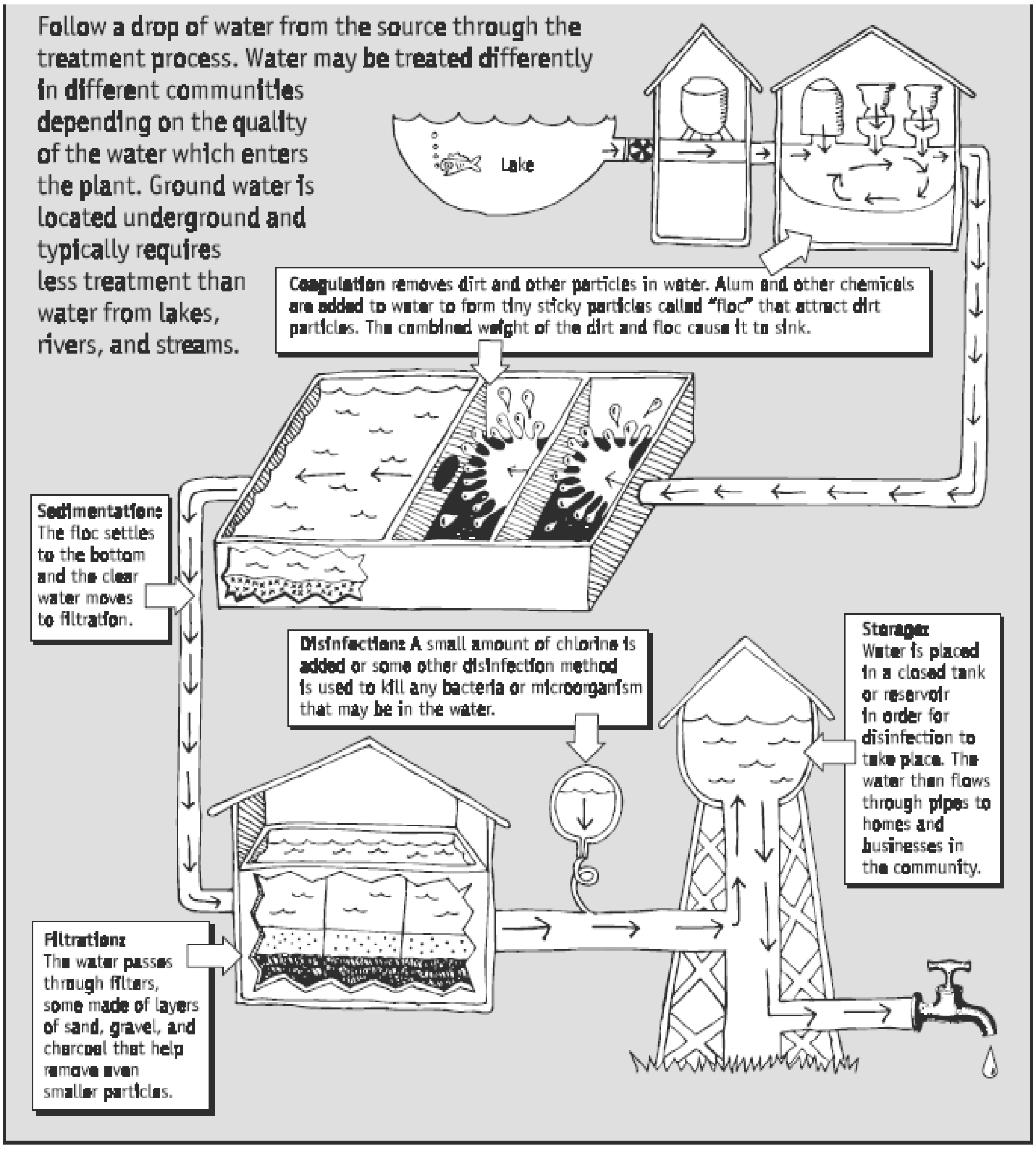

Fig. 9: A Typical Water Treatment Plant

Source: http://www.epa.gov/safewater/sdwa25/sdwa.html

3.3 Objectives of Water Treatment

A number of reasons have been given for the different stages of water treatment. The following are the more popular reasons. For surface water sources, the treatment technologies are largely based on coagulation and flocculation; and are basically to remove suspended material (turbidity) and color, and eliminate the pathogenic organisms that such water may contain. The objective of treating the groundwater supply is commonly to remove hardness and other minerals, as well as to eliminate the pathogenic organisms.

3.4 Water Treatment Processes

In general, the treatment of drinking water by municipal water systems involves a few processes:

- **Aeration**: The water is mixed to liberate dissolved gases and to suspended particles in the water column.

- **Flocculation**: The materials and particles present in drinking water (clay, organic material, metals, and microorganisms) are often quite small and so will not settle out from the water column without assistance. To help the settling process along, "coagulating" compounds are added to the water, and suspended particles "stick" to these compounds and create large and heavy clumps of material.

- **Sedimentation**: The water is left undisturbed to allow the heavy clumps of particles and coagulants to settle out. A typical sedimentation basin looks as represented in Figure 10.

Fig. 10: A Sedimentation Basin

- **Filtration**: The water is run through a series of filters which trap and remove particles still remaining in the water column. Typically, beds of sand or charcoal are used to accomplish this task (Fig. 11)

Fig. 11: Slow Sand Filtration
Drained slow sand filter in foreground
Operating slow sand filter in background

- **Disinfection**: The water, now largely free of particles and microorganisms, is treated to destroy any remaining disease-causing pathogens. This is commonly done with chlorination (the same process used to eliminate pathogens in swimming pools), ozone, or ultraviolet radiation. The water is now safe to drink and is sent to pumping stations for distribution to homes and businesses.

Advanced Treatment

For water sources that are heavily contaminated, extensive chemical treatment and disinfection are expected. Examples of such advanced treatment are as follows:

- **UV Radiation**

This type of water treatment uses a mercury arc lamp to kill pathogens in the water. Ultraviolet (UV) radiation kills most bacteria and some viruses, but is ineffective against cysts (such as *Giardia*) and worms. Cloudy or turbid water can reduce the effectiveness of UV radiation. UV lamps should be replaced annually or as suggested by the manufacturer, as they become less effective with time.

- **Ozonization**

Ozone occurs naturally in our atmosphere; in fact the ozone layer in our atmosphere protects us from ultraviolet radiation coming from the sun. In ozonization of water, electrically generated ozone kills bacteria and some other pathogens, and removes some pesticides. In combination with an activated carbon or mechanical filter, ozonization oxidizes and precipitates out iron, sulfur, and manganese. Ozone does not produce any taste or odour in the water. Ozone generators are relatively expensive to install. Ozonization does not have any residual effect in the water, unlike chlorination.

- **Activated Carbon**

Activated carbon filters absorb organic compounds and remove them from the water. These filters can remove volatile organic compounds, some pesticides, radon gas, hydrogen sulphide, mercury, and residual chlorine. Activated carbon filters are often used in combination with other water treatments such as reverse osmosis, chlorination, and ozonization. There are different types of activated carbon filters. Granular activated carbon (GAC) composed of loose granules of carbon, has some problems associated with their use. GAC filters accumulate the organic impurities they remove from the water, but these impurities can then become food for bacteria. Also, the filter can become saturated with organics, which are then released back into the water. Finally, channels can form between the granules in the filter, which reduces contact time between the water and carbon, resulting in less effective filtration. Solid block activated carbon filters (SBAC) are a solid compressed block of activated carbon. In addition to removal of chemicals mentioned above, the carbon is so tightly compressed that it can filter out some cysts such as Giardia and Cryptosporidium. Because SBAC filters are so fine, they easily become plugged with particulate matter, and frequently need to be replaced. They are also more expensive than granular activated carbon filters. Inadequately maintained carbon filters can become breeding grounds for bacteria, so the filters need to be kept clean and replaced as recommended by the manufacturer. If a carbon filter is unused for several days, run water through it for at least 30 seconds to flush any bacteria.

6.0 CONCLUSION

This unit has highlighted the structure and nature of water treatment in a typical water treatment plant.

5.0 SUMMARY

In this unit, we have learnt that:

- The objectives of water treatment include removal of suspended material (turbidity), colour and elimination of the pathogenic organisms that such water may contain
- Water treatment techniques include aeration, filtration, flocculation, etc.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the water treatment cycle.
2. Sketch a typical water treatment plant.

7.0 REFERENCES/FURTHER READING

APS Water Services Corporation (2009). www.apswater.com

Klenck, T. (2009). *How Softeners Work*. Ahdorma Water Filters Purification and Treatment www.thewatersite.com/how_they_work_water_softeners.htm.

MODULE 4 PRINCIPLES OF WASTEWATER MANAGEMENT TECHNIQUES

UNIT 1 WASTEWATER TREATMENT OPTIONS

CONTENTS

1.0 INTRODUCTION

The required treatment is determined by the influent characteristics, the effluent requirements, and the treatment processes that produce an acceptable effluent. Influent characteristics are determined by laboratory testing of samples from the waste stream or from a similar waste stream, or are predicted on the basis of standard waste streams. Effluent quality requirements are set by Federal, Interstate, State, and Local regulatory agencies. Treatment processes are selected according to influent-effluent constraints and technical and economic considerations.

2.0 OBJECTIVES

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

- describe the techniques for treating biodegradable wastes and
- non-biodegradable wastes.

3.0 MAIN CONTENT

3.1 Treating Biodegradable Wastewaters

Biodegradable wastewaters can come from domestic, institutional, commercial outfits and also from industries (especially industries dealing in food, beverages, including beer, starch, flavouring, soft drinks, flour and grain milling, meat/poultry/fish products, fruit juices, cocoa/chocolate/confectionery, sugar distillery, etc).

All things being equal, these wastewaters can be treated by biological means whereby action of microorganisms is used under suitably controlled conditions to break down the waste. Microorganisms can break down wastewater solids under aerobic or anaerobic conditions. Aerobic systems, biodegradable wastewater solids are converted, in the presence of adequate oxygen into bacterial cells:

$$\textit{Wastewater Solids} + \textit{Oxygen} \xrightarrow{\textit{bacteria}} \textit{Oxidized wastes} + \textit{New Bacteria Cells}$$

Biological systems available for treating biodegradable wastewaters, from the crudest to the most modern may be listed as follows:

- Latrine (individual household use)
- Bushrine (pronounced as lat-rine)
- Septic tank and soak-away system
- Trickling filters
- Activated sludge
- Lagoons

Most of these have been discussed earlier. Please try to read the unit again if you have forgotten them.

3.2 Treating Non-Biodegradable Wastewaters

Wastes that are non-biodegradable or that are outright toxic may not be amenable to treatment by any of the biological system earlier described. Examples of such wastewaters are those from textiles, lead – acid battery manufacturing, paint, printing, etc.

Each non-biodegradable wastewater is usually subjected to laboratory analysis and reliability studies before a treatment system is developed for it. Treatment of such wastes may involve a combination of the following physiochemical system:

- pH adjustment
- aeration
- chlorination (bleaching action)
- coagulation/flocculation (alum with mixing action)
- sedimentation
- centrifugation

- flotation
- filtration (using activated carbon and / or sand over gravel).

Table 11 illustrates the applicable processes and the possible performance of most of the available techniques. All the identified methods will be used for guidance in selecting a process chain of treatment units, which applies directly to the selection of treatment processes.

Generally, wastewater techniques are classified under the following sub – headings in the table as follows (see also Figure 12):

- **Preliminary Treatment**

Preliminary treatment is defined as any physical or chemical process at the wastewater treatment plant that precedes primary treatment. Its function is mainly to protect subsequent treatment units and to minimize operational problems. Pre-treatment at the source to render a wastewater acceptable at the domestic wastewater treatment facility is not included.

- **Primary Treatment**

Primary treatment is defined as physical or, at times, chemical treatment for the removal of settleable and floatable materials.

- **Secondary Treatment**

Secondary wastewater treatment is defined as processes which use biological and, at times, chemical treatment to accomplish substantial removal of dissolved organics and colloidal materials. Land treatment can be classified as secondary treatment only for isolated locations with restricted access and when limited to crops which are not for direct human consumption.

- **Advanced Wastewater Treatment**

Advanced wastewater treatment is defined as that required to achieve pollutant reductions by methods other than those used in conventional treatment (sedimentation, activated sludge, trickling filter, etc.). Advanced treatment employs a number of different unit operations, including ponds, post-aeration, micro straining, filtration, carbon adsorption, membrane solids separation, and specific treatment processes such as phosphorus and nitrogen removal.

Advanced wastewater treatment is capable of very high effectiveness and is used when necessary to meet strict effluent standards. Organics and suspended solids removal of over 90 percent is obtainable using various combinations of conventional and advanced wastewater treatment processes. Phosphorus levels of less than 1 milligram per liter and total nitrogen levels of 5.0 milligrams per liter or less can also be reached through advanced treatment.

Table 11: Wastewater Treatment Methods, their Applications and Efficiency

Treatment Process	Application	Advantages and Capabilities	Disadvantages and Limitations
Preliminary			
a. Equalization	Wastewaters with high variability	Dampers waste variation Reduces chemical requirements Dampens peak flows, reduces treatment plant sites	Need large areas Possible septicity, requiring mixing and/ or aeration equipment
b. Neutralisation	Wastewaters with extreme pH values	Provides the proper conditions for biological, physical and chemical treatment	May generate solids
c. Temperature adjustment	Waste streams with extreme temperatures	Provides the proper conditions for biological treatment	High initial equipment costs
d. Nutrient addition	Nutrient deficient wastes	Optimizes biological treatment	Possible septicity, requiring mixing and/ or aeration equipment
e. Screening	Waste streams containing large solids (wool, rags, etc)	Prevents pump and pipe clogging Reduces subsequent solids handling	Maintenance required to prevent screen plugging, ineffective for sticky solids
f. Grit removal	Wastewaters containing significant amounts of large, heavy solids	Lowers maintenance costs, erosion	Solids to be disposed of are sometimes offensive

Primary Treatment			
a. Sedimentation	Wastewaters containing settle able suspended solids	Reduces inorganic and organic solid loadings to subsequent biological units By far the least expensive and most common method of solid – liquid separation Suitable for treatment of wide variety of wastes Requires a simpler equipment and operation Demonstrated reliability as a treatment process	Possible septicity and odours Adversely affected by variations in the nature of the waste Moderately large area requirement
b. Dissolved-air floatation	Wastewaters containing oils, fats, suspended solids and other floatable matter. Can be used for either clarification or thickening	Removes oils, greases and suspended solids Less tank areas than for a sedimentation tank Higher concentration of solids than for sedimentation Satisfies immediate oxygen demand. Maintenance aerobic conditions	High initial equipment costs Sophisticated equipment and instrumentation High power and maintenance cost
Secondary Treatment			
a. Activated sludge (aeration and secondary sedimentation)	Biologically treatable organic wastes	Flexible – can adapt to minor pH, organic and temperature changes Produces high quality effluent – 90% BOD and suspended solids removal Small area required Available in package units The degree of nitrification is	High operating costs (skilled labour, electricity, etc.) Generates solids requiring sludge disposal Some process alternatives are sensitive to shock loads, and metallic or other poisons Requires

		controllable Relatively minor odor problems	continuous air supply
b. Aerated Pond (with secondary sedimentation)	Biologically treatable organic wastes	Flexible – can adapt to minor pH, organic and temperature changes Inexpensive construction Requires minimum attention Moderate effluent (80 – 90% BOD Removal)	Dispersed solids in effluent Affected by seasonal temperature variations Operating problems Moderate power costs Large area required No colour reduction
c. Aerobic Anaerobic Ponds	Biologically treatable organic wastes	Low construction costs Non – skilled operation Moderate quality (80 – 95% BOD Removal) Removes some nutrients from wastewaters	Large land area required Algae in effluent Possible septicity and odors Weed growth, mosquito and insect problems
d. Trickling filter	Biologically treatable organic wastes	Moderate quality effluent (80 – 90% BOD Removal) Moderate operating costs (lower than activated sludge and higher than oxidation pond) Good resistance to shock loads	Clogging of distributors or beds Snail, mosquito and insect problems
e. Chemical oxidation	Low flow, high concentration wastes of known and consistent waste composition, or removal of refractory compounds	Disinfects effluent Aids grease removal Removes taste and odour Removes organics without producing a residual waste concentrate	Chemical costs High initial equipment costs Skilled operations Requires handling of hazardous chemicals
f. Chemical	Wastewater	Removes metallic	Sophisticated

mixing flocculation and clarification	high in dissolved solids, colloids, metals, or perceptible inorganic and waste containing emulsified oils.	ions, nutrients, colloids, dissolved salts Recovery of valuable materials Provides proper conditions for biological treatment	equipment and instrumentation Residual salts in effluent Produces considerable sludge
g. Gravity filtration	Wastewaters with organic or inorganic suspended solids, emulsions, colloids	Breaks emulsions Removes suspended solids	Clogging Frequent backwashing High pressure costs
h. Pressure filtration	Wastewater high in suspended solids (i.e. sludge, organic solids)	High solids removal (190 – 95%)	High pressure coasts Clogging High pressure drop (power costs)
i. Dissolved air floatation with chemicals	Wastewaters containing oils, fats, colloids and chemically coalesced materials	Produces high degree of treatment Removes oils, greases	High initial equipment costs High operation cost Sophisticated instrumentation
j. Anaerobic contact	Wastewaters with high BOD and/or high temperature	Methane recovery Small area required Volatile solids destruction	Heat required Effluent in reduced chemical form requires further treatment Requires skilled operation
Advanced Wastewater Treatment			
a. Activated Carbon Adsorption	Wastewater containing trace amounts of organics and colour, taste and	Removes non biodegradable organics from wastewaters Removes taste and odour producing	High equipment costs Carbon costs – a. pH adjustment, b. initial carbon, c. make –up carbon

	odour producing compounds	compounds Reduces colour	No inorganic removal Wastes must be solid free to prevent clogging Air pollution potential when regenerating activated carbon Limited throughput
b. Micro straining filtration	Tertiary treatment	Up to 89% of suspended solids removed Can produce final effluent of solids less than 10mg/L	Very sensitive to solids overloading Requires automatic controls, absorbent techniques
c. Land treatment	Biologically treatable wastes with low to moderate amounts of toxic substances	Inexpensive Minimum operator attention, minimum sludge Waste conservation Crop production Very high quality effluent and/or in discharge	Large land area required Possible contamination of potable aquifers Freezing in winter Odours in summer under some conditions, usually of minor concern
d. Subsurface disposal (e.g. deep well injection)	Solids free, concentrated wastewaters	Disposal of in organics and organics Ultimate disposal of toxic or odorous material	Subsurface clogging Groundwater pollution High maintenance and operation costs Limited aquifer life High initial costs
e. Groundwater recharge	Treated wastewaters	Reduces bacteria concentration Conserves water resources Prevents salt water intrusion into potable aquifers	Possible groundwater contamination Limited to porous formation
Sludge			
a. Anaerobic digestion	Biodegradable solids	Methane production Solids stabilization and conditioning Liquefaction of solids	Heat required Process upsets when excess volatile acids

		Minimum land required Use of digested sludge as fertilizer or soil conditioner	Odours Skilled labour Explosion hazard
b. Aerobic digestion	Biological solids	Relatively little odour Solids stabilisation and conditioning Unsophisticated operation	Moderate land area required High energy usage Reduced dewatering ability
c. Autoclaving	Biological solids	Compact operation Solids conditioning Kills microorganisms	High initial equipment costs Power costs Skilled labour Maintenance cost

Source: Department of the Army Air Force Manual and the Air Force (1988) *Domestic Wastewater Treatment*, Vol. 3, pages 17 – 30.

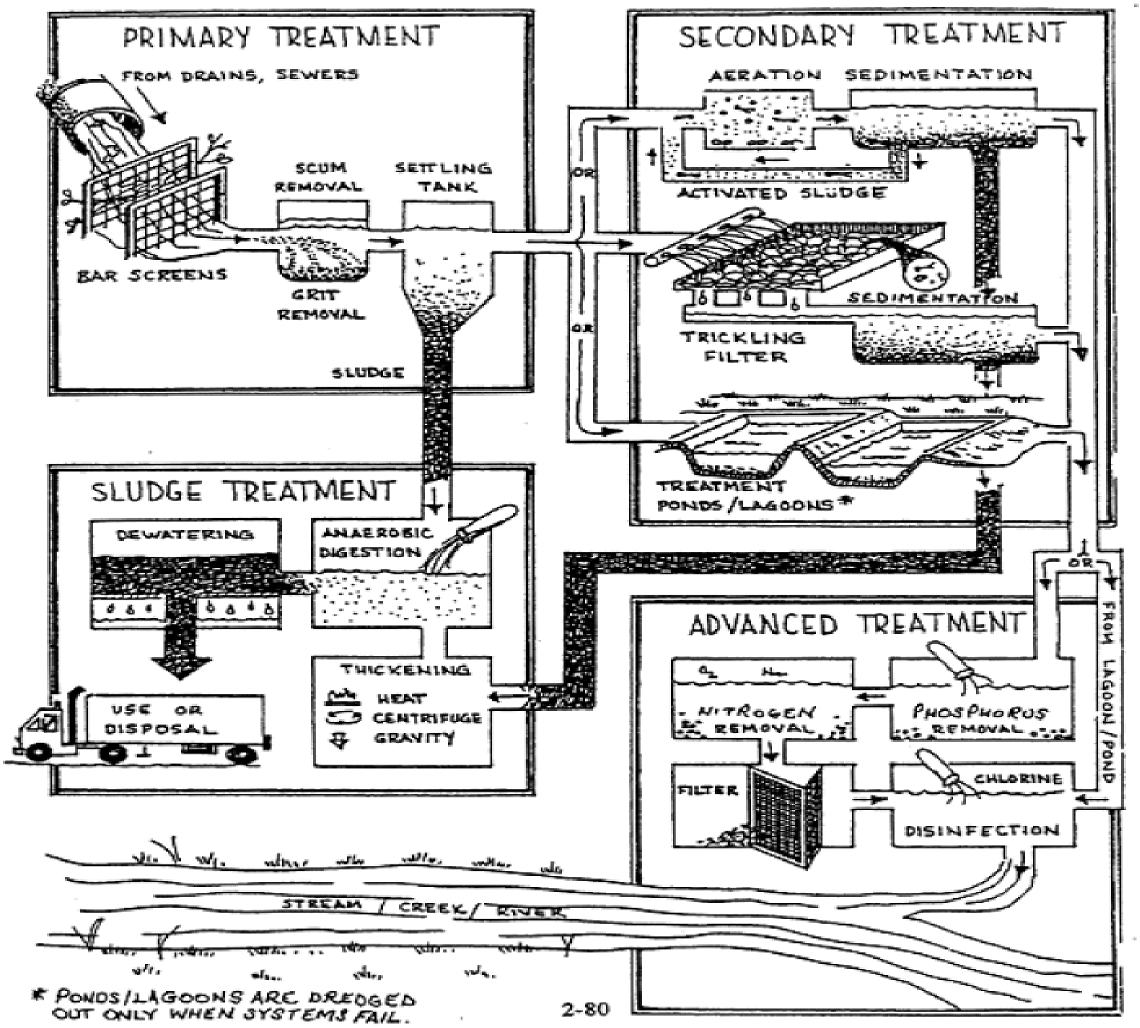

Fig. 12: An Overview of a Wastewater Treatment Facility for a Municipality

4.0 CONCLUSION

This unit concludes that wastewaters from different sources and of different chemical and physical properties should be treated using techniques with different degree of sophistication.

5.0 SUMMARY

In this unit, we have learnt that:

- Biodegradable wastes are treated using methods that are not the same as those for non- biodegradable ones.
- Different methods have their own strengths and limitations.
- Wastewater treatment methods can be grossly classified into:

- primary methods
- secondary and
- advanced or tertiary methods.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight four methods for treating biodegradable wastewaters.
2. Identify five methods for treating non-biodegradable wastewaters.

7.0 REFERENCES/FURTHER READING

Department of the Army Air Force Manual and the Air Force (1988). *Domestic Wastewater Treatment*, Vol. 3, pages 17 – 30.

Ogedengbe, M.O. (1998). Technologies for Industrial Waste Management, Lecture note Delivered at a Short Certificate Course Workshop on Environmentally Sound Technologies for Management of Wastes held November / December, 1998 under the Auspices of the Institute of Ecology and Environmental Studies and the UNIFECS.

UNIT 2 HOUSEHOLDS WASTEWATER DISPOSAL TECHNIQUES

CONTENTS

1.0 INTRODUCTION

You have learnt in the previous module that domestic wastewaters are generally those from homes. Needless to emphasise is that the treatment of these wastewaters is a matter of course in our society. It serves the protection of human health, the preservation of water as an ecosystem, and it also retains the water in a state that makes it usable by humans.

It is also important for you to note that wastewater generation is dependent on water supply. The more the quantity of water available for use, the more the quantity that would be used in kitchens, toilets, bathrooms, etc, and consequently, the more the volume of wastewater that would be generated. There is therefore a relationship between water supply development and wastewater generation. And so, in areas where there is no pipe-borne supply, the main wastewater of concern will be of faeces and urine.

Besides, it is my intention in this module to introduce you to some wastewater management techniques. Please let us go straight into the discussion. But before this, the expectations or objectives of this unit are as described below.

2.0 OBJECTIVES

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

- discuss the different methods of domestic wastewater treatment techniques

- identify the merits and demerits of each method
- describe the operations of the techniques.

7.0 MAIN CONTENT

Methods of handling wastewaters available to or used by Nigerians include the bushrine, latrine, septic and soak-away, trickling filter and activated sludge systems.

3.1 The Bushrine System

This system reveals the use of bush or any vacant land for the disposal of domestic waste, especially human faeces. Wastewaters disposed in this way usually do not undergo any treatment. Hence, it is a disposal method and not a treatment technique. It follows the Mosaic Law as reported by Moses in the Bible (Deut. 23: 12 – 13) to have told his people

Thou shall have a place also without the camp wither thou shall go forth abroad.

And thou shall have a paddle upon thy weapon and it shall be, when thou wilt ease thyself abroad thou shall dig therewith and shall turn back and cover that which cometh from thee.

Proof that even urban Nigeria is still essentially ancient on waste disposal is in the fact that a new terminology has now entered into its vocabulary. The word is '***bushrine'*** (as in lat – rine) (Ogedengbe, 1998). To go to the ***bushrine*** is to go and ease oneself in the bush nearby. The term could not have been invented by rural dwellers but by urban dwellers, especially students of higher institutions in Nigeria, who probably have water closets but have no water to flush them. These people have resulted into defecating in nearby bushes and other inappropriate places. The bushrine constitutes a giant step backwards towards the Dark Ages. As water system continues to fail and bushes are disappearing it does not take too much imagination to guess what the bushrine could become.

3.2 The Latrine System

A number of types of latrine systems exist. They can, however, be summarised as follows:

- Bucket Collection (collect and treat) (Figure 13)
- Ventilated Improved Pit (VIP) Latrines (empty and treat) (Figure 14)

- Pour-Flush Toilets (empty and treat) (Figure 15)
- Urine-Separating Latrines (treat onsite and reuse) (Figure 16)
- Flush Toilet (Figure 17)

Fig. 13: Bucket System in Shanghai, China: ***This Man has Defecated in the Bucket to Dispose in God knows where (Nelson, 2004)***

Fig. 14 The Structure of a Ventilated Improved Pit (VIP) Latrine

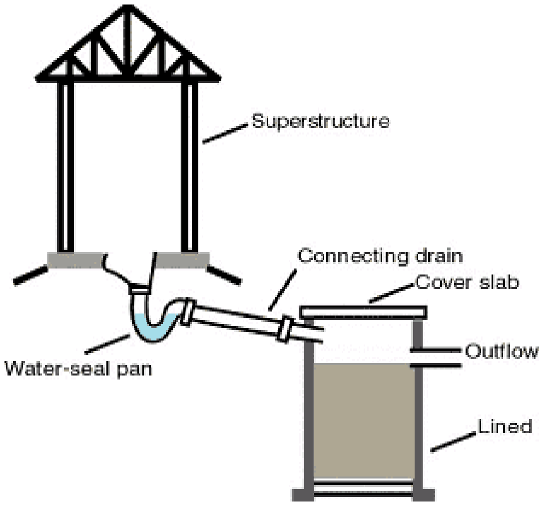

Fig. 15: A Pour Flush Latrine

http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/5.asp

Fig. 16: Urine-Separating Latrines (aka Ecological Dry Toilets)

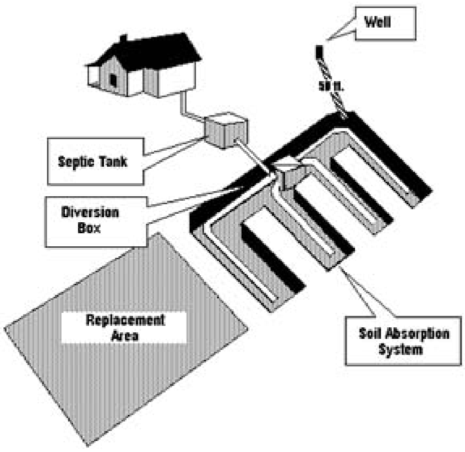

Fig. 17: Structure of a Flush Toilet System

Source: http://ohioline.osu.edu/aex-fact/0743.html

The latrine system is well known. The different types include the pit latrine, bucket latrine and (a more modern version of it) and the Ventilated Improved Latrine (VIP). In these systems, decomposition is by anaerobic bacteria. The bucket type has ceased to be used throughout the country. The pit latrine is still in common use and VIP latrine is increasingly coming into use.

The pit latrine is generally unlined and so the faeces and urine are in direct contact with groundwater. This is an important shortcoming especially when water well is dug near the pit latrine, with a great likelihood of fecal contamination of the well water.

Generally, a number of latrines are desired based on

- **Affordability**: some are more affordable than others.
- **Water requirement**: some types or models of latrines do not require large amounts of water to carry wastes. These are termed dry latrines while others require much water, and are termed flush or wet latrines. It is however desirable that most households should be dry, especially in developing countries where availability of piped water is unpredictable. However, if flush toilets are used, a community collection and treatment system is typically required. It must also provide for disposal of greywater (wash water). Nevertheless, flush toilets should not be installed unless a sewer system and wastewater treatment plants are also constructed!

3.3 The Septic Tank and Soak-Away System

In communities where water closets are used and pipe-borne water is available to run them, the most elementary form of wastewater treatment is the septic tank and soak-away system, constructed for each building. This is the commonest method of wastewater disposal in urban Nigeria today.

Septic systems are used to treat and discharge wastewater from toilets, wash basins, bathtubs, washing machines, and other water-consumptive items, which can be sources of high pollutant loads (see Table 12). Septic systems are particularly common in rural or large lot settings, where centralised wastewater treatment systems are not economical. Because of their widespread use and high-volume discharges, septic systems have the potential to pollute groundwater, lakes and streams if located or operated improperly. While septic systems are designed based on soil conditions, most are designed on the same principles. Conventional systems are comprised of a septic tank, a distribution system, and a soil absorption system (Fig. 18).

Table 12: Daily Water Use and Pollutant Loadings by Source (USEPA, 1980)

Water Use	Volume (litres/capita)	BOD (grams/capita)	Suspended Solids (grams/capita)	Total N (grams/capita)	Total P (grams/capita)
Garbage disposal	4.54	10.8	15.9	0.4	0.6
Toilet	61.3	17.2	27.6	8.6	1.2
Basins/Sinks	84.8	22.0	13.6	1.4	2.2
Miscellaneous	25.0	0	0	0	0
Total	**175.64**	**50.0**	**57.1**	**10.4**	**4.0**

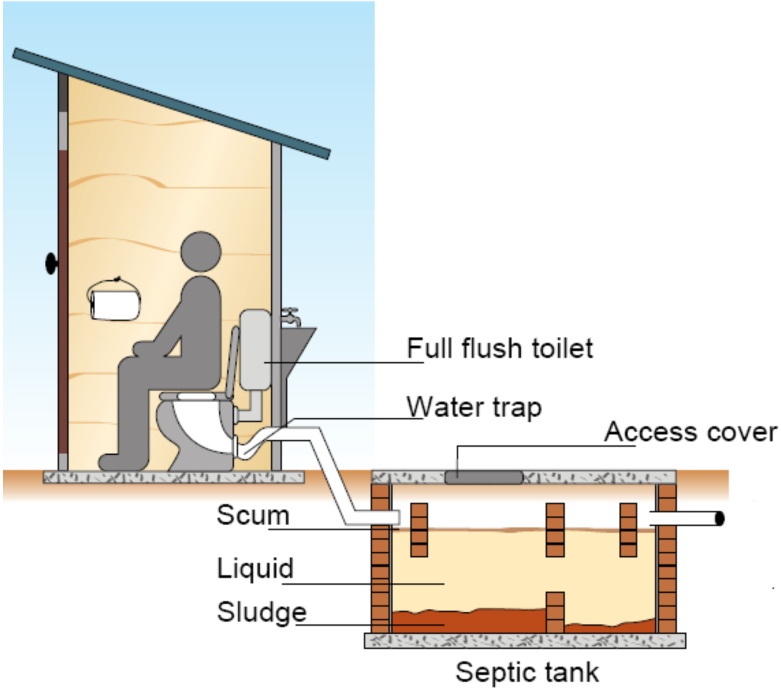

Fig. 18: A Septic Tank and Soak-Away System

Septic tanks, with appropriate effluent disposal systems, are acceptable as a treatment system for isolated buildings or for single-unit residential buildings when permitted by regulatory authority and when alternative treatment is not practical. When soil and drainage characteristics are well documented for a particular site, septic tank treatment may be permanently feasible. Septic tanks perform settling and digestion functions and are effective in treating from 1 to 300 population equivalents of waste, but will be used only for 1 to 25 population equivalents, except when septic tanks are the most economical solution for larger populations within the above range. Minimum size will be at least 500-gallons capacity.

Wastewater from toilet and kitchen are piped into the septic tank. The tank is lined (cemented) inside so that the waste entering it does not have direct contact with the groundwater. It is also covered, linked with the atmosphere only through a vent to equalize pressure. In the tank, settle-able solids in the influent waste settle and are aerobically decomposed. The supernatant (now treated) then flows out to the soak-away pit which gets the partially treated wastewater to enter the ground.

Waste from the toilet, and generally domestic wastewater, is flushed into the settling chamber where it is retained for at least 24hrs to allow settlement and biological digestion. Partially treated liquids then pass out of the tank and into the subsoil drainage / soak-away system. Digested sludge gradually builds up in the tank and requires eventual removal by tanker.

Operation and Institutional Requirements: This system requires a reliable household water connection. Specific design criteria must be applied to the settlement tank and soak away system. This option is applicable only in areas of low settlement density and where soils have a high ability to drain effluent away. Ensure access for emptying of tanks by vacuum tanker, as well as availability of sludge treatment and disposal.

Experience and comment:

- Widely used by formal rural households and farming areas, where reliable water supply is available
- Provides a high level of service and user convenience
- Failures due to poor design and construction, and use of inappropriate anal cleansing materials
- Soak-away system is particularly prone to failure in the long-term if detailed soil testing is not carried out
- Although to a lesser extent than the pit latrine system, the soak-away system can and does contaminate groundwater. In some studies carried out at the Obafemi Awolowo University, Ile-Ife, Nigeria, it was found that except those constructed in clay soils, soak-away pits and pit latrines built as far as 20 meters from hand dug wells can and do contaminate such wells. It was suggested that wells should be located as far away as possible from pit – latrines and that such wells should be lined (cemented) from top to near bottom.
- Also, soak-away built in a tight clay soil will not soak-away but ooze on top creating problems of odour, unsightliness, flies, etc.

3.4 Trickling Filter System

Using this method, sewage is trickled over a pile of stones held in concrete tank. Algae growth soon takes place on the rocks and it is in the growth that microorganisms reside which act on the waste. It is an aerobic system. Its BOD – removal efficiency is relatively low, hardly more than 75%.

3.5 Activated Sludge System

Here, the wastewater first undergoes primary settling (in a primary clarifier). The supernatant goes into an aeration tank (where oxygen is diffused into the wastewater). Here, bacteria cell growth takes place rapidly. The aerated waste is sent into a final settling tank from where the supernatant is led to a chlorination tank where it is disinfected before being discharged into a water course. The settled sludge in the final clarifier contains high concentrations of active microorganisms. The sludge is recycled into the aeration tank to increase the population of active microorganisms in the mixed liquor. When the concentration of microorganisms in the mixed liquor has reached an adequate level (1200 – 1500mg/l), the sludge is wasted (sent to the sludge digester or drying bed) rather than returned to the aeration tank.

4.0 CONCLUSION

This unit concludes that wastewater treatment techniques vary with belief, technological development and modernisation of communities.

5.0 SUMMARY

In this unit, we have learnt that:

- Domestic wastewaters have been disposed by

- Bushrine
- Latrine, and
- Septic Tanks and Soak-Away Systems

6.0 TUTOR-MARKED ASSIGNMENT

Using sketch diagrams, attempt a description of the following waste disposal systems

1. Bushrine
2. Bucket type, Pit, VIP latrine
3. Septic tank and soak-away toilet systems

7.0 REFERENCES/FURTHER READING

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http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/5.asp

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UNIT 3 ON-SITE MUNICIPAL WASTEWATERS TREATMENT

CONTENTS

1.0 INTRODUCTION

Many of our daily chores such as bathing, doing laundry, flushing toilets, repairing meals, washing dishes and other activities generate wastewater. Few people give thought to where wastewater goes after it disappears down the drain. Domestic wastewater (i.e. sewage) must be properly treated because it contains excessive nutrients, harmful bacteria/viruses and household chemicals that may contaminate the land and waters of our state and threaten public health. In the developed countries, the technology and the resources available are often adequate to properly treat their wastewaters; we are perhaps less fortunate here in Nigeria, or perhaps more fortunate than some other countries. You may need to think of this and search for cities that have witnessed breakdown of their municipal treatment plants of recent.

2.0 OBJECTIVES

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

- describe the objectives of wastewater treatment at different levels of treatment
- illustrate some techniques of wastewater treatment and
- sketch some wastewater treatment techniques plans.

3.0 MAIN CONTENT

3.1 Wastewater Treatment Objectives

The basic objectives of wastewater treatment include the followings:

- Remove sediments
- Remove organic matter (BOD)
- Remove nutrients (N and P)
- Remove or inactivate pathogens

The objectives vary with level. Table 13 below shows the specific objective of water treatment at different levels.

Table 13: Levels of Water Treatment and their Objectives

Level	Objective
Pre-treatment	Remove sand, grit and large objects
Primary	Remove suspended particles by sedimentation. Remove BOD, N, P and pathogens
Secondary	Remove dissolved solids, BOD, N and P by biological degradation (use of bacteria)
Tertiary	Additional treatment, specific to situations (e.g. nutrients, organics and colloids)
Disinfection	Remove inactive pathogens

3.2 Operations of a Wastewater Treatment Plant

Wastewater is about 99 percent water by weight and is generally referred to as influent as it enters the wastewater treatment facility. “Domestic wastewater” is wastewater that comes primarily from individuals, and does not generally include industrial or agricultural wastewater. At wastewater treatment plants, this flow is treated before it is allowed to be returned to the environment, lakes, or streams. There are no holidays for wastewater treatment, and most plants operate 24 hours a day.

Wastewater treatment plants operate at a critical point of the water cycle, helping nature defend water from excessive pollution. Most treatment plants have primary treatment (physical removal of floatable and settle able solids) and secondary treatment (the biological removal of dissolved solids).

3.3 On-Site Disposal and Treatment System

This is a system that requires that the municipal wastewater, commonly known as sewage is treated on the site. Each on-site sewage disposal system is designed for a specific site and a specific volume of wastewater. Each site is different and must be evaluated individually. Site evaluation information includes: soil conditions, topography, lot size and location, estimated water usage, depth of the groundwater tables, seasonal high water tables, water-well locations (yours and your neighbours'), location of creeks, rivers, springs, ponds and lakes, or other factors that may affect the type of system you select. It is possible that no system can be approved if adverse environmental and/or physical conditions exist on the site. Soil conditions are determined by conducting a soil percolation test or soil profile description.

Components of On-Site Sewage Disposal System

It takes both primary treatment and secondary treatment combined to make a properly designed on-site sewage disposal system.

Primary Treatment is the initial process in which the solids are removed from the liquids through settling. The two types of primary treatment are the *septic tank* and the *equalization tank* for the aerobic system. Primary treatment involves the following activities:

- screening- to remove large objects, such as stones or sticks, which could plug lines or block tank inlets.
- grit chamber- slows down the flow to allow grit to fall out, and
- sedimentation tank (settling tank or clarifier)- settle able solids settle out and are pumped away, while oils float to the top and are skimmed off

- **Septic Tanks**

The household type of septic tank has been discussed in the Unit 1 of this module. Globally, septic tanks are the most common primary treatment method used for onsite sewage disposal systems. Septic tanks can be made of pre-cast concrete, fiberglass or plastic. Septic tanks must have a minimum capacity of 1,000 gallons. They are made in different shapes and sizes to accommodate different sites. The septic tank receives household wastewater and helps the liquid wastes to separate from the solid wastes. The heavier solids settle to the bottom while the lighter solids (greases, etc.) float to the surface of the tank. The liquids (effluent) from the septic tank then discharge into a secondary treatment system.

- **Equalisation Tanks**

Equalisation tanks provide the primary treatment for wastewater entering aerobic systems with septic tanks. The job of the equalization tank is to separate `the solids from the liquids. It also equalizes the strength of the sewage entering the aerobic treatment unit. Equalization tanks must have a minimum capacity of 300 gallons and maximum capacity of 1,000 gallons.

Secondary Treatment is the biological breakdown of the remaining organic matter in the effluent after primary treatment. Secondary treatment reduces the pollutants and pathogens in the effluent prior to disposal. There are several types of secondary treatment systems available for use: Subsurface Absorption Fields, ETA Systems, Lagoons, Aerobic Systems and other approved alternative systems including Constructed Wetlands.

- **Subsurface absorption fields**

The most common on-site wastewater disposal method is the subsurface absorption field. It consists of a network of shallow trenches filled with an absorption media (usually rock gravel or other similar material). The gravel surrounds perforated pipe and is covered with the excavated native soil. Effluent from the septic tank slowly trickles through the pipes into the absorption media where it is stored. The effluent is gradually absorbed into the soil. The effluent is filtered and cleansed by the soil and natural bacteria. This type of disposal is totally dependent on the soil's permeability (its ability to absorb water). Subsurface absorption fields do not work well in tight or high clay content soils.

- **Evaporation transpiration/ absorption (ETA) systems**

ETA systems are generally used in tight clay soil. The trench construction is the same as the subsurface absorption field with the exception of the backfill material. Instead of being used as backfill, the excavated native soil (clay) must be removed. The trench is back filled with sand instead of the clay and then capped with two to four inches of new topsoil. The wastewater wicks upward through the sand where it can evaporate and/or be utilised by vegetation. Like the typical subsurface absorption field, ETA systems are sized according to water usage and location. However, they are required to be much larger than subsurface absorption fields. The use of ETA system is not recommended in areas of high rainfall and low evaporation.

- **Lagoons (oxidation ponds)**

A lagoon is a shallow total retention, pond-like structure in which the effluent is exposed to sunlight and oxygen that enables aerobic bacteria to digest the organic matter. Lagoons are sized based upon local rainfall and evaporation rates. A properly sized lagoon will have no discharge to the environment since the volume of the wastewater is reduced through evaporation. This type of system is very effective and relatively easy to maintain; however, it requires a large lot or site for construction.

- **Aerobic systems with surface application**

Aerobic systems consist of an aerobic treatment unit with surface application of the treated effluent. Aerobic treatment units (see Figure 19) are used primarily when environmental conditions preclude the use of subsurface absorption fields. Treatment occurs when air is injected into the wastewater to promote biological breakdown of the organic matter.

Chlorination completes the treatment prior to disposal. While for most on-site sewage disposal systems the secondary treatment also accomplishes disposal, this is not true for aerobic systems. The aerobic treatment process produces a high quality effluent that still requires disposal. This high quality effluent may be applied directly to lawns through a timed sprinkler system that sprays the effluent over a large vegetated area at night. Most of this water will evaporate and the rest will be absorbed and utilised by the vegetation.

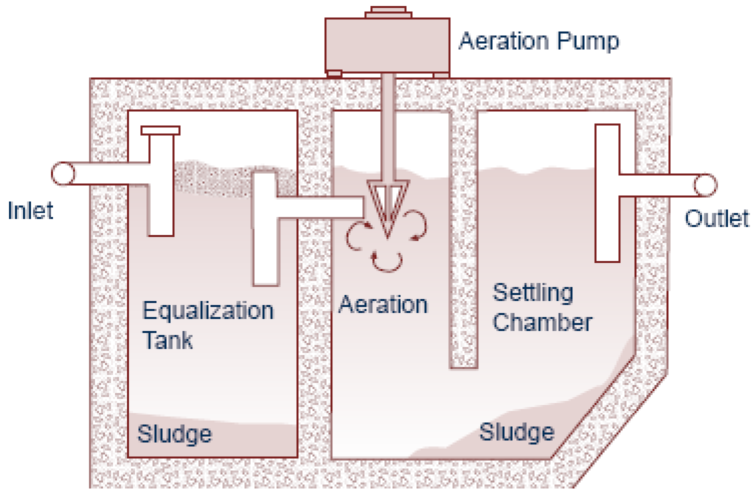

Fig. 19: An Aerobic Treatment Unit

Source: http://www.cwp.org System

- **Alternative systems**

One example of an alternative system is the constructed wetland system (Figure 20). Constructed wetlands are an effective and relatively low maintenance method of providing on-site wastewater treatment and disposal. These units consist of various sized beds that are lined with a synthetic liner, filled with filter material, usually gravel (non-limestone) or similar material, and planted with common wetland plants.

Effluent from the septic tank flows through the entire filter bed where plant roots and associated microorganisms living on the roots and gravel surfaces remove pathogens and nutrients from the wastewater. Any effluent not removed by the plants is usually disposed of using subsurface absorption fields but may be disposed of using surface application.

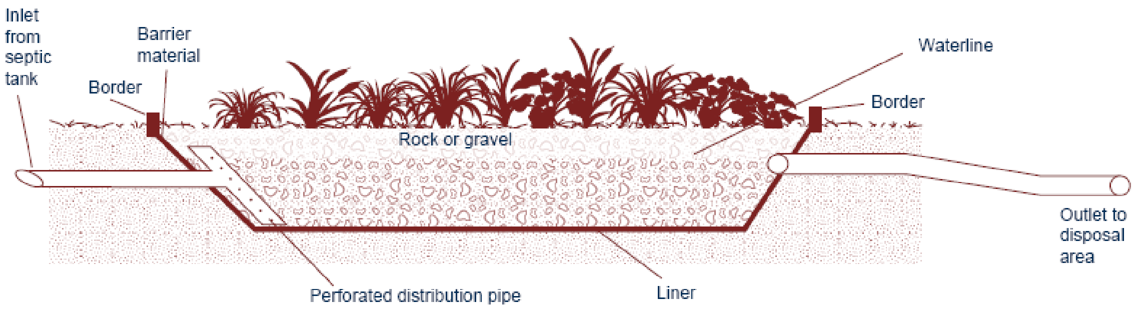

Fig. 20: A Constructed Wetland System

Source: http://www.cwp.org System

Secondary treatment typically utilises biological treatment processes, in which microorganisms convert non-settleable solids to settleable solids. Sedimentation typically follows, allowing the settle able solids to settle out. Three options include:

- Activated Sludge- The most common option uses microorganisms in the treatment process to break down organic material with aeration and agitation, then allows solids to settle out. Bacteria-containing “activated sludge” is continually re-circulated back to the aeration basin to increase the rate of organic decomposition.

- Trickling Filters- These are beds of coarse media (often stones or plastic) 3-10 ft. deep. Wastewater is sprayed into the air (aeration), and then allowed to trickle through the media. Microorganisms attached to and growing on the media, break down organic material in the wastewater. Trickling filters drain at the bottom; the wastewater is collected and then undergoes sedimentation.

- Lagoons- These are slow, cheap, and relatively inefficient, but can be used for various types of wastewater. They rely on the interaction of sunlight, algae, microorganisms, and oxygen (sometimes aerated).

After primary and secondary treatment, municipal wastewater is usually disinfected using chlorine (or other disinfecting compounds, or occasionally ozone or ultraviolet light). An increasing number of wastewater facilities also employ tertiary treatment, often using advanced treatment methods. Tertiary treatment may include processes to remove nutrients such as nitrogen and phosphorus, and carbon adsorption to remove chemicals. These processes can be physical, biological, or chemical. Settled solids (sludge) from primary treatment and secondary treatment settling tanks are given further treatment and undergo several options for disposal.

Below is a sketch diagram of a centralized municipal wastewater collection and treatment system (Figure 21). I advise that you properly study it and take your jottings. I am sure it will help you understand more of wastewater collection and passage.

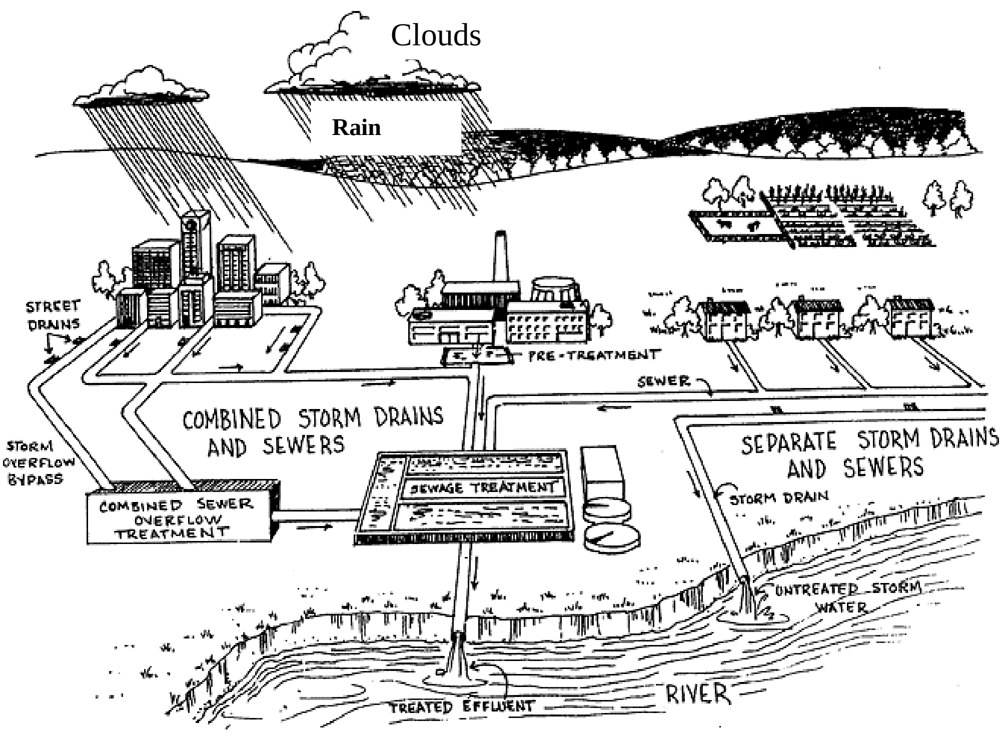

Fig. 21: A View of a Centralised Municipal Wastewater Treatment System

Source: Mara (1996).

8.0 CONCLUSION

This unit concludes that different treatment methods exist for domestic wastewaters and they vary in the degree of sophistication; the simplest being primary, then secondary and tertiary in that order.

5.0 SUMMARY

In this unit, we have learnt that:

- Wastewater treatment techniques can be classified as primary, secondary and tertiary treatment.
- On-site disposal and treatment system is a system that requires that the municipal wastewater, commonly termed sewage is treated on the site.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe primary wastewater treatment techniques and highlight their examples.
2. Illustrate the secondary treatment techniques.
3. Sketch a typical municipal treatment system.

7.0 REFERENCES/FURTHER READING

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