COURSE GUIDE

ESM 423
HYDROLOGY AND WATER RESOURCES

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Printed 2013, 2017, 2025

ISBN: 978-058-257-6

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INTRODUCTION

Welcome to ESM 423: Hydrology and Water Resources! This course consists of three modules broken down into 20 units. This course discusses waters of Earth- their properties, behaviour and distribution. The key concepts discussed in this unit include definition of hydrology, basic properties of water, application of hydrology, hydrologic cycle, groundwater resources and so on.

This Course Guide gives information about the course, the course materials you will be using and how you can work your way through these materials. It also emphasises the need for tutor- marked assignment (TMA).

WHAT YOU WILL LEARN IN THIS COURSE

In this course, you will learn the basic issues in hydrology and its application, basic properties of water, formation of rain and types of rainfall. In addition, you will be exposed to the concept of flooding, humidity, interception, infiltration, evaporation and evapotranspiration. This course will also provide you with an insight of how water resources can be managed. Your knowledge of this course will enable you understand distribution of water on the Earth, their behaviour and properties. It will also enable you understand causes, effects and control of flooding, which is fast becoming a global issue.

COURSE AIMS

This course aims at helping you to understand distribution on water on the Earth and how they can be properly managed.

COURSE OBJECTIVES

To achieve the aims set above, there are overall objectives. In addition, each unit also has specific objectives. On successful completion of the course, you should be able to:

- define hydrology
- discuss brief history of the development of hydrology
- discuss basic properties of water
- explain the hydrologic cycle
- discuss the ground and surface water resources
- explain concepts of precipitation, humidity infiltration, interception, soil moisture, runoff, evaporation and evapotranspiration.

- assess the role of ethics in the family
- examine effects of flooding and soil erosion on the earth's surface
- suggest ways in which water resources can be managed.

WORKING THROUGH THIS COURSE

To complete this course, you are required to read the study units, read the recommended books and read other materials provided by the National Open University of Nigeria (NOUN), which will help you to achieve the objectives of the course. Each unit contains some self-assessment exercises, and at points in the Course, you are required to submit assignments for assessment purpose. At the end of this Course, there is a final examination. Stated below are the components of the course.

COURSE MATERIALS

1. Course Guide
2. Study Units
3. Assignment file
4. Relevant textbooks including the ones listed in the references.

STUDY UNITS

MODULE 1

Unit 1 Definition and Scope of Hydrology
Unit 2 Brief History of the Development of Hydrology
Unit 3 Basic Properties of Water
Unit 4 Applications of Hydrology
Unit 5 The Hydrologic Cycle
Unit 6 Groundwater Resources
Unit 7 Surface Water Resources
Unit 8 Concept of the Drainage Basin

MODULE 2

Unit 1 Precipitation
Unit 2 Humidity
Unit 3 Interception
Unit 4 Infiltration
Unit 5 Soil Moisture
Unit 6 Evaporation and Evapotranspiration
Unit 7 Runoff

MODULE 3

Unit 1	Flooding
Unit 2	Erosion
Unit 3	Sediment
Unit 4	Development and Management of Water Resources
Unit 5	Problems of Water Resources Development

TEXTBOOKS AND REFERENCES

Linsley, R. K. Jr, Kohler, M.A. & Paulhus, J.L. (1982). *Hydrology for Engineers.* (3rd ed.). McGraw-Hill International Book.

Viessman, W. & Lewis, G.L. (2003). *Introduction to Hydrology*. (5th ed.). Upper Saddle River, New Jersey: Pearson Education Inc.

Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology*. (4th ed.). UK: McGraw-Hill Publishing Company.

ASSIGNMENT FILE

In this assessment file, you will find details of the work you must submit to your tutor for marking. The marks you obtain from these assignments will count towards the final mark that you obtain for this course. Further information on assignments will be found in the Assignment File itself and later in this Course Guide in the section on assessment.

ASSESSMENT

There are two aspects of the assessment of this course, the tutor-marked assignments and the written examination. The marks you obtain in these two areas will make up your total marks. The assignment must be submitted to your tutor for formal assessment in accordance with the deadline stated in the presentation schedule and the assignment file. The work you submit to your tutor will count for 30 per cent of your total score.

TUTOR-MARKED ASSIGNMENT

There are fifteen tutor-marked assignments (TMA) in this course. The best five (that is the highest 5 of the fifteen) will be counted. The total marks for the best five assignments will make up 30 per cent of your total course mark.

Assignment questions for the unit in this course are contained in the Assignment File. You should be able to complete your assignments from the information contained in your study units and textbooks. However, you are advised to use other references to broaden your viewpoint and provide a deeper understanding of the subject.

When you have completed each assignment, send it together with your assignment file to your tutor. Make sure that each assignment reaches your tutor on or before the deadline. If, however, you cannot complete your work on time, contact your tutor for the possibility of an extension.

FINAL EXAMINATION AND GRADING

The examination will consist of questions, which reflect the type of self-testing, practice exercises, and tutor-marked problems you have come across. All areas of the course will be assessed. You are advised to revise the entire course after studying the last unit before you sit for the examination. You will find it useful to review your tutor-marked assignments and the comments of your tutor on them before the final examination.

PRESENTATION SCHEDULE

The presentation schedule in your course material gives you the important dates for the completion of tutor-marked assignments and attending tutorials. Remember, you are required to submit all your assignments by the date. You should guard against lagging behind in your work.

COURSE MARKING SCHEME

The table below shows how the course mark allocation is broken down:

Assessment	**Marks**
Assignment (Best Three Assignment out of Four marked)	30%
Final Examination	70%
Total	100%

HOW TO GET THE MOST FROM THIS COURSE

In distance learning, the study units replace the university lecturer. This is one of the great advantages of distance learning; you can read and work through specially designed study materials at your own pace, and at a time and place that suit you best. Think of it as reading the lecture instead of listening to a lecturer.

In this same way that a lecturer might set you some reading to do, the study units tell you when to read your set of books or other materials. Just as a lecturer might give you an in-class exercise, your study units provide exercises for your to do at appropriate points.

Each of the study units follows a common format. The first item is an introduction to the subject matter of the unit and how a particular unit is integrated with the other units and the course as a whole. Next is a set of learning objectives. These objectives shall let you know what you should be able to do by the time you have completed the unit. You should use these objectives to guide your study. When you have finished, the units you must go back and check whether you have achieved the objectives. If you make a habit of doing this you will significantly improve your chances of passing the course. The main body of the unit guides you through the required reading from other sources.

Remember that your tutor's job is to assist you. When you need help, do not hesitate to call and ask your tutor to provide it.

- Read this Course Guide thoroughly.
- Organise a study schedule. Refer to the 'Course Overview' for more details. Note the time you are expected to spend on each unit and how the assignments related to the units. Whatever method you chose to use, you should decide on and write in your own dates for working on each unit.
- Once you have created your own study schedule, do everything you can to stick to it. The major reason that students fail is that they get behind with their course work. If you get into difficulties with your schedule, please let your tutor know before it is too late for help.
- Turn to unit one and read the introduction and the objectives for the unit.
- Assemble the study materials. Information about what you need for a unit is given in the 'Overview' at the beginning of each unit. You will usually need both the study unit you are working on and one of your set books on your desk at the same time.
- Work through the unit. The content of the unit itself has been arranged to provide a sequence for you to follow. As you work through the unit, you will be instructed to read sections from your set books or other articles. Use the unit to guide your reading.
- Review the objectives for each study unit to confirm that you have achieved them. If you feel unsure about any of the objectives, review the study material or consult your tutor.
- When you are confident that you have achieved a unit's objectives, you can then start on the next unit. Proceed unit by

unit through the course and try to pace your study so that you keep yourself on schedule.

- When you have submitted an assignment to your tutor for marking, do not wait for its return before starting on the next unit. Keep to your schedule. When the assignment is returned, pay particular attention to your tutor's comments, both on the tutor-marked assignment form and on what is written on the assignment. Consult your tutor as soon as possible if you have any questions or problems.

- After completing the last unit, review the course and prepare yourself for the final examination. Check that you have achieved the unit objectives (listed at the beginning of each unit) and the course objectives (listed in this Course Guide).

FACILITATION/TUTORS AND TUTORIALS

There are about eight hours of tutorials provided in support of this course. The dates, time and venue of these tutorials shall be communicated to you. The name and phone number of your tutor will be made known to you immediately you are allocated a tutorial group.
Your tutor will mark and comment on your assignments, keep a close watch on your progress and on any difficulties you might encounter and provide assistance to you during the course. You must mail your tutor-marked assignments to your tutor well before the due date (at least two working days are required). Do not hesitate to contact your tutor by telephone, e-mail, or discussion board if you need help. You will definitely benefit a lot by doing that. Contact your tutor if:

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

You should make an effort to attend the tutorials. Thus, it is the only opportunity you have to enjoy face-to-face contact with your tutor and to ask questions which are answered instantly. You can raise any problem encountered in the course of your study. To gain the maximum benefit from the course tutorials, prepare a question list before attending them.

SUMMARY

ESM 423 intends to introduce you to the basic issues of water distribution of the Earth, its properties and behaviour. We believe you will find the course both interesting and relevant in your life endeavours.

MAIN COURSE

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MODULE I

UNIT 1 DEFINITION AND SCOPE OF HYDROLOGY

CONTENTS

1.0 INTRODUCTION

Hydrology is a scientific discipline, which involves the application of scientific knowledge and mathematical principles to solve water related problems. The focus of this unit is to introduce hydrology as a scientific discipline, which adopts scientific methods in its studies. Sub-topics to be discussed include hydrology as a subject and highlight of the scope and branches of hydrology.

2.0 OBJECTIVES

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

- define hydrology
- discuss the scope of hydrology
- state the major branches of hydrology.

3.0 MAIN CONTENT

3.1 Definition of Hydrology

Hydrology is the science, which deals with the waters of the earth, their occurrence, distribution and circulation, their chemical and physical properties and their interaction with the environment. Similarly, Universities Council on Water Resources (UCWR, 2011) defines hydrology as the science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle. Hence, it can simply be summarised that hydrology is the detailed scientific study of water.

3.2 Scope of Hydrology

The hydrologic cycle remains the central theme of hydrology study. The circle encompasses all of the physical, chemical and biological processes involving water as it travels through its various paths in the atmosphere, over and beneath the earth's surface. This is of great interest to the hydrologist. Hence, the study of hydrology is multi-disciplinary since it incorporates professionals from various disciplines such as geography, chemistry, physics, biology, geology and engineering.

Although hydrology is concerned with the study of water, especially atmospheric and terrestrial fresh water, its emphases have changed from time to time and vary from one practitioner to another. Notable changes have been identified in the evolution of the discipline of hydrology, for example, from physical hydrology, through engineering hydrology, to water resources hydrology.

In spite of the changing emphases however, hydrological studies involve the application of scientific knowledge and mathematical principles to solve water related problems such as quantity, quality and availability in society. Hydrologists may also be concerned with finding water supplies for cities or irrigated farms, or controlling river flooding or soil erosion.

In addition, the study of hydrology involves both laboratory analysis and direct field measurements of hydrological processes, namely, rainfall, erosion, runoff, soil moisture among others. Measurement is fundamental for assessing water resources and understanding the processes involved in the hydrologic cycle. It should be noted that the hydrological cycle is so diverse, and hydrological measurement methods equally span many disciplines including soil, oceanography, atmospheric science, geology, geophysics amongst others. The data obtained through measurements of hydrological processes are analysed and interpreted by the hydrologist for the purpose of predicting or solving water resources problems.

Generally, each hydrologic problem is unique in that it deals with a distinct set of physical conditions within a specific river basin. Quantitative conclusions of one analysis are therefore not often directly transferable to another problem. However, the general solution for most problems can be developed from application of a few relatively basic concepts (Linsley et al., 1982). It should be noted at this point that the modern day hydrologist relies on computers for organising, summarising and analysing massive data set and modeling studies.

3.3 Major Branches of Hydrology

The continuous growth and development of hydrology, resulting to its several areas of application and relevance in the society, led to the evolvement of different areas of specialisation. Each of these branches or areas of specialisation is concerned with the study of an aspect of hydrology. The following are the major branches in hydrology.

Chemical Hydrology: This branch deals with the study of the chemical characteristics of water.

Ecohydrology: This branch is concerned with the study of interactions between organisms and the hydrologic cycle.

Surface Hydrology: This area focuses on the study of hydrologic processes that operate at or near earth’s surface.

Hydrogeology: This is the study of presence and movement of groundwater.

Hydrometeorology: This is the study of the transfer of water and energy between land and water body surfaces, and the lower atmosphere.

Engineering Hydrology: This area of hydrology is concerned mainly with estimating rates or volumes of flow or the changes in these values resulting from human activities.

Hydroinformatics: This is the study of the adaptation of information technology to hydrology and water resources applications.

Isotope Hydrology: This is the study of the isotopic signatures of water.

SELF-ASSESSMENT EXERCISE

Create a table showing the major branches in hydrology and discuss the focus of each branch.

4.0 CONCLUSION

This unit serves as the background knowledge of this course. Having gone through this unit, you should be well acquainted with the definition and scope of hydrology, its major branches and mode of study, which involve both laboratory analysis and field measurements of hydrological processes. To further appreciate the science of hydrology, unit two will discuss a brief history of the development of hydrology.

5.0 SUMMARY

In this unit, you have learnt that:

- hydrology is the detailed scientific study of water
- the study of hydrology is multi-disciplinary
- the hydrological cycle is the central theme of the study of hydrology
- hydrological studies involve the application of scientific knowledge and mathematical principles to solve water related problems
- the major branches of hydrology include: chemical hydrology, ecohydrology, surface hydrology, and hydrogeology amongst others.

6.0 TUTOR-MARKED ASSIGNMENT

i. The detailed scientific study of water is called________
ii. The branch of hydrology that deals with the study of the chemical characteristics of water is called_______
iii. The __________ is the central theme of the study of hydrology.
iv. A person that studied hydrology is called……….
(a) hydrocomist (b) hydronomist
(c) hydrologist (d) hydronogist
v. All except one are some of the hydrological processes measured in the study of hydrology............
(a) rainfall (b) runoff (c) soil moisture (d) rock formation
vi. Which of the following is note a branch of hydrology?
(a) chemical hydrology (b) surf hydrology (c) hydrogeology
(d) isotope hydrology

7.0 REFERENCES/FURTHER READING

Linsley, R.K. Jr, Kohler, M.A. & Paulhus, J.L. (1982). *Hydrology for Engineers.* (3rd ed.). McGraw-Hill International Book.

Universities Council on Water Resources (2011). “Hydrology: The Study of Water and Water Problems. A Challenge for Today and Tomorrow.”

Viessman, W. & Lewis, G.L. (2003). *Introduction to Hydrology.* (5th ed.). Upper Saddle River, New Jersey: Pearson Education Inc.

Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology.* (4th ed.). UK: McGraw-Hill Publishing Company.

UNIT 2 BRIEF HISTORY OF THE DEVELOPMENT OF HYDROLOGY

CONTENTS

1.0 INTRODUCTION

Having been introduced to the definition and scope of hydrology in unit 1, it is therefore important to have a peep into the historical development of hydrology. The historical aspect of the course is necessary because it provides a better understanding on how the course had faired through the various ages. The historical development of hydrology will be discussed under two broad subdivisions – early and modern stages of hydrology.

2.0 OBJECTIVES

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

- discuss the hydrology development in the early stage
- discuss advances in hydrology in the modern era
- list the major contributors to the development of hydrology during both stages.

3.0 MAIN CONTENT

3.1 Early Stage of Hydrology Development

Most of the early civilisation in the world grew up along river courses, such as the Nile Valley in Egypt and the Hwang Ho River in China. These early civilisations developed along river courses because of the proximity to water supply.

In the times of this early civilisation, hydraulic structures such as dams and channels were constructed. All the structures built were mainly to control nature. Such structures include dams and channels, which were dug to store, direct and conserve water. The people who built these dams and channels did not really understand the hydrological implications of the structures been constructed. From the period 3500-300 BC, no efforts were really made to understand the structures built by early civilisations across river valleys to get water.

The Egyptians were at the forefront for knowledge in hydrological processes. For example, about 3500 BC the Nile was dammed to improve agricultural productivity of previously barren lands. In addition, they recorded the fluctuations in water level along Nile, using an instrument called the nilumeter. The information gathered provided flood warning to inhabitants' resident at the lower Nile basin. In the field of groundwater, the Egyptians were also at the forefront. They constructed a lot of instruments used in determining the table water level and the likelihood of getting water from a given location or place.

During the Roman Empire, there was substantial development in the field of hydrology. This was the era, when practical engineers really came to the forefront in hydrological study. It is a more practical era based on empirical approach. During the era, sewers, fine harbours, roads and dams were built. In fact, the first water supply system was built in Rome. At this time, there were no established principles guiding the built structures. The only area where the Romans discussed theory as a guiding principle in their engineering works was in the process of discharge. Discharge is quantified as:

$D = V \times A$ --------- (1)
Where:
D = discharge
V = velocity
A = cross sectional area.

One of the foremost contributors to hydrological development during the first century was Marcus Vitruvius. He developed a philosophical theory of the hydrologic cycle, in which precipitation falling in the mountains infiltrated the earth's surface and led to streams and springs in the lowlands.

In the 15th century upwards various exploration works began to surface. The Europeans exploration of the whole world at this period, led to the emergence of more philosophies about water in different spheres. For instance, with the adoption of a more scientific approach, Leonardo da Vinci and Bernard Palissy independently reached an accurate representation of the hydrologic cycle.

Leonardo da Vinci (1452-1519) made three major contributions to the development of hydrology:

(1) he provided better description of the hydrological cycle
(2) he provided a clear understanding of the principle of water flow in river channels
(3) he used floats in determining water velocity, hence velocity distribution in the channel.

On the other hand, Bernard Palissy stated categorically that rivers and streams originate from rainfall. He expatiated on the principles guiding artesian wells, lag time in hydrograph and other related phenomena of water flow. He also thought about the need for afforestation in drainage basin as a means to control erosion and conserve water in soils. It was not until the 17th century that hydrologic variables began to be quantified.

3.2 Modern Hydrology Development Era

The beginning of the modern stage of hydrology development could probably be traced to the 17th century when hydrological variables began to be quantified. Pioneers of the modern science of hydrology include Pierre Perrault, Edmund Halley and Edme Mariotte. In France, Pierre Perrault (1608-1680) demonstrated that rainfall was sufficient to support the flow of streams and rivers throughout the year. He demonstrated this by demarcating the basin of River Seine and calculated the annual discharge and rainfall of the basin and found out that the discharge of River Seine was only one-sixth of the total discharge of the basin. Edmund Halley (1656-1742) proved that enough water is evaporated from the ocean and stagnant water bodies to produce rainfall and replenish rivers. What he did was to calculate the total evaporation from the Mediterranean Sea and also determine the amount of water that enters it from the nine major rivers. He found that the amount of water entering the Mediterranean was a little over one-third the amount of water lost through evaporation.

Edme Mariotte (1620-1684) major contribution to hydrology was on his work on River Seine, where he combined velocity and river cross-section measurements to obtain discharge. Other major developments during this period were the development of the automatic rain gauge and the current meter, which was used to measure the velocity of water.

During the 18th century, the Pitot tube was developed and installed at various points along river channels to know at what point the velocity is highest along the cross sectional area of a river. It was discovered that the river has its highest velocity at the centre of the cross-sectional area; and lowest on top and around the corners where it has frictional drags with the walls of the channel.

Anthony Chazy in the 18th century was the first to extend the characteristics of one stream to another. He was the first to discuss the fact that most of the hydrological processes and principles of river systems are similar. He discovered this while working on the task to improve water supply to Paris.

In the 19th century like in other sciences, hydrology experienced rapid growth. This period saw the development in groundwater hydrology, including Darcy's law, the Dupuit-Thiem well formula, and Hagen-Poiseuille's capillary flow equation.

In the 20th century, rational analysis began to replace empiricism, while governmental agencies began their own hydrological research programmes. Of particular importance were Leroy Sherman's unit hydrograph, the infiltration theory of Robert E. Horton, and C.V. Theis's Aquifer test/equation describing well hydraulics. Since the 1950s however, hydrology has been approached with a more theoretical basis than in the past, facilitated by advances in the physical understanding of hydrological processes and by the advent of computers and especially Geographic Information Systems (GIS).

SELF-ASSESSMENT EXERCISE

Identify the major contributors and their contributions to the development of hydrology.

4.0 CONCLUSION

Having gone through the history of the development of hydrology, you should be well acquainted of its various developmental stages and major contributors to its development. From the history, it is evident that the early stage of hydrological study was unscientific, while the modern stage brought the study of hydrology to the full embrace of the scientific method.

5.0 SUMMARY

In this unit, you have learnt that:

- the history of the development of hydrology can be classified into early and modern stages.
- the Egyptians were at the forefront for knowledge in hydrological processes. For example, about 3500 BC the Nile was dammed to improve agricultural productivity of previously barren lands
- the early stage of hydrological development witnesses a philosophical and empirical approach
- the 18th and 19th century witness significant growth in hydrology. This period saw the development of the Pitot tube and ground water hydrology
- the modern stage of hydrological development saw the embrace of the scientific methods
- some of the major contributors to the development of hydrology include Marcus Vitruvius, Leonardo da Vinci, Bernard Palissy, Pierre Perrault, Edmund Halley and Edme Mariotte.

6.0 TUTOR-MARKED ASSIGNMENT

i. The Egyptians recorded the fluctuations in the level of water of the Nile using an instrument called the ____________

ii. The approach to the study of hydrology during the early stage was ___________

iii. The beginning of the modern stage of hydrological development could probably be traced to what century.
(a) 15th century (b) 16th century (c) 17th century (d) 18th century

iv. Who described a philosophical theory of the hydrologic cycle, in which precipitation falling in the mountains infiltrated the earth's surface and led to streams and springs in the lowlands?
(a) Marcus Vitruvius (b) Leonardo da Vinci (c) Bernard Palissy (d) Edmund Halley.

v. The beginning of the development of groundwater hydrology could be traced to what century?
(a) 15th century (b) 17th century (c) 18th century (d) 19th century

7.0 REFERENCES/FURTHER READING

Alakpodia, J. (1989). "Lecture Notes on Hydrology and Water Resources." Bendel State University, Ekpoma.

Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology.* (4th ed.). UK: McGraw Hill Publishing.

UNIT 3 BASIC PROPERTIES OF WATER

CONTENTS

1.0 INTRODUCTION

Water is the most abundant compound in the biosphere. It has a volume of about one and a half billion cubic kilometers. Of this quantity, 97 per cent is salt water, which is a major disadvantage to man. Only three per cent is fresh water, of which about three-quarter is locked up in the poles as ice and of course on the top of high mountains. Less than one percent is left in lakes and rivers for human use. Of the available water, one of man most precious resources and an important component of the environment is not well appreciated until reduced availability or quality or both threaten its use. To appreciate water as a resource, its basic properties will be examined in this unit. These properties include the states of water, water as a universal solvent, a source of energy, its effect on climate, and structure of its molecule.

2.0 OBJECTIVES

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

- explain the three states of water
- explain why water is referred to as universal solvent
- discuss the moderating influence of water on climate
- justify water as a source of energy.

3.0 MAIN CONTENT

3.1 Structure of Water Molecule

The distance of the Earth from the sun places it within a remarkable temperate zone compared with the other planets. This temperature location allows all states of water-ice, liquid and vapour, to occur naturally on earth. Two atoms of hydrogen and one of oxygen (H_2O), which readily bond, compose a water molecule. The resulting molecule exhibits a unique stability, as a versatile solvent, and possesses extraordinary heat characteristics. As the most common compound on earth's surface, water exhibits uncommon properties. Because of the nature of the hydrogen-oxygen bond, the hydrogen side of the water molecule has a positive charge and the oxygen side a negative charge; hence it dissolves so many other molecules and elements. Thus, due to its solvent activity, pure water is rare in nature.

Water molecules are attracted to each other because of their polarity. The positive (hydrogen) side of one water molecule is attracted to the negative (oxygen) side of another. The bonding between water molecules is called hydrogen bonding, it is important to note that without hydrogen bonding, water would be a gas at normal surface temperatures.

3.2 Different States of Water

Water can exist in three states- solid (ice), liquid (water), and gas (water vapour). A change of state from solid to liquid, liquid to gas or solid to gas requires the input of heat energy called latent heat, which is drawn in from the surroundings and stored within the water molecules. When the change goes the other way, from liquid to solid, gas to liquid, or gas to solid, this latent heat is released to the surroundings.

3.2.1 Water (Liquid Phase)

In liquid phase, water assumes the shape of its container and is a non-compressible fluid, quite different from solid, rigid ice. For ice to melt, heat energy must increase the motion of the water molecules to break some of the hydrogen bonds. Despite the fact that there is no change in sensible temperature between ice at 0^0C and water at 0^0C, 80 calories of heat must be added for the phase change of one gram of ice to one gram of water. This heat is called latent heat because it is stored within the water and is liberated with a phase reversal when a gram of water freezes. These 80 calories are the latent heat of melting and of freezing. A calorie is the amount of energy required to raise the temperature of one gram of water (at 15^0C). To raise the temperature of one gram of water from freezing at 0^0C (32^0f) to boiling at 100^0C (212^0f), we must add 100 additional calories, gaining an increase of 1^0C (1.8^0f) for each calorie added.

3.2.2 Water Vapour (Gas Phase)

Water vapour is an invisible and compressible gas in which each molecule moves independently. To accomplish the phase change from liquid to vapour at boiling temperature, under normal sea-level pressure, 540 calories must be added to 1 gram of boiling water. Those calories are the latent heat of vaporisation. When water vapour condenses to a liquid, each gram gives up its hidden 540 calories as the latent heat of condensation.

In summary, taking 1g of ice at 0^0C and changing its phase to water, then to water vapour at 100^0C – from a solid to a liquid, to a gas – absorbs 720 calories (80 cal + 100 cal + 540 cal). Reversing the process, or changing the phase of 1g of water vapour at 100^0C to water, then to ice at 0^0C, liberates 720 calories into the surrounding environment.

3.2.3 Ice (Solid Phase)

Among common compounds and molecules, water is the only one whose solid form is lighter than its liquid form (it expands by about eight per cent when it freezes, becoming less dense), which is why ice floats. If ice were heavier than liquid water, it would sink to the bottom of water bodies; the biosphere would be vastly different from what it is, and life, if it existed at all, would be greatly altered. If bodies of water froze from the bottom up, they would freeze solid, killing all life in the water. Cells of living organisms are mostly water. As water freezes and expands, cell membranes and walls rupture. Finally, water is transparent to sunlight, allowing photosynthetic organisms to live below the surface. Figure 3.1 shows the three states of water and water's phase changes.

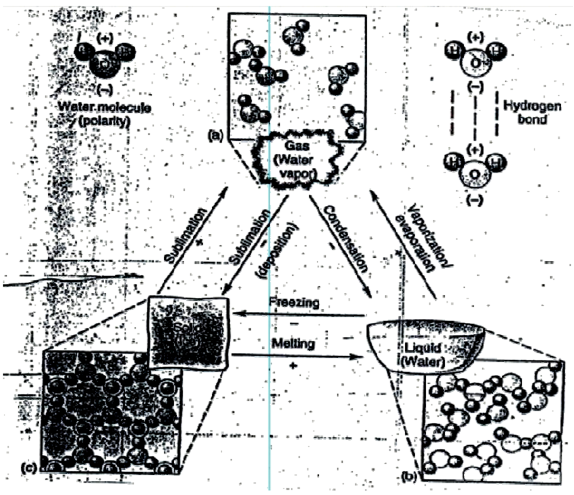

Fig.3.1: The Three States of Water and Water Phase Changes
Source: Christophherson, R. W. (2007). Elemental Geosystems

Figure 1.0 above shows the three physical states of water: (a) water vapour, (b) water, and (c) ice. Note the molecular arrangement in each state and the terms that describe the changes from one phase to another as energy is either absorbed or released. Also note how the polarity of water molecules bonds them to one another, loosely in the liquid state and firmly in the solid state. The plus and minus symbols on the phase changes denote whether heat energy is absorbed (+) or liberated (-) during the phase change.

3.3 Water as a Universal Solvent

Water is a universal solvent because it is needed by all biological lives. Water is a non-ionic polar molecule, which dissolve anything similar to it. As earlier stated, the molecule of water is made up of two atoms-hydrogen and oxygen. Out of these two, oxygen atom is negatively charged whereas the atom of hydrogen carries a positive charge. As both the charges are weak, it makes the molecule neutral in itself. It is because of the same reason that water is able to dissolve all those substances, which are of the similar type. Thus, water dissolves more of the substances rather than the liquid in it. When a substance dissolves, its molecules separate from one another and mingle with molecules of the solvent. Because water is electrically charged, it dissolves other charged molecules such as salts, but it does not dissolve uncharged molecules such as oil.

It should be noted that humans require more of water than any other substance. The food we eat and the air we breathe in contain a lot of chemicals and other toxins, which are only purified by our kidneys with the help of water.

3.4 Water as a Source of Energy

Water act as a source of energy in different ways, for example, the evaporation of water is one of the major sources through which the atmosphere gets its energy. Evaporated water on getting to the upper part of the atmosphere condenses and energy is liberated into the atmosphere.

Hydroelectric energy is produced through the force of falling water. The capacity to produce this energy is dependent on both the available flow and the height from which the water falls. Building up behind a dam, water accumulates potential energy. This is transformed into mechanical energy when the water rushes down the sluice and strikes the rotating blades of a turbine. The turbine’s rotation spins electromagnets, which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines.

3.5 Moderating Influence of Water on Climate

Bodies of water affect climate in many ways, but perhaps the most significant impact is based on the fact that large water bodies act as heat sinks. In other words, large water bodies tend to store heat in warm periods and release it in cold periods. This is because the thermal capacity of water is high, which means it takes a lot of energy to change the temperature of water. Hence, during the summer, land areas near a large body of water may not heat up as much as areas that are not close to water, because the water itself is absorbing much of the heat energy. This will cause the climate to be more moderate in summer near the coast. Likewise in winter, the water near the coast will slowly release this energy, causing coastal areas to be less cold, in general, than inland areas. In summary, large bodies of water tend to moderate temperatures in both summer and winter in nearby land areas, compared to areas that are further inland.

There are many other ways that water bodies affect climate such as warm or cold temperature currents. The Gulf stream, for example, a warm current, tends to keep the east coast of the US warmer than it otherwise would be, because it flows from the warm Gulf of Mexico past Florida and up along the east coast.

3.6 Distribution of Earth's Water

The total free water of the earth in its three states-liquid, solid and gas is generally referred to as hydrosphere. About 97 per cent of Earth's water is in the salty oceans, while another 20 per cent is found in ice caps and glaciers. Together, the oceans and ice tie up more than 99 per cent of the total water; unfortunately, both sources are generally unsuitable for human use because of salinity and location. Thus, the amount of water, which all the people, plants and animals on earth compete with, is much less than one percent of the total.

Fresh water in the liquid state is found on and beneath the earth surface. Water occupying openings in soil and rock is called subsurface water; most of which is held in deep storage, while water held in soil within the reach of plant roots is just about 0.011 per cent of the hydrosphere. Water held in streams, lakes, marshes and swamps is called surface water.

The oceans are the ultimate receptacle for terrestrial water flowing from rivers. Because of their size and mixing, the oceans dilute many human produced wastes to less harmful or harmless levels. They play a major role in regulating the climate of the earth by helping distribute solar heat through ocean currents and evaporation as part of the hydrologic cycle. They also participate in other major bio-geochemical cycles. In addition the oceans serve as gigantic reservoir of carbon dioxide, which helps regulate the temperature of the atmosphere. Oceans provide habitats for about 250,000 species of marine plants and animals, which are food for many organisms, including human beings. They also serve as a source of iron, sand, gravel, phosphate, magnesium, oil, natural gas, and many other valuable resources.

The total average annual water yield (runoff) from earth's rivers is approximately 47,000Km^3, but its distribution is far from uniform. Compare with other resources, water is used in tremendous quantities. In recent years, estimates of the total mass (or weight) of water used on earth per year has been approximately 100 times the world's total production of minerals, including petroleum, coal, metal ores, and non metals. The various location of water available in and on the earth surface is linked together by the hydrologic cycle. Table 3.1 shows the distribution of earth's water.

Table 3.1: Distribution of Earth's Water

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of fresh water	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.5
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	--	1.7
Fresh	256,000	10,530,000	30.1	0.76
Saline	3,088,000	12,870,000	--	0.94
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	21,830	91,000	0.26	0.007
Saline	20,490	85,400	--	0.006
Atmosphere	3,095	12,900	0.04	0.001
Swamp water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological water	269	1,120	0.003	0.0001
Total	**332,500,000**	**1,386,000,000**	-	**100**

Source: Gleick, P. H. (1996). Water Resources, in Encyclopedia of Climate and Weather, S.H. Schneider (Ed.). Oxford University Press, New York

SELF-ASSESSMENT EXERCISE

What evidence do you have to support the assertion that the solid state (ice) of water is lighter than the liquid state?

4.0 CONCLUSION

To understand water as a resource, there is need to understand its basic properties and its role in the biosphere. From the above discussions, water is a unique liquid;

without it, life as we know it is impossible. Compared with most other common liquids, water has a high capacity to absorb or store heat. Water is a good liquid solvent because, many natural waters are slightly acidic they can dissolve a great variety of compounds. In addition, water can exist in three different states – liquid, solid and gas; it also has a moderating effluence on climate and a good source of energy.

5.0 SUMMARY

In this unit, you have learnt that:

- two atoms of hydrogen (positive) and one of oxygen (negative), which readily bond, compose a water molecule. The molecules are attracted to each other because of their polarity. The bonding between water molecules is called hydrogen bonding
- water can exist in three states-solid, liquid and gas. A change of state from one form to another requires the input of heat energy called latent heat
- water is a universal solvent because it is needed by all biological lives. It is a non-ionic polar molecule, which dissolves anything similar to it
- evaporation of water is one of the major sources through which the atmosphere gets its energy. Water is also a source of hydroelectric energy
- water has a moderating influence on climate, as large bodies of water act as heat sinks (its ability to store heat in warm periods and release it in cold periods).

6.0 TUTOR- MARKED ASSIGNMENT

i. The bonding between water molecules is called _____________

ii. Name the three states of water
   (a) __________________
   (b) __________________
   (c) __________________

iii. Water is referred to as a universal solvent because it is needed by all ______

iv. How many calories of heat must be added for the phase change of one gram of ice to one gram of water?
   (a) 70 calories (b) 80 calories (c) 540 calories (d) 720 calories

v. Which of the following is true about water?
   (a) The solid form is heavier than the liquid form
   (b) The solid form is lighter than the liquid form
   (c) The solid form is equal to the liquid form
   (d) None of the above

vi. What happens when water freezes?
   (a) It contracts (b) it remains unchanged (c) It expands (d) None of the above

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UNIT 4 APPLICATIONS OF HYDROLOGY

CONTENTS

1.0 INTRODUCTION

There must be justifiable reasons for the study of any discipline, and the study of hydrology is not an exception. The question now is why do we study hydrology? This question will be answered by looking at the various applications of hydrology in society.

2.0 OBJECTIVE

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

- identify the various areas of application of hydrology in society.

3.0 MAIN CONTENT

3.1 Hydrology in the Society

The application of hydrology in the society can be traced to any human endeavour that requires the use of water since hydrologists apply scientific knowledge and mathematical principles to solve water-related problems in the society. Such problems include water quantity, quality and availability. Hence, they may be concerned with finding water supplies for cities or irrigated farms; or controlling river flooding or soil erosion, environmental protection, preventing or cleaning up pollution or locating sites for safe disposal of hazardous wastes can also be addressed by hydrologist.

It should be noted that most cities meet their needs for water by withdrawing it from the nearest river, lake or reservoir. Hydrologists help cities by collecting and analysing the data needed to predict how much water is available from local supplies and whether it will be sufficient to meet the city's projected future needs. To do this, hydrologist study records of rainfall, snowpack depths and river flows that are collected and compiled by hydrologists in various government agencies.

Hydrologists use topographic maps and aerial photographs to determine where the reservoir shorelines will be and to calculate reservoir depths and storage capacity. This work ensures that, even at maximum capacity, no highways, railroads or homes would be flooded. This is necessary since managing reservoirs can be quite complex, because they generally serve many purposes. Reservoirs increase the reliability of local water supplies.

In addition, deciding how much water to release and how much to store depends upon the time of year, flow predictions for next several months, and the needs of irrigation and cities, as well as downstream water-users that rely on the reservoir. If the reservoir also is used for recreation or for generation of hydroelectric power, those requirements must be considered. Decisions must be coordinated with other reservoir managers along the river. Hence, hydrologists collect the necessary information, enter it into a computer, and run computer models to predict the results under various operating strategies. Based on these studies, reservoir managers can make the best decision for those involved.

The availability of surface water for swimming, drinking, industrial or other uses is sometimes restricted because of pollution. Pollution can be merely an unsightly and inconvenient nuisance, or it can be an invisible, but deadly threat to the health of people, plants and animals. In this regard, hydrologists assist public health officials in monitoring public water supplies to ensure that health standards are met. When pollution is discovered, environmental engineers work with hydrologists in devising the necessary sampling programme. Water quality in estuaries, streams, rivers and lakes must be monitored, and the health of fish, plants and wildlife along their stretches surveyed. Related work concerns acid rain and its effects on aquatic life, and the behaviour of toxic metals and organic chemicals in aquatic environments. Hydrologic and water quality mathematical models are developed and used by hydrologists for planning and management and predicting water quality effects of changed conditions.

Hydrologists assist to protect groundwater supply by providing guidance in the location of monitoring wells around waste disposal sites and sample them at regular intervals to determine if undesirable leachate –contaminated water containing toxic or hazardous chemicals is reaching the ground water. Hydrologists are often consulted for the selection of proper sites for new waste disposal facilities.

Hydrology also finds its applications in the determination of water balance of a region; agricultural water balance, mitigating and predicting flood, landslide and drought risk. It is also relevant in designing dams for water supply or hydroelectric power generation, bridges, sewers and urban drainage system. Worthy of note is the relevance of hydrology in predicting geomorphological changes, such as erosion or sedimentation, and assessing the impacts of natural and anthropogenic environmental change on water resources.

SELF-ASSESSMENT EXERCISE

Examine the various use of water in the society and identify areas where hydrology can be applied.

4.0 CONCLUSION

From the discussions on the various possible applications of hydrology in society, it can be concluded that the applications of hydrology is as varied as the uses of water and may range from planning multibillion naira interstate water projects to advising homeowners about backyard drainage problems .

5.0 SUMMARY

In this unit, you have learnt that:

- the application of hydrology can be traced to any human endeavour that requires the use of water
- hydrology can be applied in the provision of water for domestic, agricultural and industrial and other uses
- hydrology is also relevant in predicting geomorphogical changes, such as erosion or sedimentation, and assessing the impacts of natural and anthropogenic environmental change on water resources.

6.0 TUTOR-MARKED ASSIGNMENT

i. The applications of hydrology in the society can be traced to any human endeavour that requires the use of _______________
ii. The availability of surface water for drinking, industrial or other uses is sometimes restricted because of __________________
iii. Hydrology can be applied in which of the following areas?
   (a) determination and monitoring of water quality
   (b) determination of agricultural water balance
   (c) designing dams for water supply
   (d) all of the above

7.0 REFERENCE/FURTHER READING

Universities Council on Water Resources (2011). "Hydrology: The Study of Water and Water Problems. A Challenge for Today and Tomorrow."

UNIT 5 THE HYDROLOGIC CYCLE

CONTENTS

1.0 INTRODUCTION

As noted in unit one, the hydrologic cycle is the central theme of the study of hydrology. Hence, it is important to know what hydrologic cycle is all about, and the various processes involved in the hydrologic cycle. Understanding the hydrologic cycle therefore, is basic to understanding water supply and is a key to the proper management of water resources.

2.0 OBJECTIVES

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

- define hydrologic cycle
- identify and discuss the various processes in the hydrologic cycle.

3.0 MAIN CONTENT

3.1 Definition of Hydrologic Cycle

The movement and endless recycling of water between the atmosphere, the land surface and underground is called hydrologic cycle. This movement, driven by the energy of the sun and the force of gravity, supplies the water needed to supported life. Similarly, Viessman and Lewis (2003) defined hydrologic cycle as a global sun-driven process whereby water is transported from the oceans to the atmosphere to the land and back to the sea. The ocean is the earth's principal reservoir; it stores over 97 per cent of the terrestrial water. Water is evaporated by the sun, incorporated into clouds as water vapour, falls to the land and sea as precipitation, and ultimately finds its way back to the atmosphere through a variety of hydrologic processes.

The hydrologic cycle can be considered a closed system of the earth, because the total amount of water in the cycle is fixed even though its distribution in time and space varies. There are many sub-cycles within the worldwide system, which are generally open-ended. These subsystems give rise to the many problems of water supply and allocation that confront hydrologists and water managers.

3.2 Processes in the Hydrologic Cycle

The entire process in the hydrologic cycle can be divided into five parts, which include: condensation, precipitation, infiltration, runoff and evaporation. The hydrologic cycle is very complex due to the fact that all biological lives depend on water. However, it is necessary, in spite of its complexities to look at the major pathways or processes in the movement of water through the cycle.

Starting from the ocean, which is sometimes termed as the main water reservoir, evaporation takes place due to solar heating. The evaporated water moves into the upper atmosphere, where it condenses and may fall back as rain into the ocean bodies. However, where there is an onshore wind, the evaporated water could be blown to the land in form of moisture-laden wind. Over the land, condensation can occur especially where the moisture-laden wind is forced high up into the atmosphere due to topography. This may result in orographic rains. Even right on the land evaporation could take place from stagnant water body, the soil and vegetation-in a combined processes known as evapotranspiration. Rain that falls on land is used up in many processes. Plants and animals depend on it for survival. Some of it sinks into the soil through infiltration, flows underground into river systems. Where the soils are saturated, runoffs are generated. The runoffs could flow into river systems. Man can even tap water from the soils by sinking bore holes and wells. The rivers could be dammed for irrigation purposes, domestic and industrial processes.

Water could also be evaporated from dams and in other processes in which man uses it such as irrigation. The evaporated water moves up into the atmospheric system where it can also condense and fall as rain. The movement of water continues along the river systems. As the rivers move into the ocean, evaporation continues to take place until it eventually empties into the ocean.

It is generally observed that evaporation is the driving force in the movement of water in the hydrologic cycle. The movement of water just discussed is a simplified model of the hydrologic cycle. In nature, the movement of water could be much more complex and complicated because all biological lives depend on it. The hydrologic cycle is so fundamental to sustainable water supply because it continues to move water and keep sources fresh. Without the hydrologic cycle, life on earth would be impossible. Figure 5.1 shows a simplified diagram of the hydrologic cycle.

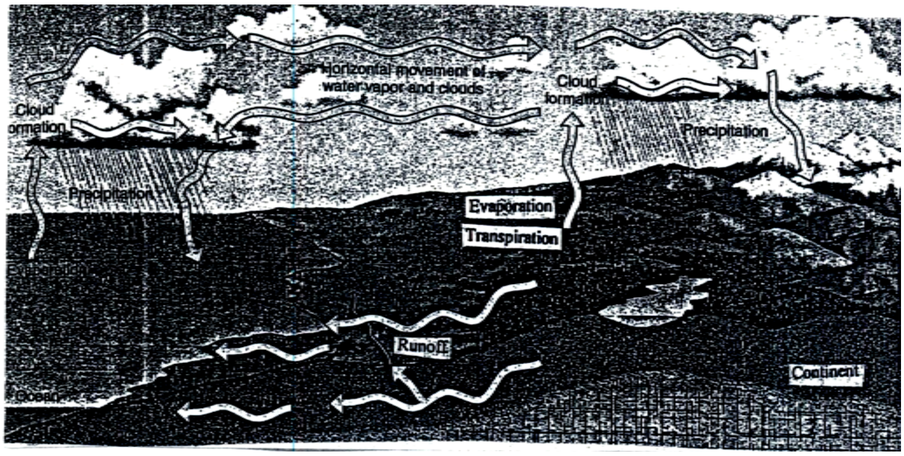

Fig.5.1: A Simplified Diagram of the Hydrological Cycle
Source: Aguado. E. & Burt, J. E. (2007). Understanding Weather and Climate

3.3 Hydrological Budget

Hydrologic budget can be defined as the accounting of the inflow, outflow and storage of water in a designated hydrologic system. A water budget comprised of the components of the hydrologic cycle that can be formulated. The variables in the water budget equation are: precipitation P, Runoff R, Interception I, Evaporation E, Transpiration T, Evapotranspiration ET, Groundwater G, and ΔS stand for change in storage. With these variables, a hydrologic budget can be derived. Inflows to the region are denoted as positive quantities and outflows as negative ones. Subscripts s and g indicate surface and underground components respectively. The development of an equation for the water budget is straightforward. For a designated period, it provides for balancing the gains and losses of water with the quantities of water stored in the region (a continuity equation).

According to Viessman Jr. and Lewis (2003), the hydrologic budget for surface flow can be written as:

$$P + R_1 - R_2 + Rg - E_S - E_g - T_S - I = \Delta S_S$$

Where precipitation, surface water inflow, and groundwater appearing as surface water (Rg) are inflows, as surface-water outflow; evaporation, and infiltration are outflows, and all variables are volumes per unit of time.

They also gave the hydrologic budget for underground flow as follows:

$$1 + G_1 - G_2 - R_2 - Rg - Eg - Tg = \Delta S_S$$

Where infiltration and groundwater inflow are inflows; groundwater outflow, groundwater appearing as surface water, evaporation and transpiration are outflows. The combined hydrologic budget for a region can however be derived by summing the two previous equations as follows:

$$P-(R_2-R_1) - (Es+Eg) - (Ts + Tg) - (G_2-G_1) = \Delta(Ss+Sg)$$

If the subscripts are dropped and the quantities in parentheses are taken as net changes, the equation reduces to:

$$P- R- E- T- G = \Delta S.$$

This is the fundamental equation of hydrology and it is the basis for all hydrologic modelling.

3.4 Global Water Balance

Ward and Robinson (2000) noted that despite the ever-changing global distribution of water vapour, evaporation, precipitation and runoff and the associated changes in soil water and groundwater storage, the global water balance is, in effect, a closed system because virtually no water is lost from the system and the occasional releases of fossil groundwater, or possible additions of water from comets, are minute. They further noted that over quite short periods of time, the input of water vapour into the atmosphere by evaporation is wholly accounted for by the condensation – precipitation process. Thus described, the global water balance is very simple. However, quantifying it has proved a difficult and elusive task. Many estimates have been made, all of which differ and the earliest of which were based on sparse and often inadequate data.

Estimates of the main fluxes in the global water balance, based on a number of sources are summarised in Table 51. These estimates are illustrative, reflecting as they do a wide range of values for each water balance component.

For example, the precipitation and evaporation estimates presented by Speidel and Agnew (1988) varied by 29 per cent and the estimates of runoff to the oceans varied by 40 per cent. Such uncertainly about the magnitude of major fluxes of water and energy makes it difficult to identify and interpret global change within the hydrologic, atmospheric and oceanic systems or to predict the likely impact of that change upon human beings and their activities.

Table 5.1: Estimated Annual Flux in the Global Water Balance

Flux	**Oceans (cukm)**	**Land (cukm)**	**Global total (cukm)**	**Oceans (mm)**	**Land (mm)**	**Global (mm)**
Precipitation	385000	111100	496100	1066	746	973
Runoff (river flow, direct groundwater flow, icemelt)	39700	39700	0	110	267	0
Net inland advection of water vapour	-39700	39700	0	-110	267	0
Total	-39700	39700	0	-110	266	0

Source: Wards & Robinson (2000) (Based on Data from Speidel and Agnew, 1988).

3.5 Human Influence on the Water Cycle

There are several cases of human interaction in the hydrosphere, which has serious implications on the hydrologic cycle. Olomo (1999) identified three of such interactions, which include.

(i) Activities that affect precipitation input into the cycle. For example, cloud seeding with silver iodide, which alters the distribution of rainfall,
(ii) Creation of artificial lakes when building dams, thus increasing the rate of evaporation and;
(iii) Decrease of evaporation caused by draining of swamps and other reclamation works, which reduces the amount of water available to the atmosphere.

In addition to the above human activities, which influence the water cycle, the process of road construction and other constructional activities coupled with urbanisation, have led to the development of concrete soil and pavements, which prevent or slow the rate of infiltration. This problem has led to the depletion of groundwater resources, with serious consequences on water quality and quantity.

Furthermore, the green house effect, which developed as a result of increase of carbon-dioxide into the atmosphere, has led to the concept of climate change, which impact on precipitation distribution, sea level rise and high temperature leading to high rate of evaporation.

In addition, diversion of water for irrigation purposes modifies natural hydrological processes and Irrigated land often has high rates of evaporation and evapotranpiration. Another human activity that equally impacts on the hydrologic cycle is the over drafting of groundwater resources. This leads to lowering of the water table and possible intrusion of salt water into the fresh water aquifers, which degrade the water quality of affected aquifers.

SELF-ASSESSMENT EXERCISE

i. To better understand the concept of the hydrologic cycle, try and identify the major pathways of precipitation and the various uses of water on the earth's surface.
ii. Draw a simplified diagram of the hydrologic cycle.

4.0 CONCLUSION

From the above discussions, it is no longer in doubt that the hydrologic cycle is the major theme of the study of hydrology. Most of the basic concepts and processes studied in hydrology have their roots in the hydrologic cycle, as would soon be revealed in the subsequent lessons. It can safely be concluded that without the hydrologic cycle that continue to purify our water supply sources, life on earth would have been greatly altered.

5.0 SUMMARY

In this unit, you have learnt that:

- the hydrologic cycle is the endless movement of water between the atmosphere, land and underground, driven by the sun and force of gravity
- the entire process in the hydrologic cycle can be divided into five parts- evaporation, condensation, precipitation, infiltration and runoff
- evaporation caused by the sun's energy is the driving force in the movement of water in the hydrologic cycle
- the hydrologic cycle is so fundamental to sustainable water supply because it continues to move water and keep sources fresh.

6.0 TUTOR-MARKED ASSIGNMENT

i. Evaporation takes place due to ________________
ii. When evaporated water moves into the upper atmosphere it __________
iii. The process of water sinking into the soil is called _________________
iv. The combined process of water loss from soil and vegetation is called what
(a) evaporation (b) infiltration (c) transpiration
(d) evapotranspiration
v. The movement of water on the land surface is called what?
(a) runoff (b) hydrologic cycle (c) evaporation (d) precipitation

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UNIT 6 GROUNDWATER RESOURCES

CONTENTS

1.0 INTRODUCTION

The two major sources of water supply on earth are ground and surface water. Groundwater is a part of the hydrologic cycle that lies beneath the surface and it is tied to surface supplies. Groundwater is the largest potential source of freshwater in the hydrologic cycle – larger than all surface lakes and streams combined.. Despite this volume and its obvious importance, groundwater is widely abused by over exploitation and pollution. This unit will define and analyse the formation of groundwater resources. It will also discuss the problems of groundwater management.

2.0 OBJECTIVES

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

- define groundwater
- discuss the formation of groundwater
- identify the problems of groundwater management.

3.0 MAIN CONTENT

3.1 Definition of Groundwater

Groundwater is the part of the sub-surface water that fully saturates the pore spaces in bedrock, regolith, or soil, and so occupies the saturated zone. Arms (1994) simply defined groundwater as water below earth's surface. Of all the water that falls on land as rain or snow, about one-third runs off the surface into streams and rivers, and another one-third evaporates or is absorbed by plants. The rest drips or percolates down through soil and rocks and becomes part of the groundwater resources.

3.2 Formation of Ground Water Resource

Precipitation that does not evaporate back into the air or run off over the surface percolate through the soil and into fractures and space of permeable rocks in a process called infiltration. The upper soil layers that hold both air and water make up the zone of aeration and moisture for plant growth comes primarily from these layers. Depending on rainfall amount, soil type, and surface topography, the zone of aeration may be very shallow or quite deep. Lower soil layers where all spaces are filled with water make up the zone of saturation. The top of this zone is the water table. The water table is not flat, but undulates according to the surface topography and subsurface structure. Water tables also rise and fall seasonally, depending on precipitation and infiltration rates. Porous layers of sand, gravel, or rock lying below the water table are called aquifers. Relatively impermeable layers of rock or clay that keep water from seeping out at the bottom always underlie aquifers.

Folding and tilting of the earth crust by geologies processes can create shapes that generate water pressure in confined aquifers (those trapped between two impervious, confining rock layers). When a pressurised aquifer intersects the surface, or if it is penetrated by a pipe or conduct an artesian well or spring result from which water gushes without being pumped.

Areas in which infiltration of water into an aquifer occurs are called recharge zones. The rate at which most aquifers are refilled is very slow however groundwater is presently being removed faster than it can be replenished in many areas. Urbanisation, road building and other development often block recharge zones and prevent replenishment of important aquifers. Contamination of surface water in recharge zones and seepage of pollutants into abandoned wells have polluted aquifers in many places, making them unfit for most uses. Many cities protect aquifer recharge zones from pollution or development, both as a way to drain off rainwater and as a way to replenish the aquifer with pure water.

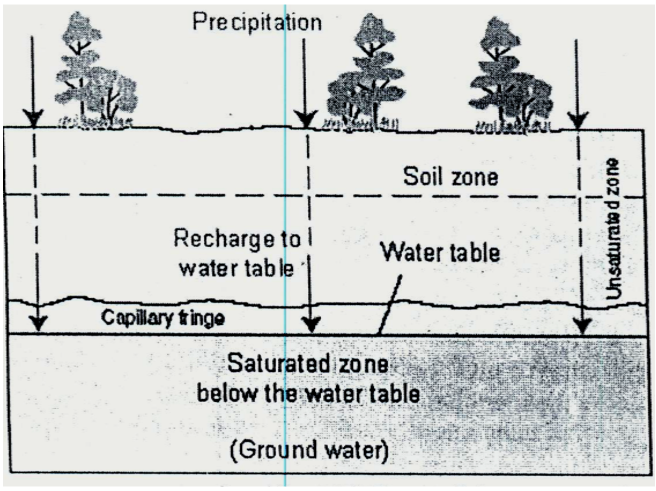

Fig. 6.1: **A Schematic Diagram of Groundwater**

3.3 Problems of Groundwater Resources

The problems of groundwater resources shall be examined from two perspectives- water table depletion and pollution.

3.3.1 Water Table Depletion

Groundwater is a major source of fresh water supplies for agricultural and domestic uses in most parts of the world. For example nearly half of all Americans and about 95 per cent of the rural population depend on groundwater for drinking and other domestic purposes.

The rapid withdrawal of groundwater has seriously impacted the environment in many places. For examples, increased urban populations and industrial developments require large water supplies needs that cannot always be met by constructing new surface water reservoirs. To fill these needs, vast number of wells using powerful submersible pumps draws huge volumes of groundwater to the surface. Such acts greatly alter nature’s balance of groundwater discharge and recharge. Over use of these supplies causes several kinds of problems, including drying of wells, natural springs, and disappearance of surface water features such as wetland, rivers and lakes.

When groundwater is being withdrawn from aquifers faster than natural recharge can replace it, at a local level, it causes a cone of depression in the water table. A heavily pumped well can lower the local water table so that shallower wells go dry. On a broader scale, heavy pumping can deplete a whole aquifer. The Ogallala Aquifer for example underlies eight states in the arid high plains between Texas and North Dakota. In spite of its depth of about 400m in its centre, this porous bed of sand, gravel, and sandstone once held more water than all the freshwater lakes, streams, and rivers on earth; due to excessive pumping for irrigation and other uses has removed so much water that wells have dried up in many places, and farms, ranches, even whole towns are being abandoned.

A major consequence of water table depletion is subsidence – a sinking of the land in response to the removal of water from underlying sediments. This problem has plagued a number of major cities that rely heavily on groundwater wells for their water supplies. For example, the US geological survey estimates that the San Joaquin Valley in California has sunk more that 10m in the last 50 years because of excessive groundwater pumping.

The development of sinkhole is also associated with groundwater depletion. Sinkholes are formed when the roof of an underground channel or cavern collapse, creating a large surface crater. Cunningham and Cunningham (2010) noted that drawing water from caverns and aquifers accelerates the process of collapse. They also observed that sinkholes can form suddenly dropping cars, houses and trees without warning into a gaping crater hundreds of meters across. Subsidence and sinkhole formation probably represent permanent loss of an aquifer because when caverns collapse or the pores between rock particles are crushed as water is removed; it may be very difficult or impossible to restore their water holding capacity.

Another major consequence of groundwater depletion apart from subsidence, sinkhole and groundwater mining (when recharge is less than withdrawal) is salt-water intrusion. This is the process whereby salt water infiltrates or intrude into fresh water aquifers used for domestic and agricultural purposes, as a result of the over use of freshwater reservoirs. This problem is more predominant in coastal areas.

3.3.2 Groundwater Pollution

Groundwater pollution refers to the degradation of groundwater quality. In defining pollution, we generally look at the intended use of the water, how far it departs from the norm, its effects on public health, or its ecological impacts. From a public health or ecological view, a pollutant is any biological physical or chemical substance that in identifiable excess is known to be harmful to other desirable living organisms. Water pollutants include excessive amounts of heavy metals, certain radioactive isotopes, faecal coliform bacteria, phosphorus, nitrogen, sodium, and other useful (even necessary) element, as well a certain pathogenic bacteria and viruses. In some instance a material may be considered a pollutant to a particular segment of the population although not harmful to other segment. For example, excessive sodium as a salt is not generally harmful, but it is to some people who must restrict salt intake for medical reasons.

Pollutants can infiltrate into the groundwater resources from industrial waste injection wells, septic tank outflows, seepages from hazardous waste disposal sites, industrial toxic-waste dumps, residues of agricultural pesticides, herbicides, fertilizers, and residential and urban wastes landfills. In fact, all segment of our society (urban, rural, industrial, agricultural, and military) may contribute to the problem of groundwater pollution.

Another source of groundwater contamination in coastal wells is saltwater intrusion. Since fresh water is less dense than salt water, coastal aquifers can be underlain by a layer of salt water from the ocean. When the aquifer is depleted, the level of saltwater rises and eventually reaches the well from below, rendering the well unusable.

It should also be noted that the pollution of surface water might also affect the quality of groundwater because they are inextricably linked. However, when surface water is polluted, it is much easier to flush out the pollution when compared to groundwater because, surface water flows rapidly. On the other hand, groundwater flows sluggishly hence, once contaminated, remain polluted virtually forever.

3.4 Global Groundwater Distribution

Water is widely distributed on earth as freshwater and salt water in the oceans. Unfortunately, about 97 per cent of global water is in the saline oceans of the world, while only about three per cent represents freshwater. The ice caps and glaciers holds about 68.7 per cent of the total world freshwater, while surface water accounts for 0.3 per cent, and groundwater accounts for about 30.1 per cent . As a result, the bulk of the water on earth is regarded as saline or salt water, with an average salinity of 3.5 per cent, roughly equivalent to 35 grams of salts in one kilogramme of seawater, though this varies slightly according to the amount of runoff received from surrounding land.

Even though the amount of total groundwater is a small percentage (1.7 per cent) of all the earth's water, it represents a large percentage of total available freshwater on earth. Table 1.1 shows that about 5,614,000 cubic miles (mi^3) or 23,400,000 cubic kilometers (km^3), of groundwater exist on earth. Of this amount, about 3,088,000 mi^3 (12,870,000 km^3) representing 54 per cent is saline, while about 46 per cent; representing 2,526,000 mi^3 (10,530,000 km^3) is freshwater.

Water in aquifers below the oceans is generally saline, while the water below the land surfaces (where freshwater, which fell as precipitation, infiltrates into the ground) is generally freshwater. There is however, a stable transition zone that separates saline water and freshwater below the ground.

Table 6.2: Global Groundwater Distribution

Water source	**Water volume, in cubic miles**	**Water volume in cubic kilometers**	**Percent of total water**	**Percent of total freshwater**
Fresh groundwater	2,526,000	10,530,000	0.8%	30.1%
Groundwater	5,614,000	23,400,000	1.7%	-
Total global water	332,500,000	1,386,000,000	-	-

Source: Gleick, P.H. (1996): Water Resources. In Encyclopedia of Climate and Weather by Schneider, S.H., Oxford University Press, New York, Vol.2, pp 817-823

The earth's largest known aquifer is the High Plains aquifer, which lies beneath the American High Plans, eight state 450,000-km² areas from southern part of South Dakota to Texas. Precipitation over the region varies from 30cm in the southwest to 60cm in the northeast. For several hundred thousand years, the aquifer's sand and gravel were charged with melt waters from retreating glaciers.

This highly rich aquifer has however suffered some decline due to heavy mining for irrigation, especially after the World War II, with the introduction of the Central-Pivot irrigation devices. During the past five decades, the water table in the aquifer has dropped more than 30m (100ft), and throughout the 1980s, it averaged a two-m (six-ft) drop each year. The United States Geological Survey (USGS) estimates that recovery of the High Plains aquifer (those portions that have not been crushed or subsided) would take at least 1000 years if groundwater mining should stopped today.

SELF-ASSESSMENT EXERCISE

Account for the formation of groundwater resources, and state how the problem of groundwater can be effectively managed.

4.0 CONCLUSION

Groundwater is a rich source of fresh water supply for domestic, agricultural and industrial uses. However, there are some militating problems in its management, which include pollution and depletion of the water table. If the problem of overuse and pollution are controlled, groundwater will continue to be a reliable source of fresh water supply.

5.0 SUMMARY

In this unit, you have learnt that:

- groundwater can be defined as water below the earth surface
- groundwater is the largest potential source of freshwater in the hydrological cycle
- groundwater is fed by surplus water, which percolates downward from the zone of capillary water as gravitational water
- water table depletion and contamination are some of the major challenges affecting the use of groundwater resources.

6.0 TUTOR-MARKED ASSIGNMENT

i. The two major sources of water supply on earth are ____ and ____ water.
ii. __ is a rock layer that is permeable to groundwater flow in useable amounts.
iii. A sinking of the land in response to the removal of water from underlying sediment is called _________
iv. A body of rock that does not conduct water in usable amounts is called what?
(a) aquifers (b) cone of depression (c) aquiclude (d) gravel
v. Which of the following is a problem of groundwater management?
(a) salt water intrusion (b) pollution (c) water table depletion (d) all of the above
vi. Pollution can enter groundwater through which of the following sources.
(a) industrial waste (b) injection wells (c) herbicides (d) all of the above

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UNIT 7 SURFACE WATER RESOURCES

CONTENTS

1.0 INTRODUCTION

As earlier noted, surface water resources are one of the two major sources of water supply on earth. It is also a major component of the hydrological cycle. This unit will focus on the definition of surface water, overland and stream flows, and surface water pollution. It will also base on tracing the flow paths of surplus water that runs off the land surface and ultimately reaches the sea. Here, the concern would primarily be on rivers and streams. In general usage, “river” is seen as large watercourses while “stream” as smaller ones. However, the word “stream” is also used as a scientific term designating the channeled flow of surface water of any amount.

2.0 OBJECTIVES

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

- define surface water
- distinguish between overland flow and stream flow
- identify the various forms of surface water pollution.

3.0 MAIN CONTENT

3.1 Definition of Surface Water

Surface water is water in a river, lake or stream. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation and unrecovered infiltration. Surface water can be withdrawn from the stream, lakes and reservoirs for human activities but only part of the total annual runoff is available for use. Some of it flows into the sea too rapidly to be captured and some are left in the stream for wildlife. Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors namely landscape, temporal variation, geographic factors and human activities. Hence, surface water is non-uniformly distributed over the earth surface.

3.2 Overland Flow and Stream Flow

Runoff that flows down the slopes of the land in broadly distributed sheets is overland flow. Overland flow can be distinguished from stream flow, in which the water occupies a narrow channel confined by lateral banks. Overland flow can take several forms. Where the soil or rock surface is smooth, the flow may be a continuous thin film, called sheet flow. Where the ground is rough or pitted, flow may take the form of a series of tiny rivulets connecting one water-filled hollow with another. On a grass-covered slope, overland flow is sub-divided into countless tiny threads of water, passing around the stems. Even in a heavy and prolonged rain, overland flow formation might not be noticed on a sloping lawn. On heavily forested slopes, overland flow may pass entirely concealed beneath a thick mass of decaying leaves.

Overland flow eventually contributes to a stream, which is a much deeper and more concentrated form of runoff. A stream can be defined as a long, narrow body of flowing water occupying a trench-like depression, or channel, and moving to lower levels under the force of gravity. The channel of a stream is a narrow trough, shaped by the forces of flowing water, which enhances the channel capacity to handle the volume of water and sediment supplied to the stream.

As a stream flows under the influence of gravity, the water encounters resistance – a form of friction – with the channel walls. As a result, water close to the bed and banks moves slowly, while water in the central part of the flow moves faster. If the channel is straight and symmetrical, the single line of maximum velocity shifts toward the bank on the outside of the curve.

Streams may be classified as influent or effluent. In an effluent stream, flow is maintained during the dry season by groundwater seepage into the stream channel from the subsurface. An influent stream is entirely above the groundwater table, and flows only on direct response to precipitation. Water from an influent stream seeps down into the subsurface.

3.3 Surface Water Pollution

Surface pollution water occurs when too much of undesirable or harmful substance flows into a body of water exceeding the natural ability of that water body to remove the undesirable material, dilute it to a harmless concentration, or convert it to a harmless form.

Water pollutants, like pollutants in general are categorised as emitted from point or nonpoint sources. Point sources are distinct and confined, such as pipes from industrial or municipal sites that empty into streams or rivers. Non-point sources, such as runoff, are diffused and intermitted and are influenced by factors such as land-use, climate, hydrology, topography, native vegetation, and geology. Common urban nonpoint sources include urban runoff from streets or fields; such runoff contains all sorts of pollutants, from heavy metals to chemicals and sediments. Rural sources of non-point pollution are generally associated with agriculture, mining, or forestry. Non-point sources are difficult to monitor and control.

From an environmental viewpoint, two approaches to deal with water pollution are to reduce the source or treat the water in order to remove or convert the pollutant to a harmless form. Whichever of the options used, depends on the specific circumstances of the pollution problem. However, reduction at the source is the most environmentally preferable way of dealing with pollutants.

3.4 Global Surface Water Distribution

The distribution of renewable river water across the earth's surface is uneven as revealed shown in Table 7.1.

Table 7.1: Global Distribution of River Water by Continent or Region

Continent or Region	**Renewable River Water (km^3)**	**Percent of World Total**
Sub-Saharan Africa	4000	9.20
Middle East and North Africa	140	0.32
Europe	2,900	6.70
Asia (excluding Middle East)	13,300	30.6
Australia	440	1.01
Oceania	6,500	14.9
North America	7,800	17.9
South America	12,000	27.6

Source: (http://en.wikipedia.org/wiki/water distribution on Earth, 2012)

Even within these regions, there can be huge variations. For example, as much as a quarter of Australia's limited renewable fresh water supply is found in almost uninhabited Cape York Peninsula. Also, continents that have high renewable river water equally have areas that are extremely short of water such as Texas in North

America, whose renewable water supply totals only 26km^3 in an area of 695,622km^2, or South Africa, with only 44km^3 in 1,221,037km^2 .

Precipitation that does not evaporate or infiltrate into the ground runs off over the surface, drawn by the force of gravity back toward the sea. According to Cunningham and Cunningham (2010), rivulets accumulate to form streams, and streams join to form rivers. Although the total amount of water contained at any one time in rivers and streams is small compared to the other water reservoirs of the world, these surface waters are very important to humans and most other biotic organisms. The major source of replenishment of surface water is precipitation.

The size of a river is measured in terms of its discharge, the amount of water that passes a fixed point in a given amount of time. This is usually expressed as litres or cubic feet of water per second. The 16 largest rivers in the world carry nearly half of all surface runoff on earth. The Amazon is by far the largest river in the world carrying roughly 10 times the volume of the Mississippi. Several Amazonian tributaries such as the Maderia, Rio Negro, and Ucayali would be among the world's top rivers in their own right. Table 7.2 shows the major rivers of the world.

Table 7. 2: Major Rivers of the World

River	**Countries in River Basin**	**Average Annual Discharge at (m^3/sec)**
Amazon	Brazil, Peru	175,000
Orinoco	Venezuela, Colombia	45,300
Congo	Congo	39,300
Yangtze	Tibet, China	28,000
Bramaputra	Tibet, India, Bangladesh	19,000
Mississippi	United States	18,400
Mekong	China, Burma Thailand, laos Cambodia Vietnam	18,300
Parana	Paraguay, Argentina	18,000
Yenisey	Russia	17,200
Lena	Russia	16,000

1m^3 = 264 gallons
Source: World Resources Institute

SELF-ASSESSMENT EXERCISE

What are the major limitations to the optimal use of surface water resources?

4.0 CONCLUSION

From the above discussions, it is evident that surface water constitutes an important source of water supply for our everyday usage. However, due to the peculiar nature of surface water, it is easily abused leading to pollution. The pollution problem has created a great burden for those who use this source of water supply. To enhance the quality of surface water supply, it has to be treated to remove the harmful substances in it.

5.0 SUMMARY

In this unit, you have learnt:

- surface water is one of the major sources of water supply; it is also an important component of the hydrological cycle
- surface water is water in a river, lake or fresh water wetland
- overland flow is runoff that flows down the slopes of the land in broadly distributed sheets; while stream flow is when the water occupies a narrow channel confined by lateral banks
- surface water pollution occurs when the water quality is degraded
- two of the approaches to dealing with water pollution are – reduce the source or treat the water to remove or convert the pollutant to a harmless form.

6.0 TUTOR-MARKED ASSIGNMENT

i. Water in a river, lake or fresh water wetland is called ____________
ii. The only natural input to any surface water system within its watershed is _______
iii. When water occupies a narrow channel confined by lateral banks it is called_____
iv. Surface water is naturally lost through which of the following
    (a) discharge to the ocean (b) evaporation (c) unrecovered infiltration
    (d) all of the above
v. Which of the following reasons accounts for the non-uniform distribution of surface water over the earth surface?
    (a) climatic factors (b) human activities (c) all of the above
    (d) none of the above
vi. Which of the following is not a non-point source of pollution of surface water?
    (a) pipes from industrial sites that empty into rivers
    (b) urban runoff from streets
    (c) agricultural runoff
    (d) runoff from fields

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UNIT 8 CONCEPT OF THE DRAINAGE BASIN

CONTENTS

1.0 INTRODUCTION

Having been introduced to the concept of the hydrologic cycle in module one, unit four, this unit will focus on the drainage basin. The drainage basin is fundamental to the understanding of the hydrologic cycle because, each drainage basin acts as an individual hydrological system, receiving quantifiable inputs of precipitations, which are transformed into flows and storages and into output of evaporation and runoff. As a result, the drainage basin is the most commonly used unit for modelling hydrological processes, for water balance studies, for chemical budgets and for examining human impacts on hydrological systems. Hence, this unit will focus on the definition, features and patterns of drainage basin.

2.0 OBJECTIVES

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

- define drainage basin
- discuss the features of a drainage basin
- discuss the various patterns in a drainage basin.

3.0 MAIN CONTENT

3.1 Definition of Drainage Basin

A drainage basin is the topographic region from which a stream receives runoff, through flow and groundwater flow. According to Gallagher (2011) drainage basin is defined as an area of the earth's surface occupied by a surface stream or other water body together with all of the tributary streams, surface, and subsurface water flows. Having defined a drainage basin, let us examine its basic features.

3.2 Features of Drainage Basin

A drainage basin consists of a branched network of stream channels and adjacent slopes that feed the channels. It is bounded by a drainage divide, which mark the boundary between slopes that contribute water to different streams or drainage systems. According to Pidwimy (2006) drainage basins are separated from each other by topographic barriers called watershed. A watershed represents all of the stream tributaries that flow to some location along the stream channel. The number, size and shape of the drainage basins found in an area vary with the scale of examination. It should be noted that drainage basins are arbitrarily defined based on the topographic information available on a map. The quality of this information decreases as map scale becomes smaller.

Large-scale features of a drainage basin include the size, shape, and relief of the basin. Small-scale features include measurements of channel length and slope, storage capacity and drainage density of the stream network within the basin. Each of these geomorphic properties can be used to compare basins.

In addition, drainage basins are open systems. Inputs to these systems include precipitation, snowmelt, and sediment. Drainage basins lose water through evaporation, and sediment through deposition, and stream flow. A number of factors influence input, output, and transport of sediment and water in a drainage basin. Such factor includes topography, soil type, bedrock, climate, and vegetation cover. These factors also influence the nature of the pattern of stream channels.

In a typical stream network within a drainage basin, each tributary receives runoff from a small area of land surface surrounding the channel. This runoff is carried downstream and merged with runoff from other small tributaries as they join the main stream. The drainage system thus provides a converging mechanism that funnels overland flow into streams and smaller streams into larger ones.

Thus, drainage basins are important to understanding the characteristics of stream habitats. The boundaries of a drainage basin are used to explain biogeographical distributions of fish species. Basin features are a factor in predicting flood patterns, estimating sediment yield, and predicting water availability and quality. The downstream transfer of water, sediment, nutrients, and organic material influence the characteristics of stream habitat. It is therefore important to understand the geologic, hydrologic, morphologic, and vegetation setting of a stream in its basin. In addition, understanding drainage basin attributes aids habitat investigators when interpreting field data.

3.3 Drainage Basin Patterns

As earlier stated above, factors such as topography, soil types, bedrock type, climate, and vegetation cover influence input, output, and transport of sediment and water in a drainage basin. These factors also influence the nature of the pattern of stream channels. Consequently, five common drainage patterns can easily be identified. They include trellised, rectangular, parallel, dendritic and deranged. Figure 8.1 shows the common drainage patterns.

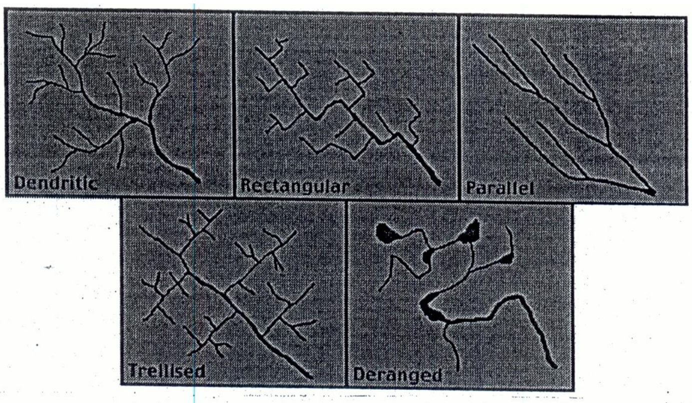

Fig.8.1: The Common Drainage Patterns
Source: Pidwimy, M. (2006) "The Drainage Basin Concept." Fundamentals of Physical Geography

Trellised Drainage Pattern: It tends to develop where there is strong structural control upon streams because of geology. In such situations, channels align themselves parallel to structures in the bedrock with minor tributaries coming in at right angles.

Rectangular Drainage Pattern: This occurs in areas with tectonic faults or bedrock joints causing a stream to take on a grid-like or rectangular pattern.

Parallel Drainage Pattern: They are often found in areas with steep relief or where flow is over non-cohesive materials.

Dendritic Drainage Pattern: They are typical of adjusted systems on erodable sediments and uniformly dipping bedrock.

Deranged Drainage Pattern: It is found in areas recently disturbed by events like glacial activities or volcanic deposition. Over time, the stream will adjust the topography of such regions by transporting sediment to improve flow and channel pattern.

3.4 Hydrograph Analysis

A hydrograph is a graph of stage or discharge versus time. It is the simplest graphical form of representing stream flow data with time. Hydrographs are usually represented in units of time and the ordinate may either be discharge or gauge height. Usually, discharge is expressed in cumecs (cubic metre per second) and the time in hours, days or weeks. The curves obtained are known as discharge or stage hydrograph, depending on whether it is discharge or gauge height respectively.

According to Gupta and Gupta (2008), a hydrograph may have a single peak or multiple peaks depending on the nature of the storm and catchment characteristics. The hydrograph shows the run-off pattern from a catchment due to a storm. It represents the characteristics of flow of a stream and indicates the graphical representation of the variation in discharge arranged in a chronological order. A hydrograph is an extremely useful tool for the estimation of yield and maximum discharge.

The analysis of a hydrograph involves the separation of the various components contributing to stream flow with respect to their sources. The combined effects of all these components form the total flow at the out let of the drainage basin. Four components can be identified on a stream flow. They include direct precipitation falling on the surface of the stream; surface runoff; sub surface flow and groundwater flow.

In plotting a hydrograph, many different methods are used depending on the purpose of the chart. For example, monthly and annual mean or total flow is used to display the record of past runoff at a station. The characteristics of a particular flood, however, cannot usually be shown successfully by plotting average flow for periods longer than a day. For detailed analysis, discharge hydrographs are plotted by computing instantaneous flow values from the water stage recorder chart. The scales used determine the visual shape of the hydrograph, and in any particular study it is good practice to use the same scale for all floods on a given basin.

Gupta and Gupta (2008) identified three segments in a typical hydrograph resulting from an isolated period of rainfall. The segments are rising limb, crest segment and falling limb or recession limb as shown in figure 8.2.

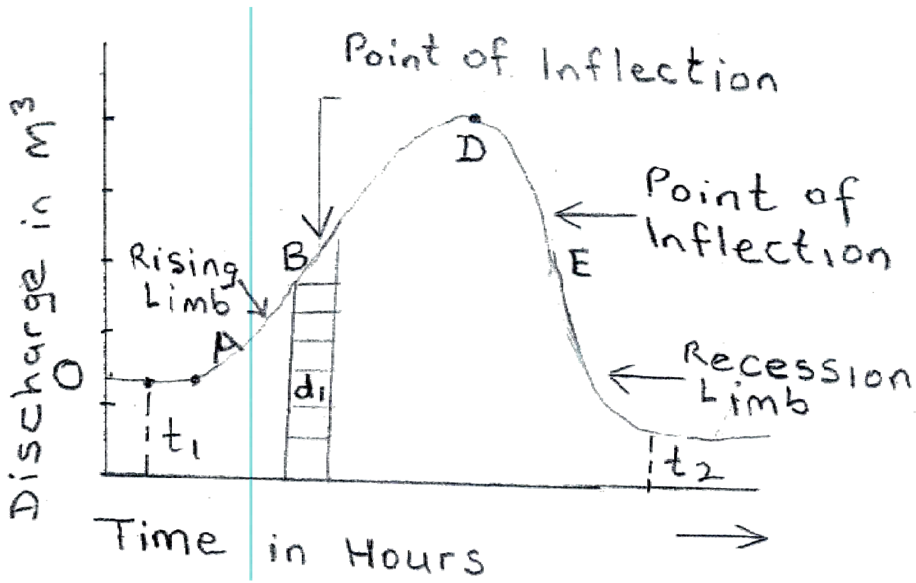

Fig.8.2: A Diagrammatical Representation of a Typical Hydrograph
Source: Gupta & Gupta (2008). Water Resources Systems and Management

Rising Limb

Stream discharge before a storm is mainly due to groundwater flow known as base flow as indicated by curve OA (see figure 1.4). Increases in surface flow as a result of a storm discharge also lead to an increase in stream flow. The peak discharge usually occurs after the occurrence of the storm as surface runoff takes some time to reach the gauging point. The time lag between the start of rising of the discharge point A and the peak is called Basin lag, which depends on both the storm and catchment characteristics. The Rising Limb AB has a well-defined point of rise, from which the discharge increases rapidly. Point B is the end of the rising limb, where the curvatures of the discharge curve changes. The highest point D on the rising limb of a hydrograph is called peak point in case of discharge hydrograph and crest in the case of stage hydrograph.

Crest Segment

On the other side of the rising limb is another inflection point 'E'. Inflection point is the point at which the curvature of the limb of the hydrograph changes. The segment of the hydrograph between point B and E is called the crest segment. The crest segment is an important part of a hydrograph as it contains the maximum discharge, which is required for various hydrological studies. The discharge occurs when different parts of the catchment contribute maximum amount of runoff simultaneously at the gauging station of the basin.

Recession Limb

Recession limb starts from the point of inflection E on the falling side of the hydrograph. It is commonly assumed as the point or time at which the surface inflow to the stream due to surface runoff ceases. After this point of inflection E, the recession represents the withdrawal of water from the storage within the basin. The point of inflection E represents the condition of maximum storage, which depletes gradually after cessation of the surface runoff. The shape of the recession curve entirely depends upon the characteristics of the catchment and is independent of the storm characteristics.

SELF-ASSESSMENT EXERCISE

Attempt a sketch of the five major drainage patterns and account for the influencing factors.

3.5 Human Impact with the Drainage System

The several activities of man impact significantly on the drainage system. For example, the overuse of water courses result in drastic reduction of water flow through rivers into natural stores. A good example of this is the situation in the Aral Sea basin where over extraction for irrigation has resulted in the cessation of inflow from contributing rivers. Diversion of water for irrigation purposes modifies natural hydrological processes and irrigated land often has high rates of evaporation and evapotranspiration.

In addition, changing the land use of river basins also has marked effects on the transfer of water as evaporation and flow characteristics are altered. This is especially evident in urbanised areas where infiltration and evapotranspiration is greatly reduced. Furthermore, urbanisation leads to increased flood risks and large surface flows.

Another significant human impact with the drainage system is pollution. Several kinds of pollutants such as metals, acidifying substances, solid matters among others are usually leached into rivers as a consequence of land use and point loading within a drainage basin. These substances cause many kinds of changes in the aquatic environment and also in the species distribution and abundance of aquatic organisms. It also diminishes the recreational value of affected river. Agricultural activities and road construction works increase sediment load to a river channel. The load transported along the river channel can modify the floor bed and attrition channel shape in the process of corrosion and attribution.

4.0 CONCLUSION

The discussions on the drainage basin have further supported the idea that drainage basin is the most commonly used unit for modelling hydrological processes. The understanding of the drainage basin concept will therefore, foster a better understanding of the hydrologic cycle and the processes involved in it.

5.0 SUMMARY

In this unit, you have learnt that:

- a drainage basin is the topographic region from which a stream receives runoff, through flow, and groundwater flow
- drainage basin acts as an individual hydrological system, receiving quantifiable inputs of precipitations, which are transformed into flows and storages and into output of evaporation and runoff
- a drainage basin is bounded by a drainage divide, which mark the boundary between slopes that contribute water to different streams or drainage systems
- a drainage basin is an open system, with an input of precipitation, snowmelt and sediment, and output of evaporation, deposition and stream flow
- there are five major drainage patterns – trellised, rectangular, parallel, dendritic and deranged.

6.0 TUTOR-MARKED ASSIGNMENT

i. A _____________ represents all of stream tributaries that flow to some location along the stream channel.
ii. A _____________ drainage pattern is often found in areas with steep relief or where flow is over non-cohesive materials.
iii. Which of the following is not an input process to a drainage basin?

(a) deposition (b) precipitation (c) snow melt (d) sediment

iv. Which of the following is not a factor influencing input, output, and transport of sediment and water in a drainage basin.

(a) topography (b) soil colour (c) climate (d) vegetation

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MODULE 2

UNIT 1 PRECIPITATION

CONTENTS

1.0 INTRODUCTION

In our discussions on surface and groundwater resources, precipitation was mention as the primary input vector of the hydrologic cycle. It replenishes both surface and groundwater sources. The major forms of precipitation are rain, snow and hail. Precipitation is derived from atmospheric water; its form and quantity are thus being influenced by the action of other climatic factors. Such factors include wind, temperature, and atmospheric pressure. In this unit, we shall attempt a definition of precipitation, its formation, types and measurement.

1.0 OBJECTIVES

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

- define precipitation
- discuss the formation of precipitation

- describe the types of precipitation
- describe the measurement of precipitation.

3.0 MAIN CONTENT

3.1 What is Precipitation?

Precipitation can be defined as water falling in solid or liquid form, for example rain, snow and hail. Precipitation is the process that provides the fresh water essential for most forms of terrestrial life. Clouds are the source of precipitation; however, evaporation and condensation processes are the driving forces.

3.2 Formation of Precipitation

Two ways can be identified in the formation of precipitation. In warm clouds, fine water droplets condense, collide, and coalesce into larger droplets that can fall as rain. In colder clouds, ice crystals form and grow in a cloud containing a mixture of both ice crystals and water droplets. The first process occurs when saturated air rises rapidly, and cooling brings about more condensation. Cloud droplets grow by added condensation and attain a diameter of 50 to 100mm. In collisions with one another, the droplets grow to about 500um in diameter. This is the size of water droplets in drizzle. Further collisions and coalescence increase drop size and yield rain. Average raindrops have diameters of about 1000 to 2000um, but can reach a maximum diameter of about 7000um. Above this value, it become unstable and breaks into smaller drops while falling. This type of precipitation occurs in warm clouds typical of the equatorial and tropical zones.

In cold clouds, a second process produces snow. Here, clouds contain a mixture of ice crystals and super cooled water droplets. As the ice crystals take up water vapour and grow by deposition, the super cooled water droplets lose water vapour by evaporation and shrink. When an ice crystal collides with a droplet of super cooled water, it induces freezing of the droplet. Ice crystals grow further, taking on shapes such as plates, columns, or needles. Under certain conditions, the ice crystals take the form of dendrites – delicate structure with six-sided symmetry.

When the underlying air layer is below freezing, snow reaches the ground as a solid form of precipitation. Otherwise, it melts and arrives as rain. A reverse process, the fall of raindrops through a cold air layer results in the freezing of rain and produces pellets or gains of ice, which are commonly referred to as sleet in North America.

3.3 Types of Precipitation

Precipitation is often classified according to the factor mainly responsible for the lifting of the air mass. Accordingly, three major types of precipitation are identified namely cyclonic, convectional and orographic precipitation

3.3.1 Cyclonic Precipitation

Cyclonic precipitation results from the lifting of air converging into a low-pressure-area, or cyclone. Cyclonic precipitation may be either frontal or nonfrontal. Frontal precipitation results from the lifting of warm air on one side of a frontal surface over, cold denser air on the other side. Warm-front precipitation is formed when warm air advances upward over a colder air mass. The rate of ascent is relatively slow, since the average slope of the frontal surface is usually between $^1/_{100}$ and $^1/_{300.}$ Precipitation may extend 300 to 500km ahead of the surface front and is generally light to moderate and nearly continues until passage of the front. Cold front precipitation, on the other hand, is of showery nature and is formed when warm air is forced upward by an advancing mass of cold air, the leading edge of which is the surface cold front. Cold fronts move faster than warm fronts, and the frontal surfaces, with slopes usually averaging $^1/_{50}$ to $^1/_{150}$, is steeper. Consequently, the warm air is forced upward more rapidly than by the warm front, and precipitation rates generally much higher. Heaviest amounts and intensities occur near the surface front.

3.3.2 Convectional Precipitation

Convectional precipitation is caused by the natural rising of warmer, lighter air in colder, denser surrounding. Generally, this kind of precipitation occurs in the tropics, where on a hot day, the ground surface gets heated unequally, causing the warmer air to lift up as the colder air comes to take its place. The vertical air currents develop tremendous velocities. Convectional precipitation occurs in the form of showers of high intensity and of short duration.

3.3.3 Orographic Precipitation

Orographic precipitation is caused by air masses, which strike some natural topographic barriers like mountains, and cannot move forward and hence rise up, causing condensation and precipitation. All the precipitation we have in Himalayan region is because of this nature. It is rich in moisture because of their long travel over oceans. At this point, it should be noted that in nature, the effects of these various types of cooling discussed above are often interrelated. Therefore, the resulting precipitation in most cases cannot be identified as being of any one type. Figure 1.1 a-d shows the four basic types of atmospheric lifting and precipitation.

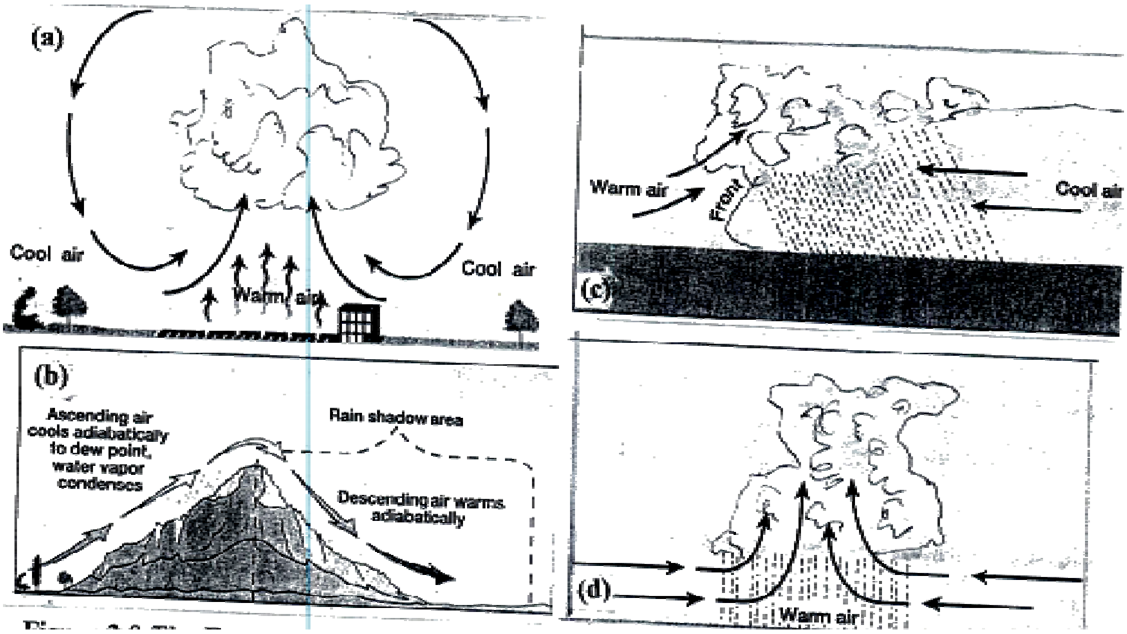

Fig. 1.1: The Four Basic Types of Atmospheric Lifting and Precipitation:
(a) Convective (b) Orographic (c) Frontal (d) Convergent
Source: Mcknight, T.L (1996). Physical Geography. A Landscape Appreciation

3.4 Measurement of Precipitation

A variety of instruments and techniques have been developed for gathering information on precipitation. Instruments for measuring amount and intensity of precipitation are the most important. All forms of precipitation are measured on the basis of the vertical depth of water that would accumulate in a level surface if the precipitation remained where it fell. In the metric system precipitation is measured in millimeters and tenths.

Precipitation is measured with a rain gauge. It consists of a collecting jar, a funnel and a container, which is dug in the ground, with 30cm of the instrument appearing above the ground. Rain gauge is usually sited is an open place, where there are no trees or tall buildings to obstruct the incoming precipitation. The diameter of the funnel is normally 13cm. The water that collects in the jar is then poured into a measurement cylinder from where the amount of precipitation that has fallen is read off. Figure 1.2 shows diagrammatic representation of rain gauges.

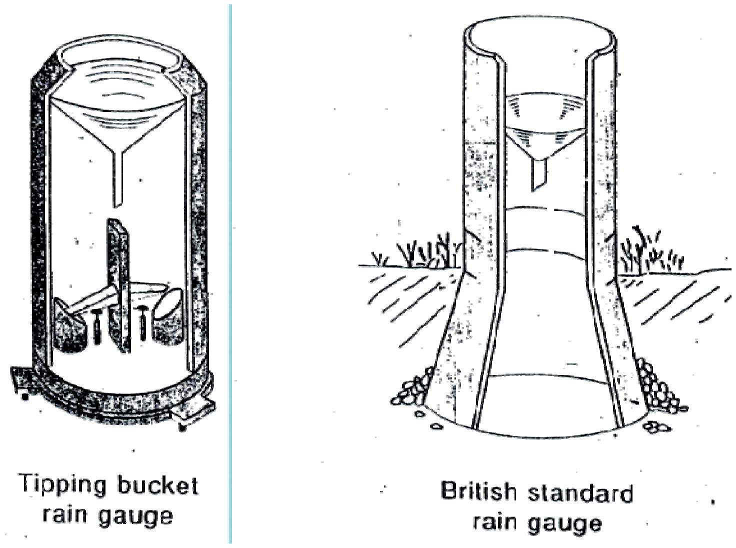

Fig. 1.2: Diagrammatic Representation of Rain Gauges
Source: Smithson, et al.(2002). Fundamentals of Physical Environment

SELF-ASSESSMENT EXERCISE

Identify the three major types of precipitation and state their modes of formation.

4.0 CONCLUSION

Precipitation is an important process of the hydrologic cycle. It helps to replenish both surface and groundwater sources. It also helps to sustain the available freshwater pool on earth. Having gone through this unit, you should appreciate the various dynamic processes that take place for us to receive precipitation on planet Earth. In addition, you should be well acquainted with the types of precipitation and mode of its measurement.

5.0 SUMMARY

In this unit, you have learnt that:

- precipitation can be defined as water falling in solid or liquid form e.g. rain, snow, and hail
- the formation of precipitation involves three basic processes lifting and cooling of air mass, condensation and droplet formation
- there are three types of precipitation – cyclonic, convectional and orographic
- rain gauge is an instrument used in measuring precipitation.

6.0 TUTOR-MARKED ASSIGNMENT

i. The instrument used in measuring rainfall is ________
ii. The type of precipitation caused by air masses, which strike some natural topographic barriers like mountain, is called______
iii. Which of the following is not a type of precipitation?
(a) snow (b) cyclonic (c) convectional (d) orographic
iv. The formation of precipitation that involves the natural rising of warmer, lighter air in colder, denser surrounding is called what
(a) orographic (b) conventional (c) cyclonic (d) none of the above
v. What type of precipitation is mainly associated with the tropics?
(a) cyclonic (b) orographic (c) conventional (d) all of the above

7.0 REFERENCES/FURTHER READING

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UNIT 2 HUMIDITY

CONTENTS

1.0 INTRODUCTION

Humidity is another subset of the hydrological cycle, and its knowledge is important to the study of hydrology. Humidity is concerned with the vapor state (gas) of water in the atmosphere. Thus, this unit will focus on the definition of humidity, types of humidity, and its measurement.

2.0 OBJECTIVES

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

- define humidity
- distinguish between specific and relative humidity
- state and describe the instruments used in measuring humidity
- calculate relative humidity.

3.0 MAIN CONTENT

3.1 What is Humidity?

Humidity refers to the amount of water vapour present in the air, which varies widely from place to place and time to time. It ranges from almost nothing in the cold, dry air of arctic regions in winter to as much as four or five per cent of given volume of air in the warm wet regions near the equator.

Understanding humidity and how the moisture content of air is measured involves an important principle, which states that the maximum quantity of moisture that can be held at any time in the air is dependent on air temperature. Warm air can hold more water vapour than cold air. For example, air at room temperature (20^0C) can hold about three times as much water vapour as air at freezing point (0^0C).

3.2 Specific Humidity

Specific humidity is the actual quantity of water vapour held by a parcel of air. This measure is important because it describes how much water vapour is available for precipitation. Specific humidity is stated as the mass of water vapour contained in a given mass of air and is expressed as grams of water vapour per kilogram of air (g/kg). Specific humidity is often used to describe the moisture characteristics of a large mass of air. For example, extremely cold dry air over arctic regions in winter may have a specific humidity as low as 0.2g/kg. In comparison, the extremely warm, moist air of equatorial regions often holds as much as 18g/kg. The total natural range on a worldwide basis is very wide. In fact, the largest values of specific humidity observed are from 100 to 200 times as great as the smallest.

Specific humidity is a yardstick for a basic natural resource – water. It is a measure of the quantity of water in the atmosphere that can be extracted as precipitation. Cold moist air can supply only a small quantity of rain or snow, but warm, moist air is capable of supplying large amounts.

Another way of describing the water vapour content of air is by its dew-point temperature. If air is slowly chilled, it eventually will reach saturation. At this temperature, the air holds the maximum amount of water vapour possible. If further cooling continues, condensation will begin and dew will form. The temperature at which saturation occurs is therefore known as the dew-point temperature. Moist air will have a higher dew-point temperature than drier air.

3.3 Relative Humidity

Relative humidity is a ratio (expressed as a percentage) of the amount of water vapour that is actually in the air compared to the maximum water vapour possible in the air at a given temperature. Warmer air increases the evaporation rate from water surfaces, whereas cooler air tends to increase the condensation rate of water vapour to water surfaces. Because there is a maximum amount of water vapour that can exist in a volume of air at a given temperature, the rates of evaporation and condensation can reach equilibrium at some point; the air is then saturated with humidity. Relative humidity varies with evaporation, condensation; or temperature changes, which affect both the moisture in the air (the numerator) and the water vapour (the denominator) in the air. The formula for calculating the relative humidity ratio and expressing it as a percentage is quantitatively expressed as:

$$\text{Relative Humidity} = \frac{\text{Actual water vapour in the air}}{\text{Maximum water vapour possible in the air at that temperature}} \times 100$$

As earlier stated, air is saturated when the rate of evaporation and the rate of condensation reach equilibrium – that is 100 per cent relative humidity. In saturated air, the net transfer of water molecules between a moisture surface and the air reaches equilibrium. Saturation indicates that any further addition of water vapour or any decrease in temperature that reduces the evaporation rate will result in active condensation (clouds, fog, or precipitation). Relative humidity therefore indicates the nearness of air to a saturated condition and when active condensation will begin.

The temperature at which a given mass of air becomes saturated is the dew-point temperature. In other words, air is saturated when the dew-point temperature and the air temperature are the same. When temperatures are below freezing, the term frost point is sometimes used. A cold drink in a glass provides a common example of these conditions. The water droplets that form on the outside of the glass condense from the air because the air layer next to the glass is chilled to below its dew-point temperature and thus is saturated.

During a typical day, air temperature and relative humidity relate inversely – as temperature rises, relative humidity falls. Relative humidity is highest at dawn, when air temperature is lowest. For example, when cars are parked outside dew condenses on the car overnight. Relative humidity is lowest in the late afternoon, when higher temperatures increase the rate of evaporation.

3.4 Measurement of Humidity

Relative humidity is measured with various instruments. The hair hygrometer is based on the fact that human hair changes as much as four per cent in length between 0 per cent and 100 per cent relative humidity. The instrument connects a standardised bundle of human hair through a mechanism to a gauge. As the hair absorbs or loses water in the air, its change in length indicates relative humidity.

Another instrument used to measure relative humidity is a sling pyschrometer. This device has two thermometers mounted side by side on a metal holder. One is called the dry-bulb thermometer; it simply records the ambient (surrounding) air temperature. The other thermometer is called the wet-bulb thermometer, because it is moist. The psychrometer is then spun by its handle; after a minute or two, the temperature of each bulb is compared on a relative humidity (psychrometric) chart, from which relative humidity can be determined. The rate at which water evaporates from the wick depends on the relative saturation of the surrounding air. If the air is dry, water evaporates quickly, absorbing the latent heat of evaporation from the wet bulb thermometer, causing the temperature to drop (wet-bulb depression). In an area of high humidity, much less water evaporates from the wick, resulting in a smaller temperature difference between the two thermometers. Figure 2.1 shows instruments for measuring relative humidity.

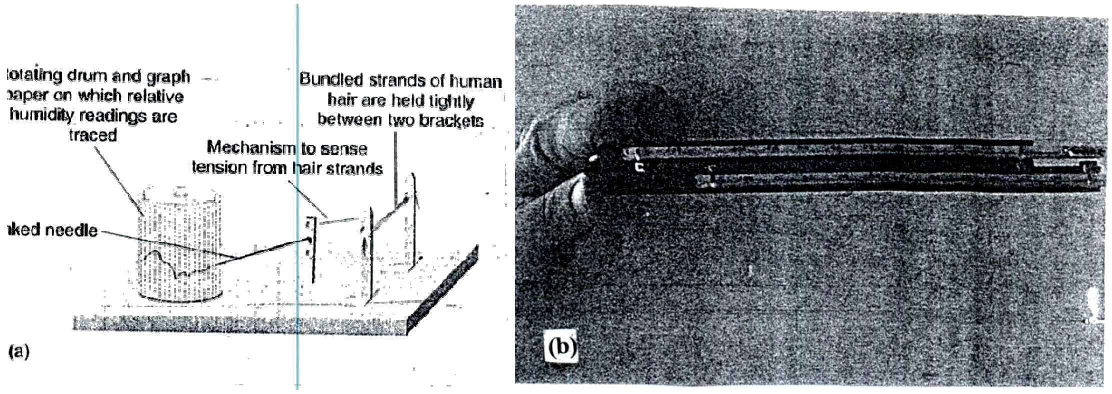

Fig. 2.1: Instruments for Measuring Relative Humidity: (a) Hair Hygrometer (b) Sling Psychrometer
Source: Christopherson R.W. (2007). Elemental Geosystems

SELF-ASSESSMENT EXERCISE

i. Based on your understanding of the concepts of precipitation and humidity, do you think there is any relationship between both concepts?
ii. What is the difference between specific humidity and relative humidity?

4.0 CONCLUSION

Having gone through this unit, you should by now be well informed of the close relationship that exists between humidity and precipitation – a significant component of the hydrologic cycle. Humidity is a measure of the quantity of water in the atmosphere that can be extracted as precipitation. In other words, the amount of precipitation received in a given area is dependent to a very large extent on the moisture characteristics of the air mass.

5.0 SUMMARY

In this unit, you have learnt that:

- humidity refers to the amount of water vapour present in air
- warm air holds much more water vapour than cold air
- the dew-point temperature of a mass of air is the temperature at which saturation will occur. The more water vapour in the air, the higher is the dew-point temperature
- relative humidity depends on both the water vapour content and the temperature of air. It compares the amount of water held by air to the maximum amount that can be held at that temperature.

6.0 TUTOR-MARKED ASSIGNMENT

i. The amount of water vapour present in the air is called _______

ii. The maximum quantity of moisture that can be held at any time in the air is dependent on __________

iii. The actual amount of water vapour held by a parcel of air is called ______

iv. Which of the following is an instrument used in measuring relative humidity?
(a) sling psychrometer (b) hair hygrometer (c) A & B (d) none of the above

v. At what percentage is relative humidity said to be saturated.
(a) 0% (b) 50% (c) 100% (d) 200%

vi. What factor influences the variation of relative humidity?
(a) evaporation (b) temperature (c) a and b (d) none of the above

7.0 REFERENCES/FURTHER READING

Christopherson, R.W. (2007). *Elemental Geosystems.* (5th ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

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UNIT 3 INTERCEPTION

CONTENTS

1.0 INTRODUCTION

Interception is another important concept in the study of hydrology. On our study of precipitation in module two, we did not expatiate on the intervening process that prevents precipitation from getting to the ground. One of the intervening processes is interception. This unit will attempt a definition of interception; analyse the factors affecting interception and measurement of interception.

2.0 OBJECTIVES

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

- define interception
- state the factors affecting interception
- describe the measurement of interception.

3.0 MAIN CONTENT

3.1 Definition of Interception

The temporary storage and prevention of precipitation from reaching the ground surface by natural and artificial objects is called interception. Ward, et al. (2000) defined interception as that segment of the gross precipitation input, which wet and adheres to above ground objects until it is returned to the atmosphere through evaporation.

When precipitation falls on a vegetated surface, only a part may actually reach the ground beneath. Depending upon the nature and density of the vegetation cover, a proportion of the rain may be intercepted by the leaves and stems of the vegetation canopy and temporarily stored on its surfaces. Some or all of this water may be evaporated back into the atmosphere, and so take no part in the land-bound portion of the hydrological cycle; this is termed the interception loss. The remaining water, which reaches the ground, constitutes the net rainfall. The bulk of this comprises throughfall consisting of raindrops that fall through spaces in the vegetation canopy and water which drips from wet leaves, twigs and stems to the ground surface. It should be noted that a generally much smaller amount of water trickles along twigs and branches to run down the main stem or trunk to the ground as stemflow.

Interception process is important because it can help to reduce runoff and erosion problems. Secondly, the net rainfall beneath a vegetation canopy is generally less than the gross rainfall falling onto the top of the vegetation canopy. In some cases the interception loss may be quite large and can have a significant impact on the water balance.

3.2 Factors Affecting Interception

Several factors affect the magnitude of interception. Some of these factors are vegetation type and density, wind system, duration and nature of rain.

Vegetation
Very dense vegetation cover is known to intercept more water than a sparse one. In addition, the general canopy density affects the rate and magnitude of interception. Also, the dryness and wetness of the vegetation is very important. Dry vegetation has higher interception storage – the ability of the vegetation surfaces to collect and retain falling precipitation, than wet vegetation, because of the differences in their surface tension.

Wind
The wind system and the duration of the rain also affect interception. The winds affect the rate of water lost through evaporation. Apart from creating turbulence within the whole system, the duration is important because the longer the period of rainfall, the more water that is likely to be intercepted. The nature of the rainfall is also important because the ability of the vegetation to intercept water is higher during low intensity rainfall than during storms.

3.3 Measurement of Interception

The most common method of measuring interception loss (I) in the field is to compute the difference between the precipitation above the vegetation layer (P) and the net precipitation below the vegetation canopy, comprising the throughfall (T) and stemflow (S), thus:

$I = P – T – S$ ------ (2)

Due to the difficulties of installing equipment underneath a vegetation canopy, this method has been used more for forest vegetation than for lower-order covers. Throughfall may be measured using funnel or trough gauges placed beneath the forest canopy, and stemflow may be collected by small gutters sealed around the circumference of the truck leading into a container.

SELF-ASSESSMENT EXERCISE

Of what importance is interception? Can you account for the factors that influence the rate of interception?

4.0 CONCLUSION

The journey of precipitation from the clouds to the ground is not a straight one as has been highlighted from the above discussions. Part of it is intercepted by both natural and artificial objects. Hence, the net rain that reaches the ground surface is less than the gross rainfall, which has implications on surface runoff and water balance.

5.0 SUMMARY

In this unit, you have learnt:

- the temporary storage and prevention of precipitation from reaching the ground surface by natural and artificial objects is called interception
- interception accounts for the variation between the gross rainfall and the net rainfall that reaches the ground
- factors that influence the magnitude of interception include vegetation type and density, wind system, duration and nature of rain.

6.0 TUTOR-MARKED ASSIGNMENT

i. The process that prevents precipitation from getting to the ground by natural and artificial objects is called _________.

ii. The major natural objects of interception are ___________.

iii. The ability of the vegetation surface to collect and retain falling precipitation is called _____________.

iv. Which of the following factors do not affect interception?
(a) soil profile (b) wind system (c) duration of rain
(d) vegetation density

v. Interception lost can be represented by which of the following equations:
(a) I=P-T+S (b) I=P-T-S (c) I=P+T+S (d) I=P+T-S

vi. Which of the following options is true of interception?
(a) vegetation intercept more during high storm
(b) vegetation intercept more during low intensity rainfall
(c) vegetation interception does not very at all
(d) all of the above.

7.0 REFERENCES/FURTHER READING

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Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology.* (4th ed.). UK: McGraw-Hill Publishing.

UNIT 4 INFILTRATION

CONTENTS

1.0 INTRODUCTION

In the preceding unit, we learnt that not all precipitation gets to the ground surface due to the process of interception. In this unit, we are going to examine infiltration, one of the processes that precipitation, which gets to the ground surface undergo. Here, we shall attempt a definition of infiltration, examine the factors that influence infiltration and measurement of infiltration.

2.0 OBJECTIVES

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

- define infiltration
- list and discuss the factors that influence infiltration
- discuss the commonly used methods in measuring infiltration.

3.0 MAIN CONTENT

3.1 Definition of Infiltration

Infiltration is the process by which precipitation moves downward through the surface of the earth and replenishes soil moisture, recharges aquifers, and ultimately supports streamflows during dry periods. Along with interception, depression storage, and storm period evaporation, it determines the availability, if any, of the precipitation input for generating overland flows. Furthermore, infiltration rates influence the timing of overland flow inputs to channelised systems. Accordingly, infiltration is an important component of any hydrological model.

3.2 Factors Influencing Infiltration

The rate at which infiltration occurs is influenced by several factors such as the type and extent of vegetal cover, the condition of the surface crust, temperature, rainfall intensity, and physical properties of the soil. Infiltration rates vary from one soil type to another. In very loose soil, such as sandy soils, the rate of infiltration is usually very high and lowest in clay soils because clay soils have very tiny particles, which make them compact. The pores are smaller in size and number when compared with sandy soils. Soils act as a kind of giant sponge containing passages and caverns of various sizes. The total space available for water and air in the soil is called porosity. Infiltration is a function of porosity. The passage of water from soil surface to stream banks or water conducting rocks (aquifers) takes place in a very tortuous way through small diameter passages. So, it is not surprising that water movement within the soil is slow.

Most soils are on sloping lands and thus soil water movement takes place towards the slope base in a process called the throughflow. The vertical movement of water in the soil is however called percolation. The degree of which is related to porosity of the soil.

The rate at which water is transmitted through the surface layer is highly dependent on the condition of the surface. For example, in wash of fine material may seal the surface so that infiltration rates are low even when the underlying soils are highly permeable. After water crosses the surface interface, its rate of downward movement is controlled by the transmission characteristics of the underlying soil profile. The volume of storage available below ground is also a factor affecting infiltration rates.

3.3 Measurement of Infiltration

Hydrograph analyses and infiltrometer are some of the commonly used methods for determining infiltration capacity. Hydrograph is a graph, which represents the changes in the level of water with time. Estimates of infiltration based on hydrograph analyses have the advantage over infiltrometers of relating more directly to prevailing conditions of precipitation and field. However, it is not better than the precision with which rainfall and runoff are measured. Of special importance in such studies is the areal variability of rainfall.

Infiltrometers are usually classified as rainfall stimulators or flooding devices. In the former, artificial rainfall is simulated over a test plot and the infiltration is calculated from observations of rainfall and runoff, with consideration given to depression storage and surface detention. Flooding infiltrometers are usually rings or tubes inserted in the ground. Water is applied and maintained at a constant level and observations are made of the rate of replenishment required. It should be noted that several other methods for measuring infiltration have been developed and are currently in use. Figure 4.1 shows types of infiltrometers.

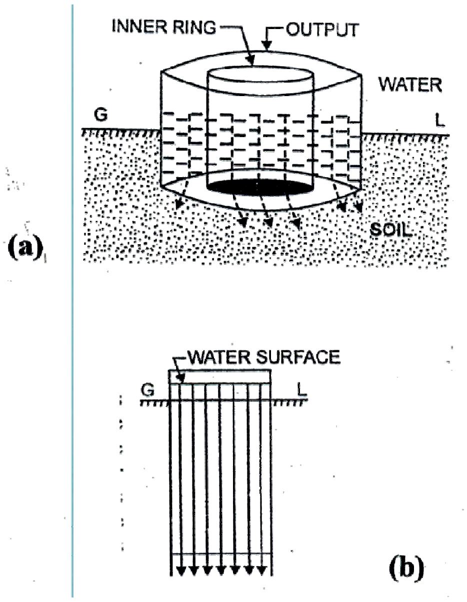

Fig. 4.1: Types of Infiltrometers: (a) Concentric Ring Infiltrometer (b) Tube Infiltrometer
Source: Gupta & Gupta. (2008) .Water Resources Systems and Management

SELF-ASSESSMENT EXERCISE

If you agree that infiltration is the downward movement of water through the surface of the earth, then state the factors that affect the rate of infiltration.

4.0 CONCLUSION

From the above discussions, it has been revealed that the study of infiltration is very vital in hydrologic studies. Its importance can be found in the determination of soil moisture, aquifer recharge, and support to stream flow during dry season. In addition, it can be use to determine runoff and erosion.

5.0 SUMMARY

In this unit, you have learnt that:

- infiltration is the process by which precipitation moves downward through the surface of the earth
- some of the factors that influence infiltration are physical properties of the soil, vegetal cover, rainfall intensity, and nature of the surface crust
- infiltration capacity is commonly measured with the aid of hydrograph analyses and infiltrometer studies.

6.0 TUTOR-MARKED ASSIGNMENT

i. The process by which precipitation moves downward through the surface of the earth is called ____________

ii. The total space available for water and air in the soil is called _____

iii. Which of the following options is incorrect about infiltration?
(a) it replenishes soil moisture (b) it affects the rate of interception
(c) it recharges aquifers (d) it supports stream flow.

iv. The rate of infiltration is highest in which of the following soil types
(a) clay soil (b) loamy soil (c) sandy soil (d) none of the above

7.0 REFERENCES/FURTHER READING

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UNIT 5 SOIL MOISTURE

CONTENTS

1.0 INTRODUCTION

In the preceding unit, we discussed the process of infiltration-downward movement of water from the surface. In this unit, we are going to examine soil moisture, which is a direct consequence of infiltration process. The discussion will centre on the definition and importance of soil moisture, factors affecting soil moisture, and measurement of soil moisture.

2.0 OBJECTIVES

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

- define soil moisture and state its importance
- identify soil properties affecting soil moisture
- describe the measurement process of soil moisture.

3.0 MAIN CONTENT

3.1 Definition and Importance of Soil Moisture

Soil moisture or soil water as it is referred to in some quarters, is normally considered to include both the water contained in the soil profile itself and the subsurface water in the unsaturated subsoil layers between the soil profile and the water table. Thus defined, soil moisture includes all the water in the zone of aeration, which may extend tens or even hundreds of metres below the ground surface. However, the ability of the shallow soil profile proper to absorb and retain moisture is generally of great hydrological importance.

Water in the soil is a critical resource needed for plant growth. The amount of water available at any given time is determined by the soil water balance, which includes the gain, loss, and storage of soil water. Water held in storage in the soil water zone is increased by recharge during precipitation but decreased by use through evapotranspiration. Surplus water is disposed of by downward percolation to the ground water zone or by overland flow.

Soil moisture storage is a “savings account” of water that can receive deposits and allow withdrawals as conditions change in the water balance. Soil moisture storage refers to the amount of water that is stored in the soil and is accessible to plant roots. Moisture retained in the soil comprises two classes of water, only one of which is accessible to plants. The inaccessible class is hydroscopic water, the thin molecular layer that is tightly bound to each soil particle by the natural hydrogen bonding of water molecules. Such water exists even in the desert but is not available to meet moisture demands. Soil is said to be at the wilting point when all that is left in the soil is unextractable water; the plant wilt and eventually die after a prolonged period of such moisture stress. The soil moisture that is generally accessible to plant roots is capillary water, held in the soil by surface tension and hydrogen bonding between the water and the soil. Most capillary water that remains in the soil is available water in soil-moisture storage and is removable to meet moisture demands through the action of plant roots and surface evaporation.

After water drains from the larger pore spaces, the available water remaining for plants is termed field capacity, or soil-storage capacity. Generally, maintaining soil moisture close of field capacity is essential to plant growing success. When soil becomes saturated after rainfall or snowmelt, some soil-water surplus becomes gravitational water. This excess water percolates downward under the influence of gravity from the shallower capillary zone to the deeper groundwater zone.

Plant roots exert a tensional force on soil moisture to absorb it. As water transpires through the leaves, a pressure gradient is established throughout the plant, thus “pulling” water into plant roots. When soil moisture is at field capacity, plants obtain water with less effort. As the soil water is reduced by soil-moisture utilisation, the plants must exert greater effort to extract the same amount of moisture. As a result, even though a small amount of water may remain in the soil, plants may be unable to exert enough pressure to utilize it. The unsatisfied demand is a deficit. Rainwater, snowmelt, and irrigation water provide soil moisture recharge.

3.2 Factors Influencing Soil Moisture

The main forces responsible for holding water in the soil are those of capillarity, absorption and osmosis. Capillary forces result from surface tension at the interface between the soil air and soil water. Molecules in the liquid are attracted more to each other than to the water vapour molecules in the air, resulting in a tendency for the liquid surface to contract. If the pressure was exactly the same on either side, then the air-water interface would be flat, but pressure differences result in a curved interface, the pressure being greater on the inner, concave side by an amount that is related to the degree of curvature. At the interface in the soil pore space, the air will be at atmospheric pressure, but the water may be at a lower pressure.

In addition to capillary forces, soil water liquid or vapour can be absorbed upon the surfaces of soil particles mainly due to electrostatic forces in which the polar water molecules are attracted to the charge faces of the solids. Since the forces involved are only effective very close to the solid surface, only very thin films of water can be held in this way. Nevertheless, if the total surface area of the particles (that is, the specific surface) is larger, and/or the charge per unit area is large, then the total amount of water absorbed in a volume of soil may be considerable.

A third force, which acts to retain water in the soil, results from osmotic pressure due to solutes in the soil water. Osmotic pressure is important when there is a difference in solute concentration across a permeable membrane. This may be at a plant root surface, making water less available to plants, especially in saline soils, or across a diffusion barrier such as an air-filled pore, by allowing the movement of water vapour, but not the solute, across the pore from the more dilute to the more concentrated solution.

The amount of water that can be held in a given volume of soil and the rate of water movement through that soil depend on both the texture that is, the size distribution of the mineral particles of the soil, and upon the soil structure, the aggregation of these particles. Water may occupy both inter structural voids and textural voids (between the particles). At high moisture contents water flow through the former may be dominant, but becomes rapidly less important as the soil becomes drier. In general, the coarser the particles, the larger will be the intervening voids and the easier it will for water movement to take place. Thus, sandy soils tend to be more freely draining and permeable than clay soils, which are both slower to absorb water and slower to drain water.

3.3 Measurement of Soil Moisture

Soil moisture measurements are made in a variety of ways but the principal method employed is the gravimetric method. In that procedure, a soil sample is weighed and placed in a container of known weight. The weight of the wet soil sample is thus known. The soil sample is sealed in its container and taken to a laboratory where it is removed and over dried at 105^0C, until all the water evaporates. The sample is then weighed again, and the loss in weight is equated to the weight, and thus the amount of soil moisture that the field sample contained.

A number of other methods for determining soil moisture include radiological, electric resistance, remote sensing amongst others.

SELF-ASSESSMENT EXERCISE

Make a case for the study of soil moisture in hydrology.

4.0 CONCLUSION

Soil moisture is a critical resource for plant growth as has been established from the above discussions. However, of more importance is capillary water, which is generally accessible to plant roots. The knowledge of soil moisture is therefore vital in planning for an effective and efficient irrigation system aimed at improving agricultural productivity.

5.0 SUMMARY

In this unit, you have learnt that:

- soil moisture includes all the water in the zone of aeration, which may extend tens or even hundreds of metres below the ground surface
- soil moisture is critical for plant growth, and the water accessible to plant is called capillary water
- the main forces responsible for holding soil moisture are capillarity, adsorption and osmosis
- one of the most popular ways for measuring soil moisture is gravimetric method.

6.0 TUTOR-MARKED ASSIGNMENT

i. Soil moisture that is accessible to plant roots is called _________.
ii. Water held in storage in the soil water zone is increased by recharge during ______.
iii. Soil moisture that is inaccessible to plant roots is called
(a) absorption (b) osmosis (c) capillary (d) hydroscopic
iv. Soil moisture is much more relevant to which of the following
(a) agriculture (b) stream flow (c) mining (d) none of the above

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UNIT 6 EVAPORATION AND EVAPOTRANSPIRATION

CONTENTS

1.0 INTRODUCTION

This unit focuses on that phase of the hydrologic cycle in which precipitation reaching the earth's surface is returned to the atmosphere as vapour. Of the precipitation falling earthward, a portion evaporates before reaching the ground. The discussions shall however centre on the definitions of evaporation and evapotranspiration, which include transpiration by plants and evaporation from soil, lakes and streams, among others. Furthermore, the factors controlling the evaporation process and its measurement will also be highlighted.

2.0 OBJECTIVES

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

- differentiate between evaporation and transpiration
- identify the factors affecting the evaporation process.

3.0 MAIN CONTENT

3.1 Evaporation and Evapotranspiration Definition

Evaporation can be defined as the process by which liquid is converted into gaseous state. It involves the net movement of individual water molecules from the surface of the earth into the atmosphere, a process occurring wherever there is a vapour pressure gradient from the surface to the air. The rate of evaporation depends on the balance between the vaporization of water molecules into the atmosphere and the condensation rate from the atmosphere. However, when the air reaches saturation (100 per cent relative humidity) no net evaporation takes place. Wind is therefore required to remove the layer of air near the surface, which would otherwise become saturated and stop net evaporation.

Transpiration is a related process involving water loss from plants. It occurs mainly by day when small pores called stomata, on leaves of the plants open up under the influence of sunlight. They expose the moisture in the leaves to the atmosphere and, if the vapour pressure of the air is less than that on the leaf cells, the water is transpired. As a result of this transpiration, the leaf becomes dry and a moisture gradient is set up between the leaf and the base of the plant. Moisture is drawn up through the plant and from the soil into the roots.

In reality, it is often difficult to distinguish between evaporation and transpiration. Wherever vegetation is present, both processes tend to be operating together, so the two are normally combined to give the composite term evapotranspiration. This process is governed mainly by atmospheric conditions. Energy is needed to power the process, and wind is necessary to mix the water molecules with the air and transport them away from the surface.

In addition, the state of the surface plays an important role since evaporation can continue only as long as there is a vapour pressure gradient between the ground and the air. Thus, as the soil dries out the rate of evapotranspiration declines. Lack of moisture at the surface often acts as a limiting factor on the process.

Hence, moisture being the limiting factor, evapotranspiration process can either be potential or actual in an environment. Potential evapotranspiration (PE) is a measure of the ability of the atmosphere to remove water from the surface, assuming no limitation of water supply. Actual evapotranspiration (AE) is the amount of water that is actually removed. Except where the surface is continuously moist, AE is usually lower than PE.

3.2 Factors Controlling the Evaporation Process

Rates of evaporation vary, depending on meteorological factors and the nature of evaporating surface. If natural evaporation is viewed as an energy-exchange process, it can be demonstrated that radiation is by far the most important single factor and that the term solar evaporation is basically applicable. On the other hand, theory and wind-tunnel experiments have shown that the rate of evaporation from water of specific temperature is proportional to wind speed and is highly dependent on the vapour pressure of the overlying air. In essence, it can be concluded that water temperature is not independent of wind speed and vapour pressure. If radiation exchange and all other meteorological elements were to remain constant over a shallow lake for an appreciable time, the water temperature and the evaporation rate would become constant. If the wind speed then suddenly doubled, the evaporation rate would also double momentarily. This increased rate of evaporation would immediately begin to extract heat from the water at a more rapid rate than what could be replaced by radiation and conduction. The water temperature would approach a new, lower equilibrium value, and evaporation would diminish accordingly.

The nature of evaporating surface is another important factor in the evaporation process. All surfaces exposed to precipitation, such as vegetation, buildings and paved streets are potentially evaporation surfaces. The rate of evaporation from a saturated soil surface is approximately the same as that from an adjacent water surface of the same temperature; as the soil begins to dry, evaporation decreases and its temperature rises to maintain the energy balance. Eventually, evaporation virtually ceases, since there is no effective mechanism for transporting water from appreciable depths. Thus, the rate of evaporation from soil surfaces is limited by the availability of water, or evaporation opportunity.

Evaporation from snow and ice constitute a special problem since the melting point lies within the range of temperatures normally experienced. Evaporation can occur only when the vapour pressure of the air is less than that of the snow surface that is only when the dew point is lower than temperature of the snow. It should be noted that only foreign material, which tends to seal the water surface or change its vapour pressure or albedo would affect the evaporation.

3.3 Measurement of Evaporation and Evapotranspiration

Evaporation pans have been widely used for estimating the amount of evaporation from free water surfaces. The device, depicted in Figure 6.1 is easy to use, but relating measurements taken from it to actual field conditions is difficult and the data it produces is often of questionable value for making a real estimates. A variety of pan types have been developed but the U.S. Weather Bureau Class A pan is the standard in the United States. Pan evaporation observations have been used to estimate both free water (lake) evaporation and evapotranspiration from well-watered vegetation. Interestingly enough, field experiments have shown a high degree of correlation of pan data with evapotranspiration from surrounding vegetation when there is full cover and good water supply. As in the case of precipitation gauges, pan data can be continuously recorded and transmitted to a central receiving station.

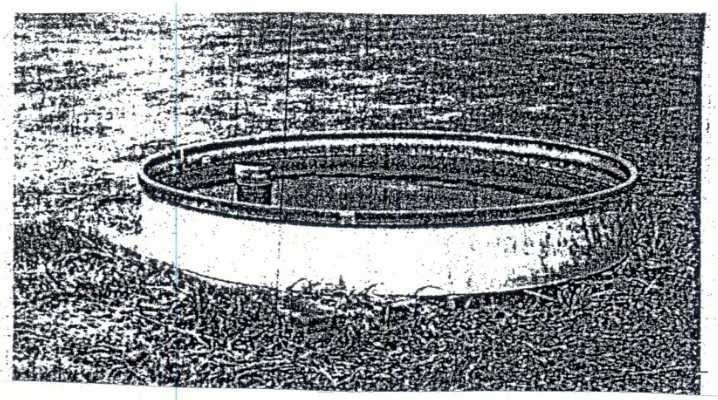

Fig. 6.1: Evaporation Pan and Gauge
Source: Smithson, et al. (2002). Fundamental of the Physical Environment

Evapotranspiration measurements are often conducted using lysimeters. These devices are containers placed in the field and filled with soil, on which some type of vegetation growth is maintained. The object is to study soil-water-plant relationships in a natural environment. The main feature of a weighing lysimeter is a block of undisturbed soil, usually weighing about 50 tons, encased in a steel shell that is 10x10x8ft. The lysimeter is buried so that only a plastic border marks the top of the underground scale sensitive enough to record even the movement of rabbit over its surface. The soil is weighed at intervals, often every 30 minutes around the clock, to measure changes in soil water level. The scales are set to counterbalance most of the dead weight of the soil and measure only the active change in weight of water in the soil. The weight loss from the soil in the lysimeter represents water used by the vegetative cover, plus any soil evaporation. Added water is also weighed and thus an accounting of water content can be kept. Crops or cover are planted in the area surrounding the lysimeter to provide uniformity of conditions surrounding the instrument. Continuous records at the set weighing intervals provide almost continuous monitoring of conditions. The data obtained can be transmitted to any desired location for analysis and/or other use. Weighing lysimeters can produce accurate values of evapotranspiration over short periods of time, but they are expensive. Non-weighing types of lysimeters, which are less costly, have also been used, but unless the soil moisture content can be measured reliably by some independent method, the data obtained from them cannot be relied upon except for long-term measurements such as between precipitation events.

SELF-ASSESSMENT EXERCISE

Evaporation has been identified as one of the driving forces of the hydrologic cycle, in your opinion, what are the major controlling forces of the evaporation process.

4.0 CONCLUSION

The above discussions revealed that evaporation process is mainly dependent on an energy source (sun) and wind-which is necessary to mix the water molecules with the air and transport them away from the surface. Without evaporation, the hydrologic cycle processes will be incomplete, with serious implications on precipitation, which would have adverse effects on plants, animals and human lives.

5.0 SUMMARY

In this unit, you have learnt that:

- evaporation is the process by which a liquid is converted into a gaseous state; while transpiration involves water lost from plants. The combine process is called evapotranspiration
- rates of evaporation vary, depending on meteorological factors and the nature of the evaporating surface

- evaporation pans and lysimeters are the common instruments used in measuring evaporation and evapotranpiration respectively.

6.0 TUTOR-MARKED ASSIGNMENT

i. The process by which precipitation reaching the earth's surface is returned to the atmosphere as vapour is called ____________
ii. At what percentage is air said to be saturated ____________
iii. The process of water lost by plants through the stomata is called___
iv. Evapotranspiration involves the combined process of which of the following.
(a) evaporation and respiration (b) evaporation and Precipitation
(c) evaporation and transpiration (d) none of the above
v. The rate of evaporation is mainly dependent on what factor.
(a) hydrological (b) meteorological (c) geological (d) biological
vi. A measure of the ability of the atmosphere to remove water from the surface assuming no limitation of water supply is called
(a) potential evapotranspiration (b) actual evapotranspiration
(c) equal evapotranspiration (d) a and b only.

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UNIT 7 RUNOFF

CONTENTS

1.0 INTRODUCTION

Two of the major pathways of precipitation received on the earth's surface are infiltration and evaporation, as was discussed in the preceding units. The third major pathway is runoff, which shall be the focus of this unit. The discussions shall centre on sub-topics such as definition of runoff, quick flow and delayed flow, sources and components of runoff.

2.0 OBJECTIVES

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

- define runoff
- distinguish between quick flow and delayed flow
- identify sources and components of runoff.

3.0 MAIN CONTENT

3.1 Definition of Runoff

Runoff or stream flow comprises gravitation movement of water in channels, varying in size from those containing the smallest ill defined trickles to those containing the largest rivers such as the Amazon or the Congo. Runoff, which is synonymous to stream flow, stream or river discharge, or catchments yield can simply be referred to as the movement of water over the earth's surface. It detailed the movement of water from one place to the other on the earth's surface. The unit

area over the earth's surface, which has been found to be most convenient for monitoring water flow, is the river basin – the boundary of a river system.
Generally, water within the basin is separated into various components. The components are channel flow, which is common in rivers and streams, and surface runoff, which is mostly experience on land after rain. It could be in form of sheet flow or channel flow. Runoff is important in hydrological study since it's the main cause of major environmental problems being experience on the landscape such as erosion and flooding.

3.2 Quick Flow and Delayed Flow

The immediacy of stream flow response to a rainfall event indicates that part of the rainfall takes a rapid route to the stream channels (that is quick flow); equally, the subsequent continuity of flow through often-prolonged dry weather period indicates that another part of the rainfall takes a much slower route as delayed flow. These two flow components are apparent in rivers of all sizes. However, in large river systems the multiplicity of flow contributions to the main channel from numerous tributary streams complicates interpretation of the hydrograph response of major rivers to precipitation. It is estimated that globally an average of 36 per cent of the total precipitation falling on the land areas reaches the oceans as runoff. Of this amount, quick flow accounts for about 11 per cent and delayed flow accounts for the remaining 25 per cent of precipitation.

3.3 Sources and Components of Runoff

The variable response of stream flow to precipitation, both spatially and temporally reflects the contrasting flow paths of precipitation towards the stream channels. Precipitation may arrive in the stream channel by a number of flow paths namely direct precipitation onto the water surface, overland flow, shallow subsurface flow (throughflow); and deep subsurface flow (groundwater flow). The relative importance of these sources of runoff may vary spatially; depending on drainage basin characteristics such as soil type, nature and density of the vegetation cover, and precipitation conditions. In addition, the importance of individual runoff sources may vary with time, for example over a period of years or season, and may change dramatically during an individual storm or sequence of rainfall events, in response to variations of infiltration capacity, water table levels and surface water area.

3.3.1 Channel Precipitation

The contribution of precipitation falling directly on water surfaces is normally small because the perennial channel system occupies only a small proportion (one-two per cent) of the area of most catchments. The channel system is more extensive where catchments contain a large area of lakes or swamps and in these circumstances; channel precipitation will tend to be a more dominant runoff component. In addition, channel precipitation will increase significantly during a prolonged storm or sequence of precipitation events, as the channel network expands, and may temporarily account for 60 per cent or more of total runoff in some small catchments.

3.3.2 Overland Flow

Overland flow comprises the water that flows over ground surface to stream channels either as quasi-laminar sheet flow or more usually, as flow anastomising in small trickles and minor rivulets. One cause of overland flow is the inability of water to infiltrate the surface as a result of a high intensity of rainfall and/or a low value of infiltration capacity. Ideal conditions are found on moderate to steep slopes in arid and semi-arid areas. Here, vegetation cover may be sparse or non-existent, exposing the surface to raindrop impact and crusting processes. Other conditions in which overland flow assumes considerable importance involve the hydrophobic nature of some very dry soils, the deleterious effects of many agricultural practices on infiltration capacity, and freezing of the ground surface. In humid area, vegetation cover is thicker and more substantial and because of the high infiltration rate, which characterises most vegetation – covered surfaces; overland flow is rarely observed, even in tropical rainforest.

However, there are many areas, both humid and sub-humid, where the effects of topography or the nature of the soil profile facilitate the rise of shallow water tables to the ground surface during rainfall or throughflow events. In such conditions, the infiltration capacity at the ground surface falls to zero and saturation overland flows.

3.3.3 Through Flow

Water that infiltrates the soil surface and then moves laterally through the upper soil horizon towards the stream channels, either as unsaturated flow or, more usually, as shallow perched saturated flow above the main groundwater level is known as throughflow. Alternative terms found in the literature include interflow, subsurface stormflow, storm seepage and secondary baseflow. Throughflow is liable to occur when the lateral hydraulic conductivity of the surface soil horizons greatly exceeds the overall vertical hydraulic conductivity through the soil profile. During prolonged or heavy rainfall on a hill slope, water enters the upper part of the profile more rapidly than it can drain vertically through the lower part, thus accumulating and forming a perched saturated layer, from which water will ‘escape’ laterally, i.e. in the direction of greater hydraulic conductivity.

3.3.4 Groundwater Flow

Most of the rainfall that infiltrates the catchment surface eventually percolate through the soil layer to the underlying groundwater zone and eventually reach the mainstream channels as baseflow, through the zone of saturation. Since water at depth can move only very slowly through the ground, the outflow of groundwater into the stream channels may lag behind the occurrence of precipitation by several days, weeks or even years. Groundwater flow tends to be very regular, representing as it does the outflow from the slowly changing reservoir of moisture in the soil and rock layers. In general, baseflow represents the main long-term component of total runoff and is particularly important during dry spells when surface runoff is absent. Figure 7.1 shows the diagrammatic representation of the runoff process.

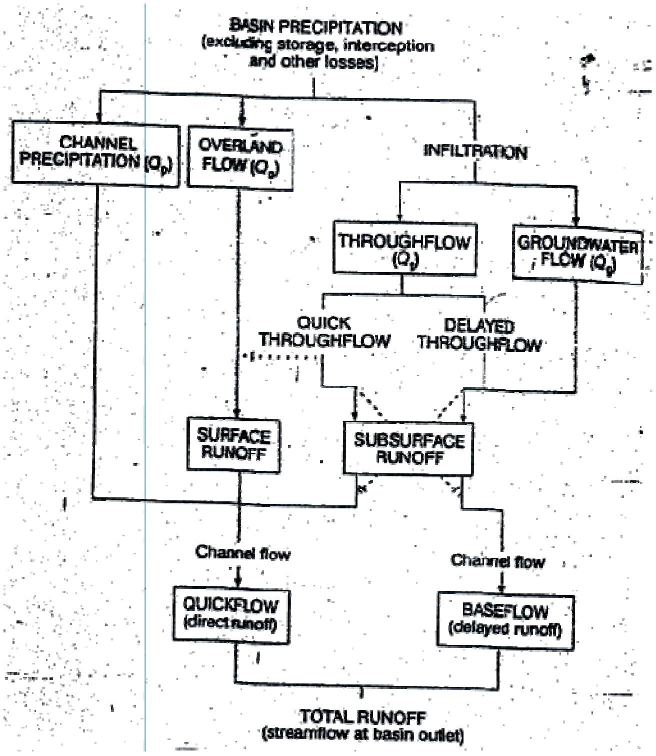

Figure 7.1: Diagrammatic Representation of the Runoff Process
Source: Ward, R.C. & Robinson M. (2000). Principles of Hydrology

3.4 Runoff Measurement

Various methods are available for measuring runoff depending upon the specific needs of the location. Each method has its own characteristics that favour its adoption under certain conditions of measurements and limit its use under other sets of conditions. Any method selected should measure runoff accurately for low, medium, and high rates of discharge. However, the H-type flume device will be examined.

H-type Flumes

Presently, three types of flumes—HS, H, and HL—are available for small-, medium-, and high-discharge rates, respectively. They have different specifications to suit various ranges of water flow. The shape of flume provides the following distinct advantages that favour its use under a variety of flow conditions:

1. The increase of throat opening with the rise of stage facilitates accurate measurement of both low and high flow of water.
2. The converging section of flume makes it self-cleaning because of increased velocity. Consequently, the flume is suitable for measuring flows having sediment in suspension and low bed-loads.
3. It is simple to construct, rigid and stable in operation, and requires minimal maintenance for retaining its rating.
4. Its installation is simple and is generally not affected by the steepness of the channel gradient.

Flumes are basically designed for free flow conditions and are therefore not recommended for submerged-flow conditions. Free flow occurs when downstream flow of the measuring structure does not affect flow conditions within and in the upstream sections of the structure, that is, there is sufficient fall near the outlet of the structure. On the other hand, submerged flow occurs when downstream flow strongly influences flow condition within and at the upstream section of the measuring structure. Flumes are also not recommended for flows carrying excessive amounts of coarse bed-loads.

Figure 7.2 H-flume attached to a Stilling well and connected to a Drum-type Recorder for measuring runoff (Pathak, P. et al., 1981)

SELF-ASSESSMENT EXERCISE

Identify the various sources of runoff to a stream channel.

4.0 CONCLUSION

The sources of runoff identified above include direct precipitation, overland flow, through flow and groundwater flow. These sources are however influenced by the characteristics of the drainage basin such as soil type, nature and density of the vegetation cover, and upon precipitation conditions. In areas where the soils are compact or where the macro and micro pores of the soil has been sealed up due to trampling, vehicular movement and other human activities, runoff generation is usually high as a result of low infiltration. This explains why there is higher runoff in urban centres than in rural areas.

5.0 SUMMARY

In this unit, you have learnt that:

- runoff comprises the gravitation movement of water in channel in varying sizes
- quick flow involves rapid flow of precipitation to stream channel while delayed flow involves a much slower flow
- the major sources of runoff include channel precipitation, overland flow, through flow and groundwater flows. These sources are influenced by the nature of the drainage basin characteristics, which include soil, precipitation and plant cover.

6.0 TUTOR-MARKED ASSIGNMENT

i. Precipitation that gets to the ground surface follows three major pathways, which include evaporation, infiltration and _____________
ii. The movement of water over the land surface is called ____________
iii. (3) Which of the following is a source of runoff?
   (a) overland flow (b) groundwater flow (c) through flow
   (d) all of the above
iv. Which of the following options is not true of runoff?
   (a) runoff is high when infiltration is high
   (b) runoff is low when infiltration is high
   (c) runoff is affected by soil characteristics
   (a) runoff is high when infiltration is low

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MODULE 3

UNIT 1 FLOODING

CONTENTS

1.0 INTRODUCTION

Flooding has been an environmental menace in most urban centres worldwide. In well-planned urban centres however, the problem is minimised. Thus, flooding is more pronounced in urban centres of developing countries due to poor planning and negative human activities. This unit will attempt a definition of flooding, examine the causes, impacts and control of flooding.

2.0 OBJECTIVES

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

- define flooding
- list the causes of flooding
- examine the impacts of flooding and control measures.

3.0 MAIN CONTENT

3.1 What is Flooding?

Flooding is the inundation of land beyond the normal confines of a channel or coastline, either by overflow of excess water or its influx via shallow subsurface or low-lying routes. Flooding can also be defined as a process whereby a river outflows its natural channel or the artificial channel constructed for it.

Periodic floods occur on many rivers, forming a surrounding region known as the flood plain. A flood plain is a flat land area beside a river that regularly becomes flooded when the river over flow its bank. During times of rain or snow, some of the water is retained in ponds or soil, some is absorbed by grass and vegetation, some evaporates, and the rest travels over the land as surface runoff. Floods occur when ponds, lakes, riverbeds, soil, and vegetation cannot absorb all the water. Water then runs off the land in quantities that cannot be carried within stream channels or retained in natural ponds, lakes, and man-made reservoirs.

3.2 Causes of Flooding

There are several causes of flooding, prominent amongst which are meteorological factors, poor development planning and poor maintenance. Flooding can however be exacerbated by increased amounts of impervious surface or by other natural hazards such as wildfires, which reduce the supply of vegetation that can absorb rainfall.

Most floods are the result of severe meteorological or climatologically conditions. They may follow severe local thunderstorms or heavy rainfall on a saturated landscape. Snowmelt, particularly when associated with further rain, can cause major flooding. Storm surges on the coast as a result of tropical cyclones can cause even more damage when reaching delta where rivers are in flood.

Flood may also occur as a result of individual disasters such as landslides or dam bursts. Although these conditions may be important, major floods are usually the result of flood-intensifying conditions, which worsen the original meteorological problem. For example, the basin characteristics may aid the movement of rainwater in unvegetated steep, impermeable slopes, variable altitude and a basin shape, which focuses the tributaries on to a particular part of the catchments. Floods often occur where there is a sudden change in channel gradient, causing decrease in flow water velocity, which might perhaps spillover the flood banks.

Severe winds over water bodies can also result to flooding, even when rainfall is relatively light. For example, the shorelines of lakes and bays can be flooded by severe winds such as hurricanes. In addition, coastal areas are sometimes flooded by unusually high tides such as spring tides, especially when steep compounded by high winds and storm surges. Tsunamis have also been identified as a trigger for flooding. Tsunamis are high large waves, typically caused by undersea earthquakes or massive explosions such as the eruption of an undersea volcano. A recent example of a tsunami triggered flood happen in Japan in the first quarter of 2011 as a result of a massive earthquake, which claimed the lives of over 10,000 people, with property worth billions of US dollars destroyed.

Apart from meteorological factors, anthropogenic (human) factors are also important in determining the severity of floods. Poor development planning and maintenance are responsible for some of the flooding episode, recorded in the world over the years. In the urban areas of most parts of the world, there are reported cases of inappropriate developments in flood plains due to pressure on available land. Inappropriate constructions of roads, car parks and buildings among others thereby prevent rainfall from draining away naturally. Such development creates impervious surfaces but accumulates, resulting in increasing flood risk from rainwater runoff. Furthermore, poor or insufficient drainage networks, inadequate maintenance of watercourses, faulty sewer networks, failure of dams, levees, retention ponds, or other structures that retain water, due to poor design, construction or maintenance also contribute to anthropogenic resultant flooding activities.

3.3 Impacts of Flooding

Flooding has many impacts. It damages property and endangers the lives of humans and other species. Rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or down a coast). The spawning grounds for fish and other wildlife habitats can become polluted or completely destroyed. Some prolonged high floods can delay traffic in areas, which lack elevated roadways. Floods can interfere with drainage and economic use of lands such as interfering with farming. Structural damage can occur in bridge abutments, bank lines, sewer lines, and other structures within floodways. Waterway navigation and hydroelectric power are often impaired. Financial losses due to floods are typically in millions of dollars each year. Recent examples include the Lagos and Ibadan floods of 2011, where lives and property worth millions of naira where lost. Also, in August 1988, the volume of water in the reservoir of Bagauda Dam in Nigeria, which has an operational capacity of two million cubic litres, actually reached 42 million cubic litres. This led to its collapse, resulting in 146 deaths and property damaged estimated at 650 million naira. The impacts of flooding will be discussed further under three board sub-heading – health, economic and social impacts.

3.3.1 Health Impact

Specifically, health effects caused by a flood event may result from the flood itself. For example, the disruptions and problems arising from trying to recover from losses and the worry or anxiety about the risk of flood re-occurrence. The potential health effects can be considered at three time periods:

- **Immediate:** Death by drowning, injuries due to being knocked over by flood water or struck by falling trees, over-exertion during the event, hypothermia, electrocution, exposure to contaminants, and the stress of the event itself.
- **Medium term:** Gastrointestinal illnesses, cardiovascular disease from over-exertion during recovery/clean-up processes, lacerations, sprains/strains, dermatitis, respiratory illnesses and carbon monoxide poisoning.
- **Longer term:** Longer-term effects are mostly psychologically related. Sewer flooding and the health issues associated with it is a key issue for urban flooding, whereas concern is growing over the effects of diffuse pollution in rural flooding. In terms of density and sparsely issues, because of the close proximity of people to one another within the urban environment, there are more chances of an outbreak of epidemic, especially if sewer flooding is involved.

3.3.2 Economic Impact

This includes the cost of damage done to a property by a flood, the cost of clean-up (for example, cost of bailing water out of the flooded house), costs of living in temporary accommodation, and possibly costs of selling a house previously flooded or a house in a defined flood plain. In rural areas where there are few facilities, the loss of services and shops could have a disproportionately large economic impact on small communities. There could also be a negative impact in deprived urban neighbourhoods where business confidence is vital to regeneration. If businesses fail because of the impacts of flooding, this could damage the perception of the area as an attractive place for investment. An example of such area is the Makoko area in Lagos.

3.3.3 Social Impact

Social impact of flood includes every other kinds of discomfort, which is not directly economic or health related. Social impacts may include household disruption, community and neighbourhood changes, and associated impacts of evacuation homeless and temporary accommodation provision.

Household disruption includes the stress of cleaning up the house, dealing with builders, and dealing with living in a damp environment. These activities are rated as something that is very stressful for a lot of people . In both rural and urban areas, there is likely to be pressure on services to aid the cleanup of the flooding. In urban areas, if a large area has been flooded there may be difficulties in finding workmen to repair flood damage.

Impacts associated with evacuation and temporary accommodation include both the effects of having to leave home and those of having to live away from home. In urban areas, if there are large numbers of people to be relocated will put pressure on available services, and may mean that people have to live in cramped and overcrowded conditions, or have to move a distance from their homes. Thus, for people in both rural and urban centres, severe difficulties will be experienced, if relocated to areas, at distance from their homes. Specifically, since it will be harder to keep in touch with repairs being carried out on their homes, and harder to maintain normal routines due to greater travelling distances and new routes to schools, work and services.

3.4 Flood Control

Flood control refers to all methods used to reduce or prevent the detrimental effects of floodwaters. Some methods of flood control have been practiced since ancient times. These methods include afforestation to retain extra water, terracing hillsides to slow flow downhill, and the construction of floodways (man-made channels to divert floodwater). Other techniques include the construction of levees, dikes, dam (reservoirs or retention ponds to hold extra water during times of flooding).

Many dams and their associated reservoirs are designed wholly or partially to aid in flood protection and control. In many countries, rivers prone to floods are often carefully managed. Defences such as levees, bunds, reservoirs, and weirs are used to prevent rivers from overflowing their banks. When these defenses fail, emergency measures such as sandbags or portable inflatable tubes are used. A weir, also known as low head dam, is most often used to create millponds. For example, on Humber River in Toronto, a weir was built near Raymore Drive to prevent a recurrence of the flood damage caused by Hurricane Hazael in 1954. Coastal flooding has been addressed in Europe and America with coastal defenses, such as sea walls, beach nourishment, and barrier islands.

Other methods of flood control include the stoppage of further developments of flood plains, proper channelisation of drainage systems, discouraging indiscriminate to disposal of waste (especially rubber bags and cans), which are not biodegradable and have the capacity to block drainage systems, leading to flooding.

SELF-ASSESSMENT EXERCISE

Flooding is a global environmental menace especially in urban centres. In your own opinion what are the causes, impacts and controls of flooding?

4.0 CONCLUSION

Floods are the most common of all environmental hazards. Each year, thousands of people die as a result of flooding and millions are affected by indirect consequences, such as damage to crops, housing, transport, and so on. Most flood problems are found on riverine flood plains, in both developed and developing countries, though the impact is often greater in the latter, where high populations are to be found on extensive and often relatively fertile flood plains such as those of Rivers Ganges and the Yangtse.

Having gone through this unit, you should be well informed of the causes, impacts and control measures of flooding. This knowledge should therefore, be transform to positive actions in contributing to solving the flooding menace in our environment.

5.0 SUMMARY

In this unit, you have learnt that:

- flooding is a process whereby a river outflows its natural channel or the artificial channel constructed for it
- the major causes of floods are meteorological or climatological conditions. However, human activities tend to exacerbate its effects
- flooding has noticeable impacts on health, economic and social well being of the affected people
- flooding can be control by several coordinated measures which include planting vegetation, construction of dams, levees etc, and avoidance of areas prone to floods such as flood plains.

6.0 TUTOR-MARKED ASSIGNMENT

i. The process by which a river outflows its natural channel or the artificial channel constructed for it is called ___________

ii. The area of land surrounding a river whose floods occur periodically is called____________

iii. The causes of flooding can broadly be classified into natural and ____ factors

iv. Which of the following conditions would favour the process of flooding?
(a) light rainfall (b) heavy rainfall that is well infiltrated (c) heavy rainfall on vegetated surface (d) heavy rainfall on concrete surface

v. Which of the following statements is true of the social impact of flooding?
(a) cost and damage done to a property by a flood
(b) inconveniences of relocating to a temporary accommodation
(c) psychological problems
(d) exposure to contamination

vi. One of the following is a measure for flood control.
(a) planting vegetation (b) building on floodplains
(c) deforestation (d) none of the above

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UNIT 2 EROSION

CONTENTS

1.0 INTRODUCTION

In the preceding unit, the runoff process-which simply means the movement of water over the earth’s surface, was discussed. This process acting with other natural agents such as wind and ice leads to erosion. The question now is what is erosion? What are the agents of erosion, and how can the problem of erosion be controlled? Answers to these questions will be the focus of this unit.

2.0 OBJECTIVES

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

- define erosion
- list and discuss the agents of erosion
- state how the problem of erosion can be controlled.

3.0 MAIN CONTENT

3.1 Definition of Erosion

Erosion is the wearing away and removal of soil and rock fragments on the surface of the earth by wind, water, ice, or other natural agents. It is part of the process known as gradation, which besides the wearing away of rocks to form sediments also involves the transportation and eventual deposition of the sediments. Working together, the processes of erosion and deposition have done much to shape the earth's surface.

The New Encyclopedia Britannica (2007) defines erosion as the removal of surface material from the earth's crust, primarily soil and rock debris, and the transportation of the eroded materials by natural agencies from the point of removal. Erosion will often occur after rock has been disintegrated or altered through weathering. Weathered rock material will be removed from its original site and transported by natural agent such as water, wind, stream, and so on. With both processes often operating simultaneously, the best way to distinguish erosion from weathering is by observing the transportation of materials. Erosion is the part of a geological cycle events that may be complemented by processes that originate beneath the earth's surface. For example, mountain ranges are first raised by great crustal movements and are then slowly worn away by the agents of erosion.

3.2 Agents of Erosion

Rocks are continually being worn away and land areas gradually lowered as agents of erosion attack the minerals of which the rocks are made. The fragments thus produced are carried elsewhere by wind, water, ice or other transporting agents. Most of the sediment is eventually deposited in ocean, settling at the bottom to probably become the sedimentary rocks of the future geological structure. There are five principal agents of erosion-running water, wind, groundwater, glacier and marine.

3.2.1 Running Water

Any mass of water flowing over the land surface is known as running water. It includes streams, rivers, and surface runoff (torrents), which occur after heavy rainfall. Running water has both source and mouth. The source is where the running water originates from (for example, a spring, a marsh, end of a glacier or collected surface water during rainfall), while the mouth is water it empty into ends. For example, many streams or rivers have their mouths open into the sea (for example, the River Niger), some have theirs open into other rivers (for example, the River Benue) while some end in an inland lake (for example, River Hadeja). It should be noted that the materials carried by running water during the process of erosion is called 'load'.

Factors Influencing the Action of Running Water

Streams have been recognised to cause more erosion than all other geological agents. The ability of a stream to erode is governed by several factors, which include the following:

(i) The power of the river, which principally depends on its velocity and volume. For example, an increase in water volume and stream flow velocity greatly increases the rate of erosion and probably determines the stream's sediment load at a given time.

(ii) The steepness of the slope. The steeper a slope the higher the rate of running water, which increases the erosive force of the running water.

(iii) The nature of the rock is also an influencing factor of running water. When running water flows along an area with soft rocks the soil and rocks in that area is more easily erodable than an area with hard rock, and compact soil structure.

(iv) Presence of joints or crevasses. Rocks with a lot of joints cracks or crevasses are much more susceptible to the erosional forces of running water than those without cracks or crevasses.

Processes of River Erosion

According to Ojo, et al. (2007), the processes involved in river or running water erosion include hydraulic action, corrosion, attrition and solution.

(i) **Hydraulic Action:** This process of erosion depends mainly on the velocity and volume of the river or running water alone, without the use of the load carried by it. This process is very effective in areas with soft rocks and where the rocks have a lot of cracks and joints. It is equally effective in areas with steep slopes, especially in the upper course of a river.

(ii) **Corrosion:** This process of river erosion, involves the wearing away of the sides and the river bed by the transported load. The load may include boulders, pebbles, sand and silt. This process results in the enlargement and deepening of the river bed, and increases in the river load. In addition, where bed rocks are soft, pot holes may result.

(iii) **Attrition:** This process involves the wearing down of a river load, as the load fragments strike against one another, thus progressively reducing the size of the load in the river or running water.

(iv) **Solution:** This is the erosion process whereby the material water through chemical reaction. This form of erosion is common in areas where limestone and chalk are predominant.

Wind

Wind erosion is more likely to occur in dry areas where soil is loose and unprotected by vegetation. Winds of high velocity in these areas carry a load of rock fragments that cause wind abrasion. Evidence of such abrasion is seen on rock fragments with facets that have been cut and polished by the sandblasting action of wind-blown sediments, and in rocks undercut to form table rocks or pedestals. A form of erosion that occurs when loose rock particles are blown away by the wind is called deflation. Features produced by deflation include blowouts, and desert pavement.

Processes of Wind Erosion

Ojo, et al. (2007) stated that the processes of wind erosion include deflation, abrasion and attrition.

(i) **Deflation:** This process involves the lifting and blowing away of loose sand and dust materials from the ground, using the force of the wind. It involves erosion without the use of the load. The process is particularly effective where there are loose sand or dust particles which can easily be blown and carried by wind.
Deflation results in the lowering of land surface. The main landforms resulting from the process are large depressions also called deflation hollows. An example is the Quattara Depression in Egypt. This depression is about (450 feet) below the sea level.

(ii) **Abrasion:** This process involves the use of the load, mostly sand and dust particles, to erode rock surfaces. Such sand blasting causes surfaces to be scratched, polished and worn away. A great variety of desert features result from the abrasive effect of wind. Such features include rock pedestals mushrooms amongst others.

(iii) **Attrition:** This process of wind erosion involves the collision of the eroded particles or materials against one another; thus, leading to the reduction in the sizes of the particles as they wear against each other.

Factors Influencing Wind Erosion

Several factors influence the action of wind as an erosional agent. Some of which are listed below:

(i) The size of the materials carried by the wind.
(ii) The velocity and direction of the wind.
(iii) The location and nature of the surface over which the particles are transported.
(iv) The presence or absence of obstacles such as water, or vegetation along the path of the wind.

3.2.3 Groundwater

Erosion by groundwater takes place just beneath the earth’s surface. Carbon dioxide from the air and decaying organic matter from the soil may combine with groundwater to form carbonic acid. Groundwater containing carbonic acid and circulating through rocks commonly removes soluble minerals and carries them away in solution.

3.2.4 Glaciers

Glacier is a powerful erosional agent. As a glacier advances, the moving ice quarries pieces of material from the bedrock over which it passes. The fragments become embedded in the ice and serve as abrasive tools that further scratch and gouge the bedrock.

3.2.5 Marine

The ocean acts as an erosional agent primarily through waves and the currents produced by waves. Most ocean waves are generated by wind currents that agitate the water surface. Large waves may pound the shore with tremendous force, producing a hydraulic-lifting action that dislodges large masses of coastal rock. The blocks fall to the ocean bottom, where they undergo more erosion along with other wave-battered rock debris that has accumulated there. The sand and rock fragments grind against each other and scour the shore. In areas where the coast is formed of soluble rocks, the ocean may also erode the rocks by dissolving their minerals.

3.3 Types of Erosion

There are different types of erosion. However, the following types are mostly recognized. They include splash, sheet, rill and gully erosions.

3.3.1 Splash Erosion

Splash erosion is the first stage of the erosion process. It occurs when raindrops hit bare soil, and the explosive impact breaks up soil aggregates so that individual soil particles are ‘splashed’ to the soil surface. The splashed particles can rise as high as 60cm above the ground and move up to 1.5 metres from the point of impact. The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff.

3.3.2 Sheet Erosion

Sheet erosion is the removal of soil in thin layers by raindrop impact and shallow surface flow. It results in loss of the finest soil particles that contain most of the available nutrients and organic matter in the soil. Soil loss is so gradual that the erosion usually goes unnoticed, but the cumulative impact accounts for large soil losses.

Soils most vulnerable to sheet erosion are overgrazed and cultivated soils where there is little vegetation to protect and hold the soil. Hence, vegetation cover is vital to prevent sheet erosion because it protects the soil, impedes water flow and encourages water to infiltrate into the soil.

3.3.3 Rill Erosion

Rills are shallow drainage lines less than 30cm deep. They develop when surface water concentrates in depressions or low points through paddocks and erodes the soil. Rill erosion is common in bare agricultural land, particularly overgrazed land, and in freshly cultivated soil where the soil structure has been loosened. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion.

3.3.4 Gully Erosion

Gullies are channels deeper than 30cm that cannot be removed by normal cultivation. Gullies occur when smaller water flows concentrate and cut a channel through the soil. Most gullies extend upslope as a result of the head of the gully being continually undercut and collapsing. Figure 3.0 shows a diagrammatic representation of types of erosion.

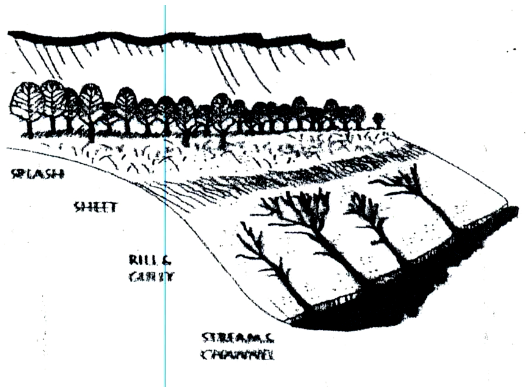

Fig. 2.1: Diagrammatic Representation of Types of Erosion
Source: http://www.cep.unep.org/pubs/techreports/tr41en/image11.gif

3.4 Erosion Control

Erosion can be controlled through various measures, which include reforestation, contour ploughing, strip cropping, crop rotation, control grazing and deforestation, avoidance of over cultivation amongst other measures. Reforestation is the re-stocking of existing forests and woodlands, which have been depleted. Trees can be used as windbreakers or shelterbelt. This involves a plantation usually made up of one or more rows of trees or shrubs planted in a regular pattern with the aim to provide shelter from the wind and to protect soil from erosion. They are commonly planted around the edges of fields or farms.

Contour ploughing or contour farming is the farming practice of ploughing across a slope following its elevation. The rows formed slow water runoff during rainstorms to prevent soil erosion and allow the water time to settle into the soil.

Strip cropping is a method of farming used when a slope is long and steep or when other types of farming may not prevent soil erosion. Strip cropping helps to stop soil erosion by creating natural dams for water, helping to preserve the soil. Certain layers of plants will also absorb minerals and water from the soil more effectively than others. When water reaches the weaker soil that lacks the minerals needed to make it compact, it normally washes it away. However, when strips of soil are compact enough to slow down water from moving through them, it normally prevents erosion.

The carrying capacity of land for cattle varies with the rainfall and the fertility of the soil. However, when the carrying capacity is exceeded, the land is overgrazed. Overgrazing reduces the diversity of plant species, lead to reduction in the growth of vegetation and dominance of plant species that are relatively undesirable to the cattle, increases the loss of soil by erosion as the plant cover is reduced and results to damage from the cattle trampling on the land. For example, paths made as the cattle travel to the same water hole or stream develop into gullies, which erode rapidly in the rain. To control erosion caused by overgrazing, proper care should be taken to ensure that the carrying capacity of the land is not exceeded.

Another practice that encourages erosion is deforestation – harvesting trees for commercial and other uses and burning forest to convert lands to agricultural purposes. This practice exposes the land to the active agents of erosion. Deforestation has to be properly managed by ensuring that trees are replanted to replace fell ones, and the forest has to be given time to regenerate. This management method will help in achieving sustainability of the forest, and consequently reduce erosion.

Over cultivation of farmlands is another negative agricultural practice that promotes erosion. Over cultivation exposes the land to erosion. For example, when a particular farmland is tilled year in year out, the soil structure is affected, and the loose soil can easily be eroded away by rain or wind. Fallow cultivation can however help to maintain the soil structure, thereby enhancing its ability to withstand erosion.

Another effective way of preventing soil erosion is the practice of crop rotation. This practice can greatly affect the amount of soil lost from erosion by water. In areas that are highly susceptible to erosion, farm management practices such as zero and reduction in tillage can be supplemented with specific crop rotation methods to reduce raindrop impact, sediment detachment, sediment transport, surface runoff, and soil loss. Protection against soil loss is maximized with rotation methods that leave the greatest mass of crop stubble (plant residue left after harvest) on top of the soil. Stubble cover in contact with the soil minimises erosion from water by reducing overland flow velocity, stream power, and thus the ability of the water to detach and transport sediment. Crop rotation helps to prevent the disruption and detachment of soil aggregates that cause macrospores to block, infiltration to decline, and runoff to increase. This significantly improves the resilience of soils when subjected to periods of erosion and stress.

SELF-ASSESSMENT EXERCISE

Identify the agents of erosion, and propose how erosion menace can be ameliorated.

4.0 CONCLUSION

Even though most people see erosion as a negative process, it also has its benefits to man though they are usually not so striking. Erosion usually helps in breaking down bedrocks to form soil. However, erosion unless kept in check, destroys soils and removes them from the land. Urban development aggravates some erosional problems, for example, housing projects can be built on unstable soils that are subject to landslides. In addition, commercial operations such as strip mining, quarrying, and poor agricultural practices take their toll on precious soil. Thus, soil-conservation practices are becoming increasingly important as population grows and land areas are abused on a wider scale.

5.0 SUMMARY

In this unit, you have learnt that:

- erosion is the wearing away and removal of soil and rock fragments at the surface of the earth by wind, water, ice or other natural agents
- there are five principal agents of erosion, which include running water, wind, groundwater, glacier and marine
- some measures of erosion control include reforestation, contour ploughing, strip cropping, crop rotation, control grazing and deforestation, and stoppage of over cultivation.

6.0 TUTOR-MARKED ASSIGNMENT

i. ___________ erosion is more likely to occur in dry areas where soil is loose and unprotected by vegetation.
ii. A form of erosion that occurs when loose rock particles are blown away by wind is called ___________
iii. _________ erosion takes place just beneath the earth's surface
iv. Erosion control measures include all of the following except which
(a) deforestation (b) afforestation (c) strip cropping (d) contour ploughing
v. Which of the following is not an agent of erosion?
(a) marine (b) groundwater (c) wind (d) evaporation
vi. Erosion rate may be increased through which of the following measures
(a) planting of cover crops (b) over cultivation (c) control grazing
(d) crop rotation

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UNIT 3 SEDIMENT

CONTENTS

1.0 INTRODUCTION

Sediment and erosion are closely related concepts in hydrology. The erosion process produces sediment in form of both organic and inorganic materials, which are transported and eventually deposited. This unit will examine the sources, transportation process, deposition, impacts, and control measures of sediment.

2.0 OBJECTIVES

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

- define sediment
- list the transport modes of sediment
- identify the sources of sediment
- state the preventive and control measures of sediment.

3.0 MAIN CONTENT

3.1 What is Sediment?

Sediment is naturally occurring material that is broken down by processes of weathering and erosion and subsequently transported by the action of wind, water, or ice, and by the force of gravity acting on the particle itself.

In the context of stream hydrology, sediment is inorganic and organic material that is being transported suspended or deposited by streams. Sediment load, which is the quantity of sediment transported by a stream, is a function of stream discharge, soil and land cover features, weather conditions and land use activities among others.

Sediment load constituents being carried by streams and rivers can be either of fine materials, mostly silts and clays, or coarse materials like sand.

3.2 Sources of Sediment

Sediment is a natural product of stream erosion through which load may be increased by human activities. Such enhanced sources of sediment in watershed include unvegetated stream banks and uncovered soil regions, including construction sites, deforested areas, and croplands. It should also be noted that when soils erode, sediment load are washed into streams and rivers. Sediment in waterways is often high in areas where riverbanks are grazed by livestock, farms with steep slopes cleared of trees and areas devoid of riparian vegetation.

Grazing along riverbanks also removes or damages existing vegetation, increases compaction of the soil, and damages the banks of a waterway. With time, such practices may result in instability in the soil structure of the area around the stream making it highly prone to slips and vulnerable to erosion, especially during floods. This activity causes soil compaction and erosion, which may lead to the formation of drainage channels that then transport water and sediment to the nearest stream. Forest increases soil stability because their roots bind the soil together. Thus, when large areas of land are cleared and harvested of trees, the soil becomes vulnerable to erosion as tree roots die and the land is exposed to direct rainfall. Trees increase the soil ability to take up water, and as a result, there is usually a significant increase in the amount of surface water runoff from the surrounding catchments, when trees are removed. Removal of riparian vegetation directly next to a waterway is likely to cause banks to become unstable and prone to slips thereby increasing erosion, especially during floods. Other impacts that can produce sediment include earthwork for roads and landing sites, and hauling logs across bare slopes.

When land is cleared for urban development, earthworks are required to establish roads and building sites. The exposed soils are prone to erosion and can cause large quantities of sediment to be washed into nearby waterways through surface runoff especially after heavy rain. Small streams and rivers may also be completely modified through channelization, construction of revetments (concrete structures), and in stream barriers (for example culverts and dams), and removal of riparian vegetation.

Dam affects the amount of sediment that moves downstream. Sediments are trapped behind a hydro-dam reservoir (hydro-lake) and build up. This reduces the reservoir storage capacity. The rate at which this happens varies greatly among hydro-dams. Dams also reduce the amount of sediment deposition downstream. This increases erosion and scouring and decreases the amount of sediment available to replenish downstream habitats.

In addition, the conversion of wetlands or woodlands to cropland can increase soil erosion and the associated sedimentation in streams, particularly when bare soil is exposed. Wind-blown particles from bare soil also contribute to sedimentation problems. Activities such as dredging and channelisation that increase stream slope and velocity thereby increases the streams erosive capacity and sediment-transport capability. Hence, construction projects within or adjacent to stream can contribute to the sedimentation problems as they dislodge or expose soil and sediment.

3.3 Sediment Transport Process

Sediment is transported based on rate of flow velocity and particle size, volume, density, and shape. For example, high flows velocity increases the lift and drag of particles, while slow flows velocity increases the chances of deposition.

Sediment is most often transported by water (fluvial processes), wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition. Deserts sand dunes and loess are examples of aeolian transport and deposition. Glacial moraine deposits and till are ice transported sediment.

As rivers and streams carry sediment in their flows, the sediment can be at different locations within the flow, depending on the balance between the upwards velocity on the particle (drag and lift forces), and the settling velocity of the particle. These relationships are given in Table 3.0 for Rouse number. Rouse number is a ratio of sediment fall velocity to upwards velocity.

$$\text{Rouse} = \frac{\text{Setting Velocity}}{\text{Upwards velocity from lift and drag}} = \frac{W_s}{KU^*}$$

Where:
Ws is the fall velocity
K is the von Karman constant
U* is the shear velocity

Table: 3.1: **Ratio of Sediment Fall Velocity to Upwards Velocity**

Mode of Transport	**Rouse Number**
Bed load	> 2.5
Suspended load 50% suspended	>1.2, < 2.5
Suspended load 100% suspended	>0.8, < 1.2
Wash load	< 0.8

Source: http://en.wikipedia.org/wiki/sediment, 23/5/11

If the upwards velocity approximately equal to the settling velocity, the entire sediment will be transported downstream as suspended load. If the upwards velocity is much less than the settling velocity but still high enough to transport the sediment to move, it will move along the bed as bed load by rolling, sliding, and saltation (jumping up into the flow, being transported for a short distance then settling again). If the upward velocity is higher than the settling velocity, the sediment will be transported as wash load. As there are generally a range of different particle sizes in flow, it is common for material of different sizes to move through at different locations for a given stream condition.

The overall balance between sediment in transport and sediment being deposited on the bed is given by the Exner equation. This expression states that the rate of increase in bed elevation due to deposition is proportional to the amount of sediment that falls out of the flow. This equation is important in that changes in the flow velocity changes the ability of the flow to carry sediment, and this is reflected in patterns of erosion and deposition observed throughout a stream. It should be noted that deposition could occur due to dam emplacement that causes the river to pool, and deposit its entire load or due to base level rise.

Solid sediment load can be divided into two components on the basis of the mode of sediment transport as suspended and bed load sediment. Each of these is produced by mechanical weathering processes. It is clearly visible and able to settle out of water. Suspended sediment consists of silt-sized and clay-sized particles held in suspension by turbulence in flowing water. Bed load sediment consists of larger particles, which slide, roll, or bounce along the stream bed by the velocity of moving water. Dissolved load consists of inconspicuous material in solution moving downstream, which is produced by chemical weathering processes.

Sediment yield is the total quantity of sediment transported from a watershed (drainage basin) at a given location in a given period of time. Low suspended sediment yields can be attributed to, among other factors, low erosion rate. It should be noted that permeable soils and low topographic relief, do limit the availability of eroded material in a watershed. Conversely, relatively impermeable soils and steep topography can yield high erosion rates and therefore greater sediment yield.

3.4 Sediment Deposition

Deposition begins once the flow velocity falls below the settling velocity of a particle, which for a given particle size is less than that required for entrainment. Settling velocity is closely related to particle size; hence, coarsest fraction in motion is deposited first with progressively finer grains being deposited as the flow velocity reduces. The net effect is a vertical and horizontal (downstream and transverse) gradation of sediment sizes.

The most common depositional feature is the flood plain, formed from a combination of within-channel and overbank deposition, although many sedimentary forms are involved. During lateral channel migration, riverbank erosion is approximately compensated by deposition. With continuing migration, a point-bar is built stream-ward and increases in height through the deposition of sediment carried to the bar surface by inundating flows. The sediment deposited by overbank floodwaters results from material carried in suspension, either as wash load (silts and clays) or the finer fractions of the bed-material load (fine and medium sand). Since the transportation ability of the flow tends to decrease away from the channel margins, both the amount and mean deposited sediment size similarly vary. Also, as the flood recedes and flow velocities over the flood-plain decline, an upward fining of sediment may develop.

Flood plains provide storage space for sediment as it moves through a drainage basin. The flood plain is an integral part of the fluvial system, whose deposits influence channel form through the composition of the channel boundary.

3.5 Impacts of Sediment

One of the principal causes of degraded water quality and aquatic habitat is the depositing of eroded soil sediment in water bodies. Excessive amounts sediment load resulting from natural or human-induced causes can result in the destruction of aquatic habitat and a reduction in the diversity and abundance of aquatic life. Diversity and population size of fish species, mussels, and benthic (bottom-dwelling) macro invertebrates associated with course substrates can be greatly reduced if the substrates are covered with sand and silt. Where sand or silt substrates have historically predominated, however, increased deposition may have little detrimental impact on benthic aquatic life.

Suspended sediment causes the water to be cloudy (turbid). Increased turbidity reduces light transmission (photosynthesis), thereby reducing the growth of algae and aquatic plants since photosynthesis is hampered, and this can adversely affect the entire aquatic ecosystem. Increased turbidity also decreases the water's aesthetic appeal and impairs human access of satisfactory usage. If the river cross-section is sufficiently reduced by sediment build up, sedimentation can increase downstream flooding. In addition, some metal ions, pesticides and nutrients may adhere to sediment particles and be transported downstream.

Increased sediment in surface-water bodies (rivers, lakes, and reservoirs) may have an economic impact on public water systems that use them as a source of drinking water. High turbidity not only is aesthetically displeasing, but also interferes with disinfection of the water prior to it being pumped to customers. Communities whose water-supply source has been more turbid often invest millions of naira to upgrade their treatment faculties in order to remove the increased sediment load.

Excessive erosion can reduce the soil inherent productivity whereas the associated sedimentation can damage young plants and fill drainage ditches, lakes, and streams. Erosive processes can reduce farm income by decreasing crop yields and increasing maintenance costs for drainage systems. Additional erosion damages in both rural and urban areas include reduced ditches, and surface-water supplies.

Erosion is also an issue in areas of modern farming, where the removal of native vegetation for the cultivation and harvesting of a single type of a crop has left the soil unsupported. Many of these regions are near rivers and drainage. Loss of soil due to erosion removes useful farmland, adds to sediment loads and can help transport anthropogenic fertilizers into the river system, which leads to eutrophication, with negative consequences on aquatic lives.

3.6 Sediment Control

Sediment control is a practice or device designed to keep eroded soil on a construction site or other places, so that it does not wash off and cause water pollution to a nearby stream, river, lake, or bay. Sediment controls are usually employed together with erosion controls, which are designed to prevent or minimise erosion and thus reduce the need for sediment controls.

Coordinated efforts by federal and state agricultural programmes can help reduce the amount of soil erosion and sedimentation. Farmers should be encouraged to utilize a variety of conservation practices to reduce erosion and limit sedimentation, such as conservation tillage methods, use of conservation buffers and riparian habitat, and establishment of conservation easements.

Water quality can be protected by controlling and minimising erosion. Federal and state laws should provide some consideration for erosion and sedimentation control along streams and lakes during flood control, drainage, highway, bridge, and other stream-related construction projects. Both the public and private agencies should be engaged in a variety of programmes for erosion control. Such programmes should include research projects, education programmes, technical assistance, regulatory measures, and cost-share financial assistance.

In a nutshell, preventive measures for reducing excessive sediment load in streams should include:

- proper repair and maintenance of drainage ditches and levees.
- minimal disturbance of the stream banks.
- avoidance of structural disturbance of rivers.
- reduction of sediment excesses arising from construction activities.
- application of artificial and natural means for preventing erosion, and
- use of proper land and water management practices on the watershed.

These preventive measures are preferred over remedial measures, which include:

- construction of detention reservoirs, sedimentation ponds, or settling basins.
- development of side-channel flood-retention basin and
- removal of deposited sediment by dredging.

SELF-ASSESSMENT EXERCISE

Examine the relationship between sediment and erosion processes and account for the sources, transport mode, impacts and control measures of sediment.

4.0 CONCLUSION

Discussions in this unit have established the close relationship between erosion and sedimentation processes. Erosion process exacerbates sedimentation problems; therefore, in designing any control measures for sedimentation problems, accounts must be taken of erosion control.

5.0 SUMMARY

In this unit, you have learnt that:

- sediment is naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and by the force of gravity acting on the particle itself
- There are several sources of sediment, which include eroded uncovered soils, construction sites, dredging and channelisation of streams, grazing along riverbanks, and so on
- sediment is transported based on the strength of the flow that carries it and its own size, volume, density and shape. Sediment are most often transported by water, wind and glacier
- some of the major impacts of sediment are pollution – increase in water turbidity, eutrophication, and disruption of aquatic ecosystems
- there are two broad categories of sediment control – preventive and remedial measures. Preventive measures are proactive, while remedial measures are reactionary.

6.0 TUTOR-MARKED ASSIGNMENT

i. Sediment load may be increased by both natural and ____ activities.
ii. Sediment is most often transported by water, wind and ______
iii. Solid sediment load can be divided into two components on the basis of the mode of transportation; they are suspended and _____ sediment.
iv. Which of the following is not a means of sediment transport?
(a) wind (b) ice (c) water (d) none of the above
v. Which of the following activities is most likely to contribute less to sedimentation?
(a) riparian vegetation (b) grazing (c) deforestation (d) dredging
vi. The total quantity of sediment transported from a watershed at a given location in a given period of time is called.
(a) sediment transport (b) sediment load (c) sediment yield (d) sediment deposit

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UNIT 4 DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES

CONTENTS

1.0 INTRODUCTION

One of the most fundamental objects of hydrological studies is to provide adequate water supply for domestic, industrial and agricultural uses. In spite of this however, the problem of inadequate water supply is still prevalent in most parts of the world including Nigeria. The question now is how can we develop and manage water resources to meet our current and future forecasted needs? This question will form the central theme of discussions in this unit.

2.0 OBJECTIVES

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

- define water resources development
- list and discuss the key dimensions in the development and management of water resources.

3.0 MAIN CONTENT

3.1 Defining Water Resources Development

Water resources development is the process by which the world water sources are engineered to deliver adequate quantities of high-quality water to serve the forecasted need of society. Management of water resources for water supply is a complex issue, which becomes more difficult as future water demand increases. This difficulty will be especially apparent in the semiarid and arid parts of the world where water is or soon will be in short supply. Options for minimising potential water supply problems include locating alternative water supplies and managing existing supplies better. These options were also advocated by Miller (1999) who stated that the two general approaches to water resources management are to increase the unstable supply and to decrease unnecessary loss and waste. Most water resource experts believe that any effective plan for water management should combine these approaches.

3.2 Key Dimensions in Water Resources Development and Management

According to Mcdonald and Kay (1988), water management is multidimensional. It embraces planning, design, construction, operation and maintenance. It must be conducted within the constraints of technology, social goals, laws and regulations, political viewpoints, environmental concerns, and economic realities. To be effective, water management must recognise and take advantage of interconnections between surface and groundwater bodies. It must also exploit the potential for coordinated use of existing facilities, acknowledge that water quantity and quality are single issue, devise new ways to operate old systems, blend structural and non-structural approaches, accept that the expansiveness of water resources systems may require regional rather than local solutions to problems. In concept, water management is simple; the trouble is that the boundaries of the physical systems that must be dealt with often differ markedly from the political boundaries that affect how water is used and developed.

According to Wurbs (2003), the development and management of water resources include the following key dimensions.

- Facilities provision
- Demand management
- Desalination
- Water allocation
- Integrated water management

3.2.1 Facilities Provision

Water supply facilities include wells, dams and storage reservoirs, pipelines and pump station, water treatment plants, municipal distribution pipe network, wastewater collection and treatment systems, and irrigation equipment. Dams, reservoirs, and associated structures play a key role in water supply and multipurpose water management. Most of the world’s rivers are characterised by highly variable flows, with seasonal fluctuations aggravated by severe droughts and extreme floods. Reservoir storage is therefore necessary to regulate stream flow fluctuations and develop reliable water supplies (Wurbs, 2003). Also, highlighting the role of dams in water resources management as stated by Miller (1996) stated that rainwater and water from melting snow that would otherwise be lost can be captured and stored in large reservoirs behind dams built across rivers. He further noted that damming increases the annual supply by collecting fresh surface water during wet periods and storing it for use during dry periods.

3.2.2 Demand Management

Hydrologic, environmental and economic conditions have led to heightened constraints on developing additional water supplies. Consequently, demand management in the form of reducing waste and increasing efficiency of use has become a major focus in the development of water resources in some parts of the world.

Water demand management strategy is concerned with the prevention of water wastages in any form – domestic, industry or agriculture. Water wastages through undetected pipeline leaks in aging water-distribution systems, agricultural losses through seepage and evaporation, and other forms of looses are therefore involved in the strategy.

3.2.3 Desalination

Removing dissolved salts from ocean water or brackish (slightly salty) groundwater is an appealing way to increase freshwater supplies because of the huge volume of, seawater adjacent to coastal cities. Until recently, the high salt content of the oceans, inland seas, and certain segment of rivers and groundwater has severely restricted our ability to use their waters. Now, however, desalination technology is well established and readily available.

The primary limiting factor of desalination is its cost relative to the water-supply options. However, due to over drafting of the groundwater system, large wetlands area extent are being permanently damaged with lakes drying up, and domestic wells for hundreds of families being lost. This type of scenario will lead to increased usage of improved efficient desalination technology, with the challenge for future research and development being to continue to minimise cost without compromising the effectiveness and efficiency of the technology.

3.2.4 Water Allocation

Water rights systems and interstate and international agreements allocating water resources are becoming increasingly important. Around the world, 261 river basins are shared by two or more countries, often leading to disputes and conflicts related to water supply. As a result, methods of cooperation and conflict mitigation need to be brought into play. Example of such cooperation is the Niger River Basin Development Authority.

3.2.5 Integrated Water Management

Water resources are tapped by multiple users for a variety of purpose. Effective water management therefore requires a systems approach, with comprehensive integration of a number of factors with particular, attention being given to both water quality and quantity. Conjunctive management of groundwater and surface water resources is also required and the water needs to be appropriately allocated to the various users. In addition, human needs must be balanced with ecosystem needs, economic development with environmental protection. It should be noted that efforts have to be made toward optimising the mix of demand management programmes, new facilities construction, and improved operations and maintenance of existing facilities. Water-management approaches also need to incorporate ongoing advances in water supply technologies such as desalination processes and efficient irrigation techniques – and the technology chosen have to be appropriate for the particular country, region, and local culture. In addition, computer technology can be used adequately in the area of data collection, analysis, systems modeling and management.

SELF-ASSESSMENT EXERCISE

As a newly appointed minister of water resources, what are the measures you will put in place to ensure effective and efficient development and management of water resources in Nigeria?

4.0 CONCLUSION

As we look to the future, we can expect that the planning and management of water resources will move toward a holistic systems approach, which will coordinate and integrate various aspects, including water supply (for domestic, industrial, and agricultural needs), hydroelectric power, flood control, and ecosystem conservation. The reduction of waste and enhancement of efficiency should be increasingly stressed. And the decision making process will have to consider the views of various stakeholders such as scientists, engineers, political officials, interest groups, users and the public at large. The success of this approach will depend on how well the diverse factors are integrated to make up the larger picture of water resources development and management framework.

5.0 SUMMARY

In this unit, you have learnt that:

- water resource development is the process by which the world's water sources are engineered to deliver adequate quantities of high-quality water to serve the forecasted need of society

- the key dimensions in water resources development and management include facilities provision, demand management, water allocation, desalination and integrated water management.

6.0 TUTOR-MARKED ASSIGNMENT

i. The process of removing dissolved salts from ocean water or brackish groundwater is called ____________

ii. Which of the following options is not a key dimension in water resources development?
(a) Desalination (b) facilities provision (c) demand management
(d) none of the above

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UNIT 5 PROBLEMS OF WATER RESOURCES DEVELOPMENT

CONTENTS

1.0 INTRODUCTION

Several problems militating against water resources development have been identified in literature. Some of the identified problems include precipitation pattern, population growth, pollution, increase affluence, economic growth and development, corruption in the water sector, energy, finance, technology, political will and management. These problems are not limited to certain regions but extend throughout the world.

2.0 OBJECTIVES

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

- list the major problems of water resources development
- discuss how these problems militate against water resources development.

3.0 MAIN CONTENT

3.1 Precipitation Patterns

Precipitation patterns have been identified as one of the primary problems militating against water resources development, since precipitation is the primary source of replenishment of both surface and groundwater sources. In areas where there is lower than normal precipitation, there is usually water stress, which may result to a drought situation. It should be noted that reduced average annual precipitation, higher than normal temperatures, or both, usually trigger drought situation. Such situations do not favour adequate water resources development.

3.2 Population Growth

Population growth has been identified as a major factor in water resources development. At the most fundamental level, water is needed to supply people's basic domestic needs, in quantities directly proportional to the number of people. For instance, the National Research Council (1999) stated that with population growth; demand for the world's finite fresh water supply is rising, putting strains even on the industrialized countries. Global population projections suggest that the world population of over 6 billion people in 2000 will increase by 20 per cent to over 7 billion by 2015, and to 7.8 billion by 2025, a 30 per cent rise. Thus, enormous strains will be put on existing services, since substantial increases in the provision of water and sanitation will be needed to meet the needs of the ever-growing population. As populations grow and demands for water and other services expand, pollution levels will be at increase thereby reducing water resources accessibility, which will then reduce the availability of water available for human consumption.

3.3 Pollution

Pollution is another major problem in the development of water resources. Water pollution according to Botkin and Keller (1998) refers to degradation of water quality. In defining pollution, the intended use of the water, needs to be considered in its disparity from the norm, its effects on public health, or its ecological impacts. From a public health or ecological view, a pollutant is any biological, physical or chemical substance that in identifiable excess is known to be harmful to other desirable living organisms. Water pollutants include excessive amounts of heavy metals, certain radioactive isotopes, *faecal coliform* bacteria, phosphorus, nitrogen, sodium, and other useful (even necessary) elements, as well as certain pathogenic bacteria and viruses.

The primary causes of deterioration of surface water quality are municipal and domestic wastewater, industrial and agricultural wastes (organic, inorganic, heat) and solid and semi-solid refuse. Groundwater quality is influenced by the quality of its source. Changes in source water or degraded quality of source supplies may seriously impair the quality of the groundwater supply. Municipal and industrial wastes entering an aquifer are major sources of organic and inorganic pollution. A municipal obtaining its water supply from a surface body may find its source so fouled by wastes and toxic chemicals that it becomes unsuitable or too costly to treat for use as a water supply.

Another form of pollution that has impacted negatively on water resources development, especially in the coastal regions of the world is salt-water intrusion. According to Oteri and Atolagbe (2003), potable water supply to inhabitants in some of the communities in the coastal belt of Nigeria has been a major problem due to salt-water intrusion. For instance, communities such as Burutu in Delta State and Aiyetoro in Ondo State have no potable water source; their surface water is salty, thus all the boreholes drilled so far have yield saline water. The inhabitants therefore depend on rainwater harvesting (in the midst of numerous gas flares from oil production platforms) and water vendors from the hinterland in boats. They noted that the high degree of restiveness and agitations against oil companies and installations in their areas is partly due to the lack of basic infrastructure especially potable water.

3.4 Corruption

Corruption has also been identified as a major problem of water resources development worldwide. For instance, Stalgen (2007) in his analysis of corruption in the water sector observed that the main reason for the inadequate water supply is not the lack of a natural supply of water nor is it primarily an engineering problem, that is, stemming from the lack of technical solutions. Instead, the global water crisis is primarily problem of governance. As a group of experts working under the UN Millennium Project puts it, the problem is "the lack of appropriate institutions at all levels and the chronic dysfunction of existing institutional arrangements." Stalgren affirms that corruption is at the core of the governance crisis in the water sector. Whereas the scope of corruption varies substantially across the sector and between different countries and governance systems, estimates by the World Bank suggest that 20 per cent to 40 per cent of water sector finances are being lost to dishonest and corrupt practices. The magnitude of this figure is distressing, especially, if one considers current efforts to aggregate the $6.7 billion needed annually to meet the Millennium Development Goals (MDGs) for water and sanitation in sub-Saharan Africa. An average level of corruption of 30 per cent represents a leakage of $20 billion over the next decade. This situation is not healthy for water resources development.

3.5 Energy

Inadequate energy supply has also been identified as a factor in water resources development, most especially in developing economies. Onyekakeyah (2007) in his analysis of national power blackout and water supply, noted that Nigerians lives in cities without water, and that the absence of power to pump water further compounds the problem. He stated that water supply is directly tied to regular supply of electricity. Without electricity, there can be no potable water supply. Pipe water flows when power is energized. But in a situation where the entire nation is in blackout, water supply is drastically reduced and becomes critical.

3.6 Other Factors

Apart from the problems discussed above, other factors that affect the development of water resources include poor maintenance culture (evidence abounds of pipe leakages, rusted pipes, unlocked taps, broken valve etc); high cost of facilities, economic growth and development (putting pressure on existing water infrastructure) and increasing affluence (increase in demand for water, through the use of washing machines, dishes, and the watering of lawns). All these factors act in one way or the other to militate against water resources development.

SELF-ASSESSMENT EXERCISE

What are the factors you can identify as militating agent water resources development in your locality?

4.0 CONCLUSION

The discussions above have made it very clear that there are several problems militating against adequate water resources development worldwide. Apart from precipitation pattern, which is an obvious natural factor, the others are human factors that can be surmounted. With adequate planning and management, change of negative habits (pollution, corruption, poor maintenance and wastages) the task of water resources development, can be made easier, more effective and efficient.

5.0 SUMMARY

In this unit, you have learnt that:

- problems militating against water resources development over the world are similar; though vary in severity from one region or country to another
- the problems can be classified into human and natural. Precipitation seems to be the only major natural factor
- the human factors include pollution, energy, corruption, population growth and so on
- with adequate planning and management, and change of negative habits, the task of water resources development could be simplified.

6.0 TUTOR-MARKED ASSIGNMENT

(1) The problems of water resources development can be classified into human and ______________
(2) The act of degradation of water resources is called __________
(3) Which of the following is a problem affecting water resources development?
(a) population growth (b) high precipitation (c) adequate power supply
(d) none of the above

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