

COURSE GUIDE

SLM 314 COMPUTER-BASED TERRAIN ANALYSIS

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INTRODUCTION

Computer-Based Terrain Analysis is a 2 unit-course. Each unit has specific objectives which are included at the beginning of the unit. As a way of background information about the course, the terrain is a reflection of the topography of an area. Topography, on its part, is the study of the forms, features and configuration of land surfaces. The elevation, slope, aspect and landforms, are all features of the topography of an area.

The topography of an area plays a crucial role in determining the use to which we put the land. For instance, we grow swamp rice in valleys or lowland swamps. Maize, which does not survive in swampy soils cannot be grown in these areas; if it must be grown there, we plant on very large mounds or ridges to ensure that the plant roots are not submerged by water. On the other hand, swamp rice cannot be grown on the top of a mountain or plateau, but maize can be grown there. This relevance is not limited to agriculture as you cannot build your house in swampy lowlands, unless the area is first drained of its excess moisture. It is also worthy of note that after heavy rains, the speed and amount of runoff water flowing down a steep slope is very high, compared to the section of the landscape with gentle-sloping or level lands. As such, more erosion is expected on steeply sloping land if the land is cleared of its natural vegetative cover.

Given the foregoing, before the implementation of any project, there is the need to assess the nature of the terrain and its potential impacts on a land use of interest. On a local setting, or within a small piece of land, this is relatively easy to assess. For a very large area that cannot be viewed at a glance, this becomes a very difficult task. Luckily, with recent developments in remote sensing and computer technologies, this task has been simplified considerably, irrespective of the size of the land. This is essentially where computer-based terrain analysis becomes relevant.

Prerequisites

The background knowledge from soil science, geology, remote sensing, (land) surveying and statistics is required.

WHAT YOU WILL LEARN IN THIS COURSE

The Course consists of Modules (made up of units) and a course guide. This course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully. It gives you guidance in respect of your Tutor-Marked Assignment in the assignment file. There will be regular online

facilitation classes of the course. It is advisable for you to attend these facilitation sessions. The course will prepare you for the challenges you will meet in the field of terrain analysis, soil studies and land use planning.

COURSE AIMS

The aim of the course is not complex. The course aims to provide you with an understanding of computer-based terrain analysis; it also aims to provide you with solutions to problems with terrain analysis for land use planning.

COURSE OBJECTIVES

To achieve the aims set out, the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after completion of each unit. By doing so, you would have followed the instructions in the unit. Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. Thus, after going through the course, you should be able to:

- Define the ecosystem
- Describe the nature and structure of an ecosystem
- Enumerate and describe the types of the ecosystem
- Describe the functions of an ecosystem
- Describe ecosystem services
- Understand the implications and value of ecosystem (services)
- Understand the concept of the soil-landscape
- Describe the soil catena
- Describe the toposequence and how it is related to the soil catena
- Enumerate and describe the factors of soil formation
- Describe how the soil-landscape is related to the factors of soil formation
- Explain the effect of topography on ecosystem variability
- Explain the effect of the topography on the soil variability
- Understand how terrain analysis is related to soil mapping
- Explain the concept of remote sensing
- Outline the agricultural and allied applications of remote sensing
- Outline the elements of remote sensing
- Outline the advantages of remote sensing
- Outline the limitations of remote sensing
- Describe the electromagnetic spectrum
- Outline the parts of the electromagnetic spectrum used in remote sensing

- Discuss the interaction between electromagnetic radiation and the atmosphere
- Discuss the interaction between electromagnetic radiation and the earth surface
- Describe the types of remote sensing
- Enumerate and describe the types of remote sensors
- Enumerate and describe the types of remote sensing platforms
- Discuss the elements of image interpretation
- Outline the principle of image classification
- Describe the process of digital image classification
- Define geographic information system (GIS)
- Discuss the essence of the cartographic data models
- List open-source and commercial GIS software applications
- Describe the geographic coordinate systems
- Describe the projected coordinate systems
- Be able to download QGIS software
- Be able to download GRASS GIS software
- Be able to install both GIS software
- Discuss satellite navigation
- Explain the meaning of geographical positioning system
- List and briefly discuss other global navigation satellite systems (GNSS)
- Explain the importance of the GNSS
- Download and install of GNSS applications
- Collect geographic coordinates using GNSS applications
- Be able to download administrative maps of an area of interest
- Be able to display vector maps in GIS application
- Download remote-sensed data
- Be able to display vector data in a GIS application
- Be able to analyze vector data in a GIS application
- Be able to manipulation of raster data (DEMs) in a GIS application
- Be able to map the slope of an area using the digital elevation model (DEM)
- Be able to map the landform of an area
- Be able to map the drainage lines (rivers, streams, runoff flow channels) of an area
- Outline the principal components of a map layout
- Generate a printable map
- Understand the difference between population and sample statistics
- Discuss descriptive and inferential statistics, with examples
- Perform some basic statistical analysis with Microsoft Excel
- Understand the concept of geostatistics
- Outline main tenets of geostatistics
- Describe some underlying concepts of geostatistics
- Describe kriging and outline pre-kriging operations

- Outline the types of kriging
- Outline the statistical modeling methods
- Describe the types of statistical models
- Discuss the regression model
- Make predictions using basic linear regression models
- Understand the difference between spatial and non-spatial models
- Describe SoilGids250m as the product of a spatial modeling operation

WORKING THROUGH THE COURSE

To complete this course, you are required to read each study unit, read the textbook and other materials which may be provided by the National Open University of Nigeria. Each unit contains self-assessment exercises and at certain points in the course you would be required to submit assignment for assessment purpose. At the end of the course there is a final examination. The course should take you a total of 17 weeks to complete. Below you will find listed all the components of the course, what you have to do and how you should allocate your time to each unit in order to complete the course on time and successfully. I will advise that you avail yourself the opportunity of attending the tutorial sessions where you have the opportunity of comparing your knowledge with that of other people.

COURSE MATERIAL

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Reading/Web Resources
4. Assignments
5. Presentation Schedule

STUDY UNITS

The study units in this course are as follows:

Module 1 The Ecosystem

- Unit 1 Structure of the Ecosystem
- Unit 2 Types of Ecosystems
- Unit 3 Ecosystem Services

Module 2 Soil-Landscape Model

- Unit 1 Concept of Soil-Landscape
- Unit 2 Factors of Soil Formation
- Unit 3 The Soil-Landscape and the Factors of Soil Formation
- Unit 4 Effects of the Topography on Soil-Landscape and Ecosystem Variability

Module 3 Digital Remote Sensing

- Unit 1 Remote Sensing Concept
- Unit 2 The Electromagnetic Spectrum
- Unit 3 Interaction of Electromagnetic Radiation with the Atmosphere and the Earth Surface
- Unit 4 Types of Remote Sensing
- Unit 5 Elements of Image Interpretation
- Unit 6 Digital Image Classification

Module 4 Geographic Information System (Gis)

- Unit 1 Data Models
- Unit 2 Coordinate Systems
- Unit 3 Download and Installation of Open-Source GIS Software

Module 5 Global Navigation Satellite Systems (GNSS)

- Unit 1 Satellite Navigation
- Unit 2 Importance of the GNSS
- Unit 3 Download and Installation of GNSS Applications

Module 6 Computer Cartography

- Unit 1 Administrative Maps
- Unit 2 Satellite and Elevation (DEM) Data
- Unit 3 Manipulation of Vector Data
- Unit 4 Manipulation of Raster Data (DEMs)
- Unit 5 Generation of Slope Map
- Unit 6 Generation of Landform Maps Reflecting the Soil-Landscape
- Unit 7 Generation of Maps of the Rivers and Streams of an Area
- Unit 8 Map Layout

Module 7 Introductory Geostatistics

- Unit 1 Descriptive and Inferential Statistics
- Unit 2 Geostatistics Concepts

Unit 3	Estimation Methods
Unit 4	Modeling
Unit 5	Spatial Modeling

**MAIN
COURSE**

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MODULE 1 THE ECOSYSTEM

- Unit 1 Structure of The Ecosystem
- Unit 2 Types of Ecosystems
- Unit 3 Ecosystem Services

UNIT 1 STRUCTURE OF THE ECOSYSTEM

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 The Ecosystem
 - 1.3.2 Structure of the Ecosystem
 - 1.3.2.1 Biotic Components
 - 1.3.2.2 Abiotic Components
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

An ecosystem is simply an ecological system. Ecology, on its part, is the scientific study of the interactions that determine the distribution and abundance of organisms. Typically, ecology deals with three levels of organization, namely, the individual organism, the population and the community. Ecosystems are often connected to form a larger biome. Examples of biomes include forests, ponds, reefs, and tundra. An ecosystem has a biotic and abiotic component. The biotic component is made up of producers, consumers and decomposers. It is noteworthy that when a unit of one component changes, it affects the entire ecosystem either directly or indirectly. For instance, when an ecosystem has high rainfall, you will have more luxuriant vegetation, which might on the long run support forests. The forests, in turns, supports specific species of animals. For instance, monkeys cannot survive in grasslands; they require a forest environment, which is a function of vegetation affected by the intense rainfall. As such, a good understanding of ecosystem dynamics is very important.

1.2 Learning Outcomes

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

- define the ecosystem
- describe the nature and structure of an ecosystem

1.3 Main Content

1.3.1 The Ecosystem

Ecology can be defined as the scientific study of the interactions that determine the distribution and abundance of organisms. The environment of an organism consists of all those factors and phenomena outside the organism that influence it, whether these are physical and chemical (abiotic) or other organisms (biotic).

The living world can be viewed as a biological hierarchy that starts with subcellular particles, and continues up through cells, tissues and organs. Ecology deals with the next three levels: the individual organism, the population (consisting of individuals of the same species) and the community (consisting of a greater or lesser number of species populations).

At the level of the organism, ecology deals with how individuals are affected by (and how they affect) their environment. At the level of the population, ecology is concerned with the presence or absence of particular species, their abundance or rarity, and with the trends and fluctuations in their numbers. Community ecology then deals with the composition and organization of ecological communities. Ecologists also focus on the pathways followed by energy and matter as these moves among living and non-living elements of a further category of organization.

An **ecosystem** is simply an ecological system. It can be defined as a system that includes all living organisms (biotic factors) and the physical environment (abiotic factors) functioning together as a unit within a geographic area. Ecosystems contain biotic or living, parts, as well as abiotic factors, or nonliving parts. Biotic factors include plants, animals, and other organisms. Abiotic factors include rocks, temperature, water, humidity, etc. Every factor in an ecosystem depends on every other factor, either directly or indirectly. A change in the temperature of an ecosystem will often affect what plants will grow there, for instance. Animals that depend on plants for food and shelter will have to adapt to the changes, or move to another ecosystem, or perish.

Ecosystems can be very large or very small. The whole surface of Earth is a series of connected ecosystems. Ecosystems are often connected in a larger biome. **Biomes** are large sections of land, sea, or atmosphere. Forests, ponds, reefs, and tundra are different types of biomes. They are organized very generally, based on the types of plants and animals that live in them. Within each forest, each pond, each reef, or each section of tundra, you'll find many different ecosystems.

Self-Assessment Exercise

Mention one abiotic component of an ecosystem.
Briefly outline how changes in the abiotic component would affect other parts of the ecosystem.

1.3.2 Structure of the Ecosystem

The structure of an ecosystem is characterized by the organization of both biotic and abiotic components. The structure of an ecosystem can be split into two main components, namely:

- Biotic Components
- Abiotic Components

The biotic and abiotic components are interrelated in an ecosystem. It is an open system where the energy and components can flow throughout the boundaries.

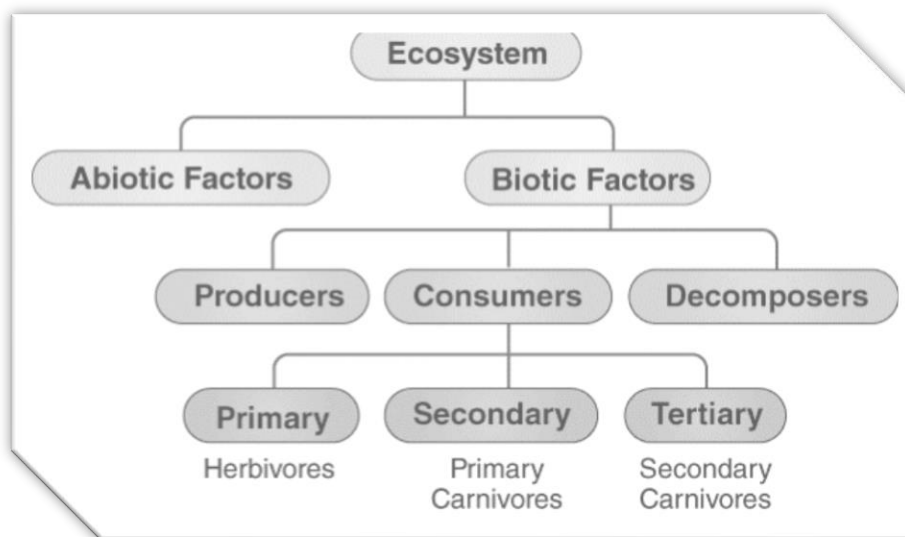


Figure 1: Structure of the Ecosystem

Self-Assessment Exercise

Draw a flowchart, depicting the structure of the ecosystem.

1.3.2.1 Biotic Components

Biotic components refer to all living components in an ecosystem. Based on nutrition, biotic components can be categorized into autotrophs, heterotrophs and saprotrophs (or decomposers).

- **Producers** include all autotrophs such as plants. They are called autotrophs as they can produce food through the process of photosynthesis. Consequently, all other organisms higher up on the food chain rely on producers for food.
- **Consumers** or heterotrophs are organisms that depend on other organisms for food. Consumers are further classified into primary consumers, secondary consumers and tertiary consumers.
- **Primary consumers** are always herbivores as they rely on producers for food.
- **Secondary consumers** depend on primary consumers for energy. They can either be carnivores or omnivores.
- **Tertiary consumers** are organisms that depend on secondary consumers for food. Tertiary consumers can also be carnivores or omnivores.
- **Quaternary consumers** are present in some food chains. These organisms prey on tertiary consumers for energy. Furthermore, they are usually at the top of a food chain as they have no natural predators.
- **Decomposers** include saprophytes such as fungi and bacteria. They directly thrive on dead and decaying organic matter. Decomposers are essential for the ecosystem as they help in recycling nutrients to be reused by plants.

1.3.2.2 Abiotic Components

Abiotic components are the non-living component of an ecosystem. It includes air, water, soil, minerals, sunlight, temperature, nutrients, wind, altitude, turbidity, etc.

Self-Assessment Exercise

List the biotic components of the ecosystem and give two examples of each.

1.4 Conclusion

The ecosystem is diverse, both in nature and size. It may range from a small pool of water to a large forest. Naturally irrespective of the size and nature of the ecosystem, it must have biotic and abiotic components; and the biotic components would include producers, diverse consumers and

decomposers. For humans to effectively and sustainably exploit these ecosystems, a good understanding of the inherent dynamics is essential. Let us say for instance, there was an oil spill, to effectively counter its impact and ensure rapid reclamation, a good understanding of the prevalent ecosystem dynamics is fundamental.

1.5 Summary

From this unit, you have learnt about the ecosystem. Some of the key things learnt include the following;

- Definition of ecosystem
- Structure of the ecosystem
- Biotic components
- Abiotic components

1.6 Tutor-Marked Assignment

1. Define ecosystem.
2. Describe the structure of the ecosystem.
3. What is the difference between biotic and abiotic components of the ecosystem

1.7 References/Further Reading/Web Resources

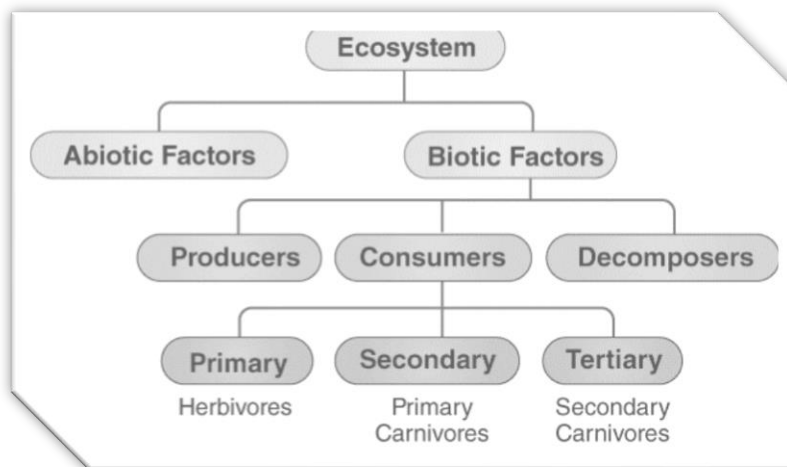
Begon, M., Townsend, C.R., HARPER, J.L. (2006) Ecology: From Individuals to Ecosystems. Malden, USA: Blackwell Publishing Ltd.

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

- 1a. List four abiotic component of an ecosystem.
i) Water ii) Temperature iii) Light iv) Air (Oxygen)
- b. Briefly outline how changes in one component would affect other parts of the ecosystem.

With regards to water, for instance, if an ecosystem is located in a region with high rainfall amount and intensity, its vegetation would be luxuriant, supporting forest growth. The forests, in turns, supports specific species of animals like tree squirrels and monkeys. Also, the dense canopy cover of the trees would cover the soil, protecting it from direct solar radiation, consequently reducing temperature, thereby, changing the microclimate. This would result in greater soil moisture due to reduced evaporation. This may increase the population of earthworms, crabs etc. The leaf falls from the trees would also increase the organic matter content of the soil, thereby, supporting increased soil microbial activities. And the complex interactions continue.

2. Draw a flowchart, depicting the structure of the ecosystem.



3. List the biotic components of the ecosystem and give two examples of each.
 - i. Producers or autotrophs. E.g., Rice plant, Mango tree, etc.
 - ii. Consumers or heterotrophs. E.g., Humans, Lions, etc.
 - iii. Decomposers or saprophytes. E.g., bacteria, fungi, etc.

UNIT 2 TYPES OF ECOSYSTEMS

Unit Structure

- 2.1 Introduction
- 2.2 Learning Outcomes
- 2.3 Main Content
 - 2.3.1 Types of Ecosystems
 - 2.3.1.1 Terrestrial Ecosystem
 - 2.3.1.2 Aquatic Ecosystem
 - 2.3.1.3 Wetland Ecosystem
 - 2.3.2 Significance of Ecosystem Diversity
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

Irrespective of the size and/or spatial extent of the ecosystem, they can be classified into three different types, namely, terrestrial, wetland and aquatic ecosystem. Terrestrial are land-based ecosystems; aquatic are water-based ecosystems; while wetland ecosystems are the transition zones between land and aquatic ecosystems. The biotic and abiotic components of these ecosystems are very distinct from each other. However, within the wetland ecosystems, you can find terrestrial and aquatic components. For instance, given the submergence of the land with water, fishes and other aquatic organisms thrive in wetlands, trees, which are usually land-based, also thrive here. Changing the nature of the wetland, can however, make the wetland more aquatic or more terrestrial. For instance, artificial drainage will automatically convert a wetland into a terrestrial ecosystem. On the other hand, flooding and coastal or river bank erosion can result in the conversion of a wetland into an aquatic ecosystem. The ecosystem is diverse in nature and is very valuable to the sustenance and survival of human societies. It has economic, ecological, recreation, cultural and scientific significance. It must consequently be protected and used sustainably.

2.2 Learning Outcomes

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

- Enumerate and describe the types of the ecosystem
- Describe the functions of an ecosystem

2.3 Main Content

2.3.1 Types of Ecosystems

An ecosystem can be as small as an oasis in a desert, or as big as an ocean, spanning thousands of miles. There are three types of ecosystems:

- Terrestrial Ecosystem
- Aquatic Ecosystem
- Wetland Ecosystem

2.3.1.1 Terrestrial Ecosystem

Terrestrial ecosystems are land-based ecosystems that depend largely on the climate and soil. Higher plants and animals have evolved on land. The dominant species on the terrestrial ecosystem include seed plants, insects, warm-blooded vertebrates and micro-organisms. The major terrestrial communities consist of herbaceous plants, shrubs, grass and also woody trees besides numerous insects, arthropods, birds, etc. There are different types of terrestrial ecosystems. They include forest, grassland, tundra and desert ecosystem.

1. **Forest Ecosystem:** A forest ecosystem consists of several plants, particularly trees, animals and microorganisms that live in coordination with the abiotic factors of the environment. Forests help in maintaining the temperature of the earth and are the major carbon sink.
2. **Grassland Ecosystem:** In a grassland ecosystem, the vegetation is dominated by grasses and herbs. Temperate grasslands and tropical or savanna grasslands are examples of grassland ecosystems.
3. **Tundra Ecosystem:** Tundra ecosystems are devoid of trees and are found in cold climates or where rainfall is scarce. These are covered with snow for most of the year. Tundra type of ecosystem is found in the Arctic or mountain tops.
4. **Desert Ecosystem:** Deserts are found throughout the world. These are regions with little rainfall and scarce vegetation. The days are hot, and the nights are cold.

Self-Assessment Exercise

1. List the different types of terrestrial ecosystems
Which of these ecosystems can be found in Nigeria, and in which regions of Nigeria?

2.3.1.2 Aquatic Ecosystem

Aquatic ecosystems are ecosystems present in a body of water. These can be grouped into freshwater and marine ecosystems.

1. **Marine Ecosystem:** The marine ecosystem includes seas and oceans. Oceans occupy 70 per cent of earth's surface, offering habitat to numerous plants (mainly algae), animals like zoo plankton, shrimps, oysters, fishes, reptiles, birds and mammals (whales, dolphins, seals, etc.). They serve as the sink of a large quantity of runoff and wastes from land. Marine water has a high salt content and poor fertility due to lack of nitrates and phosphates as compared to freshwater. Marine life is abundant near the shore and in the continental shelf. In comparison, they have greater biodiversity than freshwater ecosystem.
2. **Freshwater Ecosystem:** The freshwater ecosystem is an aquatic ecosystem that includes lakes, ponds, rivers and streams. These have little to no salt content in contrast with the marine ecosystem. They are rich in nutrients (nitrates, phosphates, etc.) and provide good habitat for phytoplankton, zooplankton, aquatic plants and fishes.

2.3.1.3 Wetland Ecosystem

Wetlands are transitional zones between terrestrial and aquatic ecosystems where water stands at 2.5 to 300 cm during most of the year. They include valuable natural ecosystem harboring a wide variety of plants, animals, fishes and microorganisms. They are at present in danger due to increasing urbanization and drainage. Mangrove swamp forests are important wetlands bordering the oceans/seas and terrestrial ecosystems. Mangroves are important forest communities in tidal zones or equatorial/tropical coasts. Examples are the saltwater and freshwater (mangrove) swamps of the Niger Delta.

Self-Assessment Exercise

Which types of aquatic and wetland ecosystems can you find in Nigeria and where are they usually located?

2.3.2 Significance of Ecosystems Diversity

Ecosystem diversity is defined as a form of variability between ecological systems within a geographical location. An ecosystem is, in turn, defined as a system that includes all living organisms (biotic factors) and the physical environment (abiotic factors) functioning together as a unit.

The diversity of the ecosystems in a particular geographical location may be identified and studied so as to understand their overall impact on human existence and the environment. It can be dealt with at a micro-level (small scale) or at a macro-level (large scale). Macro-scale ecosystem diversity would therefore be concerned with the variations in the ecosystems at a large scope, such as oceans, forests, and wetlands. Conversely, small-scale ecosystem diversity would be interested in the variations in the ecosystems over a relatively small geographical space or area. Ecosystem diversity plays a crucial role in human societies. Some of these roles are:

- **Economic:** ecosystem diversity, including biodiversity, provides humans with raw materials for consumption and production. Many livelihoods, such as those of farmers, fishermen and timber workers, are dependent on biodiversity.
- **Ecological Life Support:** ecosystem diversity provides functioning environment that supply oxygen, clean air and water, pollination of plants, pest control, wastewater treatment and many ecosystem services.
- **Recreation:** many recreational pursuits rely on our ecosystem diversity, such as birdwatching, hiking, camping and fishing. Our tourism industry also depends on ecosystem diversity.
- **Cultural:** the culture and tradition of a people is closely tied to ecosystem diversity. Places without access to rivers or lakes will probably not pay homage to river gods or goddesses due to the absence of an adequate aquatic ecosystem to support such belief systems. For the forest dwellers of southeastern Nigeria, for instance, the Iroko tree has special cultural value, a situation that will not arise if the same people live in the savanna region of northern Nigeria.
- **Scientific:** ecosystem diversity represents a wealth of systematic ecological data that help us to understand the natural world and its origins. Ecosystem diversity is defined by, to a large extent, climate and landscape dynamics. As such, the nature of the ecosystem provides scientists and even local people with insight into the climate and landscape dynamics of an area. For instance, the existence forests in an area may be indicative of high rainfall, whereas, areas that are predominantly grasslands whose greenness varies from season to season, would be diagnosed as low rainfall regions. Similarly, the plants that grow on lowland marshes would be drastically different from those that grow on adjacent upland areas, providing insight into the nature of the landscape.

Self-Assessment Exercise

List the roles that ecosystems play in human societies.

2.4 Conclusion

Understanding the types and diversity of ecosystems within an area is a necessary prerequisite to sustainable land use planning and land allocation. Ecosystem evaluation is consequently a necessary prerequisite to sustainable human development and survival.

2.5 Summary

From this unit, you have learnt about types of ecosystems. Some of the key things learnt include the following;

- Types of ecosystems
- Significance of ecosystems diversity

2.6 Tutor-Marked Assignment

1. Describe the major types of ecosystems.

2.7 References/Further Reading/Web Resources

Begon, M., Townsend, C.R., HARPER, J.L. (2006) Ecology: From Individuals to Ecosystems. Malden, USA: Blackwell Publishing Ltd.

2.8 Possible Answers to Self-Assessment Exercise(S) Within The Content

- 1a. List the different types of terrestrial ecosystems
i) Forest ii) Grasslands iii) Desert iv) Tundra
- b. Which of these ecosystems can be found in Nigeria, and in which regions of Nigeria?
*i) Forest Ecosystem – Rainforests of Southern Nigeria
 ii) Grasslands – Savannas (Guinea, Sudan and Sahel) of Northern Nigeria
 iii) Desert – Sahara Desert on the northern fringes of Nigeria
 iv) Tundra – No part of Nigeria has such conditions. The montane regions of Jos and Adamawa may have a cold climate somewhat similar to the Tundra, but still not snow or ice covered.*
2. Which types of aquatic and wetland ecosystems can you find in Nigeria and where are they usually located?
 - i) Freshwater Ecosystem – These are rivers, lakes and streams. They are found in every region of Nigeria. E.g., River Niger, River Benue, Lake Chad, Agulu Lake, Anambra River, etc.*
 - ii) Saltwater Ecosystem – These are primarily found in the Atlantic Ocean, off the coast of Nigeria*
 - iii) Freshwater Wetlands – These are found along river banks and lake shores all over Nigeria. The most prominent of them all is the Freshwater Swamp Forest of the Niger Delta.*
 - iv) Saltwater Wetlands – These are usually found on the southern coastlines of Nigeria, particularly the Mangrove Swamp Forests of the Niger Delta.*
3. List the roles that ecosystems play in human societies.
 - i) Economic value ii) Ecological Life Support iii) Recreational value*
 - iv) Cultural value v) Scientific value*

UNIT 3 ECOSYSTEM SERVICES

Unit Structure

- 3.1 Introduction
- 3.2 Learning Outcomes
- 3.3 Main Content
 - 3.3.1 Functions of Ecosystems
 - 3.3.2 Ecosystem Services
 - 3.3.3 The Soil and the Ecosystem
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

The ecosystem has many functions, but ecosystem services can be classified into provisioning, regulating, cultural and supporting services. The functional components can however be viewed in terms of productivity, energy flow, decomposition and nutrient cycling. Similarly soil as a part of the ecosystem supports such ecosystems services as nutrient cycling, moderation/maintenance of water relations, provision of biodiversity and habitat, filtering and buffering the ecosystem components and provision of physical stability and support for the habitat. In other words, life on earth as we know it, cannot survive, if we destroy the soil. The extensive gully erosion in southeastern Nigeria is a case in point. As soon as the gullies commence, the forest, farms, houses, etc., that used to exist in that region of the landscape cease to exist, and returning the land back to its original state may be impossible. Soil conservation to sustain the ecosystem services of the soil is thus, of vital importance.

3.2 Learning Outcomes

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

- Describe ecosystem services
- Understand the implications and value of ecosystem (services)

3.3 Main Content

3.3.1 Functions of Ecosystem

The functions of the ecosystem include:

1. It regulates the essential ecological processes, supports life systems and renders stability.
2. It is responsible for the cycling of nutrients between biotic and abiotic components.
3. It maintains a balance among the various trophic levels in the ecosystem.
4. It cycles the minerals through the biosphere.
5. The abiotic components help in the synthesis of organic components that involve the exchange of energy.

So, the functional units of an ecosystem or functional components that work together in an ecosystem are:

- **Productivity** – It refers to the rate of biomass production.
- **Energy flow** – It is the sequential process through which energy flows from one trophic level to another. The energy captured from the sun flows from producers to consumers and then to decomposers and finally back to the environment.
- **Decomposition** – It is the process of breakdown of dead organic material. The top-soil is the major site for decomposition.
- **Nutrient cycling** – In an ecosystem, nutrients are consumed and recycled back in various forms for the utilization by various organisms.

Self-Assessment Exercise

List four functions of the ecosystem.

3.3.2 Ecosystem Services

Ecosystem services are the outputs, conditions, or processes of natural environmental systems that directly or indirectly benefit humans or enhance social welfare. Because ecosystem services are not usually bought and sold directly in markets, market activities do not fully reflect the benefits provided by the services. A tree can be seen as a source of timber and fuelwood, both of which can be sold in the market, and consequently have market/economic value. The same tree, if left alone, provides shade, modifies the microclimate, sequesters carbon, provides habitat for birds and other animals, can support a beehive, providing much-needed honey, etc. All the afore-mentioned do not have market value, even though they are still fundamentally important to human

survival. These are classified as ecosystem services provided by the tree and its allied ecosystems.

Figure 2 illustrates the diversity of the ecosystem services. Ecosystem services can generally be classified into:

1. **Provisioning Services:** When people are asked to identify a service provided by nature, most think of food. Fruits, vegetables, trees, fish, and livestock are available to us as direct products of ecosystems. A provisioning service is any type of benefit to people that can be extracted from nature. Along with food, other types of provisioning services include drinking water, timber, wood fuel, natural gas, oils, plants that can be made into clothes and other materials, and medicinal benefits.
2. **Regulating Services:** Ecosystems provide many of the basic services that make life possible for people. Plants clean air and filter water, bacteria decompose wastes, bees pollinate flowers, and tree roots hold soil in place to prevent erosion. All these processes work together to make ecosystems clean, sustainable, functional, and resilient to change. A regulating service is the benefit provided by ecosystem processes that moderate natural phenomena. Regulating services include pollination, decomposition, water purification, erosion and flood control, and carbon storage and climate regulation.
3. **Cultural Services:** As we interact and alter nature, the natural world has in turn altered us. It has guided our cultural, intellectual, and social development by being a constant force present in our lives. The importance of ecosystems to the human mind can be traced back to the beginning of human civilization, with the humans of ancient civilizations drawing pictures of animals, plants, and weather patterns on cave walls. A cultural service is a non-material benefit that contributes to the development and cultural advancement of people, including how ecosystems play a role in local, national, and global cultures; the building of knowledge and the spreading of ideas; creativity born from interactions with nature (music, art, architecture); and recreation.
4. **Supporting Services:** The natural world provides so many services, sometimes we overlook the most fundamental. Ecosystems themselves cannot be sustained without the consistency of underlying natural processes, such as photosynthesis, nutrient cycling, soil formation, and the water cycle. These processes allow the Earth to sustain basic life forms, whole ecosystems and people. Without supporting services, provisional, regulating, and cultural services would not exist.

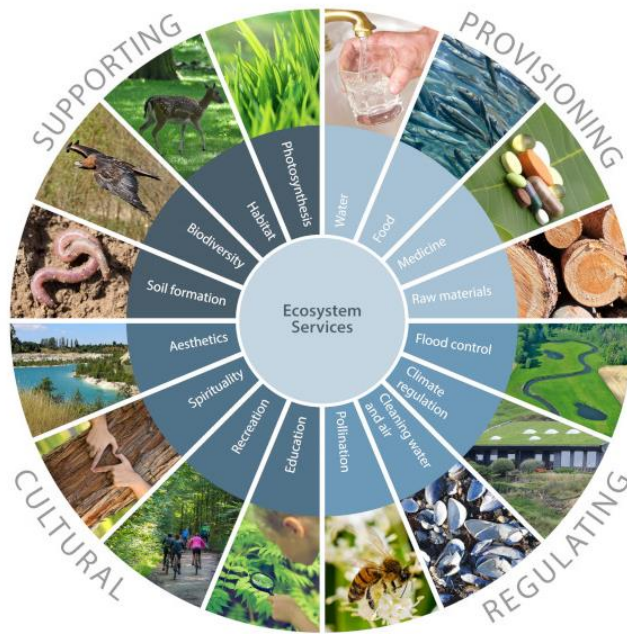


Figure 2: Schematic Representation of Ecosystem Services

Self-Assessment Exercise

List the four major classes of ecosystem services.

3.3.3 The Soil and the Ecosystem

The soil can be defined as the thin layer of material on the Earth's surface in which plants have their roots. A more technical definition of soil is the unconsolidated mineral or organic matter on the surface of the Earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time.

As such, the soil is a product of the intricate interaction of the biotic (living organisms) and abiotic (parent materials, topography, climate) factors/environment, acting over a prolonged period of time. The factors of soil formation are consequently, part of the ecosystem, along with the soil itself.

On the other hand, the soil, to a large extent, also determines the nature of the ecosystem. Some soils can support trees, while others cannot; some soils can support rice or mangrove plants, while others cannot; some soils can support luxuriant vegetative plant growth while others cannot. These diverse plant groups equally support diverse micro- and macrofauna. A monkey, for instance, cannot survive on grasslands; trees are part and parcel of its own ecosystem, and not all soils can support such trees. Consequently, the soil directly influenced the plants, and indirectly, the

monkey population. It is however, noteworthy that the soil can also directly affect the animal diversity and population. Wetland soils provide habitat for crabs, something that dry upland soils cannot provide.

The soil performs various functions that sustain the ecosystem services provided by nature. Healthy soils provide us with clean air and water, bountiful crops and forests, productive rangeland, diverse wildlife, and beautiful landscapes, etc. (Figure 3). Soil does all these by performing five essential functions, namely:

1. **Nutrient Cycling** - Soil stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, analogous to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water.
2. **Water Relations** - Soil can regulate the drainage, flow and storage of water and solutes, which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals.
3. **Biodiversity and Habitat** - Soil supports the growth of a variety of plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat.
4. **Filtering and Buffering** - Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals.
5. **Physical Stability and Support** - Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archeological treasures.

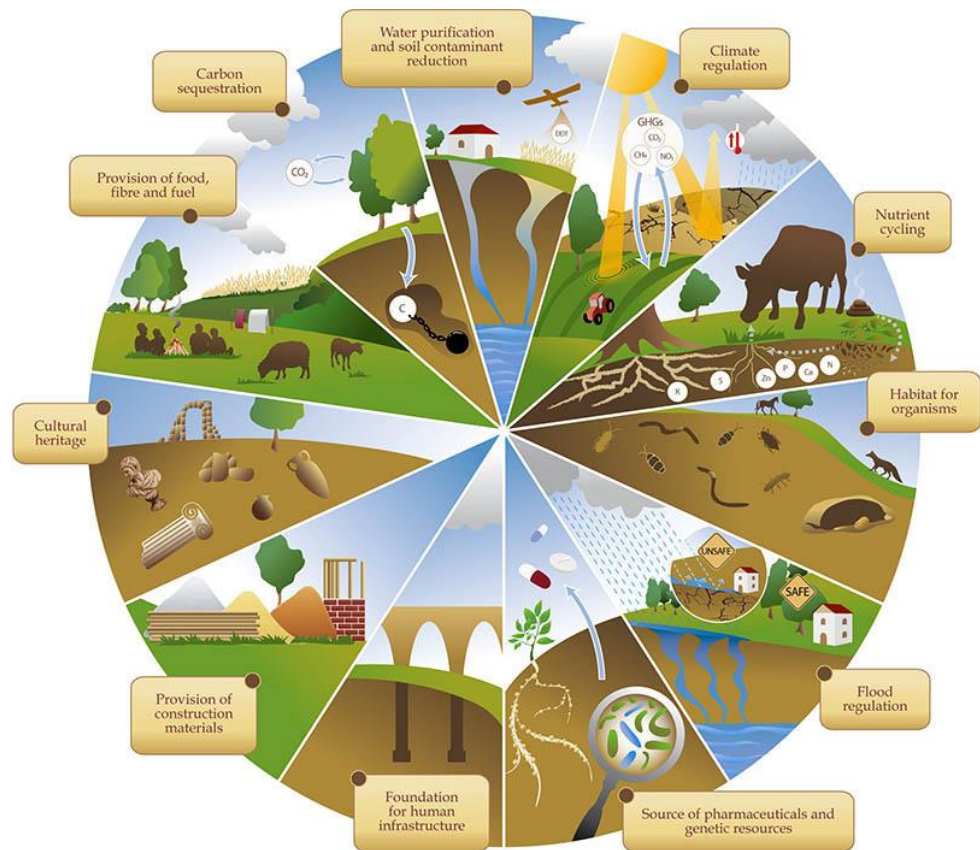


Figure 3: Functions of the Soil

Self-Assessment Exercise

List the five essential functions of the soil.

3.4 Conclusion

The ecosystem is fundamentally importance to the survival and human societies and civilization. The destruction of the global ecosystem will ultimately result in the destruction of life as we know it; it may even result in the extinction of the human race. Furthermore, life on land is irrevocably tied to the soil. The soil provides food, foundation for engineering/architectural structures, building materials, flood control, carbon sink, habitat for organisms, source of pharmaceutical/genetic resources, etc., all of which are tied to the ecosystem services provided by nature. A good understanding of the ecosystem and the soil would consequently provide insight into how to best manage natural resources to ensure the survival of human societies.

3.5 Summary

From this unit, you have learnt about the ecosystem services. Some of the key things learnt include the following;

- Functions of ecosystem
- Ecosystem services
- The soil as an ecosystem

3.6 Tutor-Marked Assignment

1. What are ecosystem services?
2. Briefly describe the soil as an ecosystem.

3.7 References/Further Reading/Web Resources

Begon, M., Townsend, C.R., HARPER, J.L. (2006) *Ecology: From Individuals to Ecosystems*. Malden, USA: Blackwell Publishing Ltd.

Baveye, P.C., Baveye, J. and Gowdy, J. (2016) Soil “Ecosystem” Services and Natural Capital: Critical Appraisal of Research on Uncertain Ground. *Front. Environ. Sci.* 4: 41. DOI: 10.3389/fenvs.2016.00041

Chapin, F.S., Matson, P.A., Vitousek, P.M. (2011). *Principles of Terrestrial Ecosystem Ecology*. New York, USA: Springer.

FAO and ITPS (2015) *Status of the World’s Soil Resources (SWSR) – Main Report*. Rome, Italy: Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils.

3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List four functions of the ecosystem.
 - a) *It regulates the essential ecological processes, supports life systems and renders stability.*
 - b) *It is responsible for the cycling of nutrients between biotic and abiotic components.*
 - c) *It maintains a balance among the various trophic levels in the ecosystem.*
 - d) *It cycles the minerals through the biosphere.*

2. List the four major classes of ecosystem services.
 - a) *Provisioning Services*
 - b) *Regulating Services*
 - c) *Cultural Services*
 - d) *Supporting Services*
3. List the five essential functions of the soil.
 - i) *Nutrient Cycling*
 - ii) *Water Relations*
 - iii) *Biodiversity and Habitat*
 - iv) *Filtering and Buffering*
 - v) *Physical Stability and Support*

MODULE 2 SOIL-LANDSCAPE MODEL

- Unit 1 Concept of Soil-Landscape
- Unit 2 Factors of Soil Formation
- Unit 3 The Soil-Landscape and the Factors of
Soil Formation
- Unit 4 Effects of the Topography on Soil-
Landscape and Ecosystem Variability

UNIT 1 CONCEPT OF SOIL-LANDSCAPE 21

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Soil-Landscape Model
 - 1.3.2 The toposequence concept
 - 1.3.3 The Soil Catena
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the
content

1.1 Introduction

Soil is not easy to map directly because it is usually covered by vegetation and other land cover types. Given the importance of soil and the fact that it varies from place to place, there is the need to delineate soils. Delineating the spatial extent of each unit will enable effective land use planning as different soils support different land uses. The soil-landscape model was developed to enable the indirect mapping of the soil by mapping the variation in the landscape. This is predicated on the fact that there exists a strong relation between the landscape that we see and the soil below. The soil catena and the toposequence are the conceptual manifestations of the soil-landscape model.

1.2 Objectives

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

- Understand the concept of the soil-landscape
- Describe the soil catena
- Describe the toposequence and how it is related to the soil catena

1.3 Main Content

1.3.1 Soil-Landscape Model

Soil is the part of the landscape that is less easily observed because it is below the surface. There, however, exist strong relationships between the landscape that we see and the soil below. These relations exist because soil and landscape are affected by the same processes, and also because soils and landscape influence each other. Hence, the birth of the soil-landscape concept.

Soil-Landscapes are areas of land that have recognizable and specifiable topographies and soils, reflect the nature of the terrain and are capable of presentation on maps. Soil Landscapes have a spatial extent that is delineated on a map by discreet polygons. Accompanying descriptions outline the soils and landforms of the map units. Because similar causal factors are involved in the formation of both soils and their landscapes, the Soil-Landscape concept permits the integration of both soil and landscape characteristics into a single map unit.

This is especially important because spatial soil variation cannot be observed easily as the soil is usually covered by vegetation and other land cover types. As such, if we can map the variations in the landscape, alongside other factors of soil formation like parent materials, climate, living organisms – particularly vegetation – we would be indirectly mapping soil variation.

Digital soil-landscape modeling techniques have been developed as a quantitative method to predict patterns of soil properties from observed patterns in soil-forming factors. The major input of this modelling process is the digital elevation model (DEM). Nevertheless, the toposequence and soil catena concepts were developed before the advent of digital soil-landscape modeling; in fact, these concepts form the basis for digital soil-landscape modeling.

Self-Assessment Exercise

Since soils are usually below the surface and are not always directly visible to the observer, how do we depict their spatial variability in a map? Define the soil-landscape.

1.3.2 The Soil Catena

The catena concept originated in Central Uganda, put forward by a chemist named, W.S. Martin to describe a hill slope sequence at the Bukalasa research station. The term catena (Latin: chain) was first coined

by Geoffrey Milne to describe these soil-topography units. The concept of a catena was developed in order to analyze the regular variation of soils across a slope. Milne originally defined a catena as ‘a unit of mapping of soils which while they fall widely apart in a natural system of classification on account of fundamental and morphological differences, are yet linked in their occurrence by conditions of topography and are repeated in the same relationships to each other where the same conditions are met.’

A soil catena is a sequence of different soil profiles that occur down a slope, from the hilltop to the valley floor. They occur on hill slopes where the geology/parent material is uniform and there is no marked difference in climate from the top to the bottom of the slope. The essential feature is that soil and water can and do move downslope. This aspect is particularly considered to be important in studies of soil variability, as the factors forming the soil will differ from top to bottom, resulting in the development of different soil types.

The variations in soil profile that occur down the slope are largely the result of changes in slope gradient. Soil can be eroded easily from a steep slope, but will tend to accumulate on gentler gradients. Soil water will drain freely on steep slopes, but will take much longer to drain from gentler ones. The increased runoff/drainage of water down steeper slopes implies that more soils will be eroded and transported down the slope – particular, finer size fractions like silt and clay. When the runoff slows down on gentler slopes and finally stagnate in valleys, these fine sediments are deposited. This has the effect of changing the soil texture and other physico-chemical properties of soils across the landscape. Furthermore, runoff water tends to infiltrate more in the flatter areas at the foot of the slope, and encourage more plant growth there than on the steep part of the slope.

As such, the differences between the soil of a catena are generally related to difference in their position and their drainage characteristics so that emphasis is placed on the difference between the freely drained upper part of the slope and imperfectly to poorly drained lower portions. This provides a continuum between those sites where the influence of soil moisture is at minimum and those sites where maximum influence of soil moisture is felt.

Slope steepness is one of the most important factors that cause a variation in soil moisture conditions as the steeper the angles, the lower the amount of water percolating through the soil, increasing the removal, perhaps through accelerated erosion, of the upper portion of the soil profile. Each catena is, thus the result of the complex interrelationships between soil

and slope processes and will be governed by the differing ratio of erosion to deposition occurring on different parts of the slope.

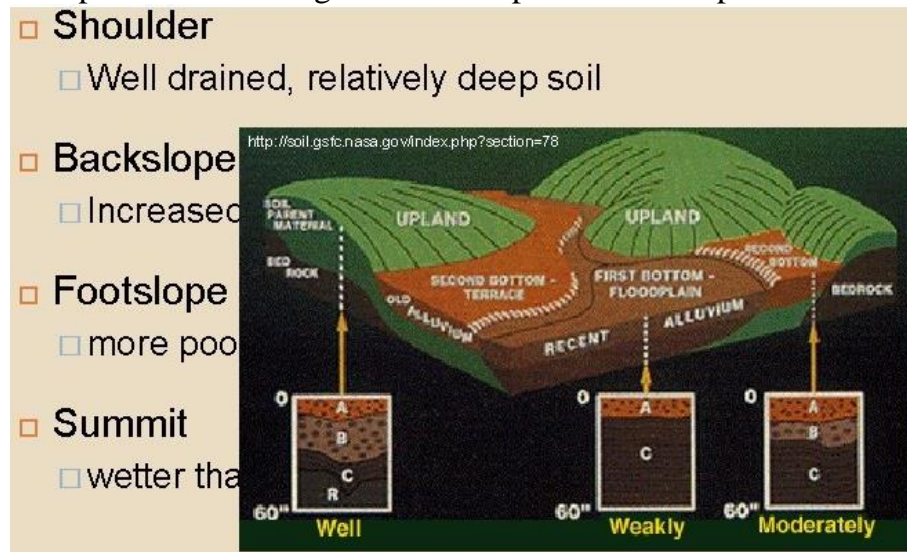


Figure 4: Schematic Diagram of the Soil Catena

Self-Assessment Exercise

List the underlying concepts of the soil catena.

1.3.2 The Toposequence Concept

A toposequence describes a soil association that can be defined in terms of topography, but does not necessarily imply the more strictly defined process-based linkage of a soil catena. They are however, sometimes used interchangeably. The soil catena describes a sequence of soils occurring on the same parent material and related to each other by topography. Topographic variation influences soil processes such as soil erosion and soil solute movement that impacts on the other downhill members of the soil sequence, thereby developing the linkage between soil types.

Toposequence models provide a conceptual understanding of soil and landscape relationships on a hillslope and are developed intuitively by soil surveyors' observations to assist with soil mapping and delineation of map units. Farmers' understanding of soil variation is also strongly influenced by terrain. While soil survey maps and map legends provide information on how soils vary across an area, toposequence models can be used to bridge the gap and graphically convey information about soil variation in a form that non-soil experts understand. Indeed, a simplified soil identification system combined with a toposequence model can help farmers, and their advisors delineate the soils on a farm at an appropriate scale. Figure 5 shows a schematic diagram of the toposequence, indicating the five constituent physiographic positions.

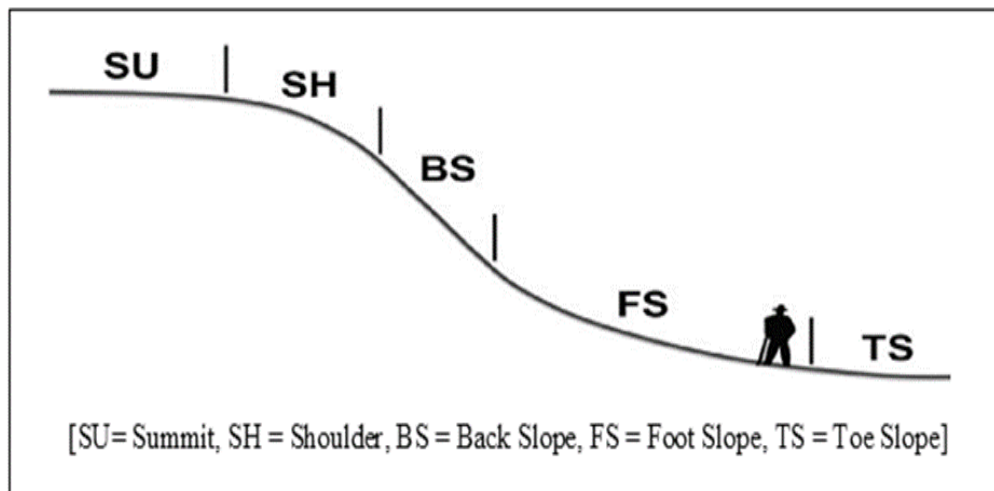


Figure 5: Schematic Diagram of the Toposequence Showing the Five Physiographic Positions

Self-Assessment Exercise

How is the toposequence related to the soil catena?

1.4 Conclusion

The soil-landscape model is a concept that enables us to better understand soil genesis, provide the basis for soil delineation and land use planning, and enable non-soil scientists to understand the spatial dynamics of soils and the attendant land uses. Soil catena and the toposequence are often used interchangeably, but they are not necessarily the same. Both concepts describe a soil association that can be defined in terms of topography. The soil catena describes a sequence of soils occurring on the same parent material and related to each other by topography, while toposequence models provide a conceptual understanding of soil and landscape relationships on a hillslope and were developed intuitively by soil surveyors' observations to assist with soil mapping and delineation of map units.

1.5 Summary

From this unit, you have learnt about the concept of the soil-landscape. Some of the key things learnt include the following;

- Soil-landscape model
- The soil catena
- The toposequence concept

1.6 Tutor-Marked Assignment

1. Briefly discuss the following:
 - a) Soil Catena
 - b) Toposequence

1.7 References/Further Reading/Web Resources

- Grealish, G.J. and Fitzpatrick, R.W. (2014) Assisting non-soil specialists to identify soil types for land management: an approach using a soil identification key and toposequence models. *Soil Use and Management* 30: 251–262.
- Iticha, B. and Takele, C. (2018) Soil–landscape variability: Mapping and building detail information for soil management. *Soil Use and Management* 34: 111–123

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

- 1a. Since soils are usually below the surface and are not always directly visible to the observer, how do we depict their spatial variability in a map?
If we can map the variations in the soil-landscape, alongside other factors of soil formation like parent materials, climate, living organisms – particularly vegetation – we would be indirectly mapping soil variation
- b. Define the soil-landscape.
Soil-Landscapes are areas of land that have recognizable and specifiable topographies and soils, reflect the nature of the terrain and are capable of presentation on maps.
2. List the underlying concepts on a soil catena.
- i) *It is a sequence of different soil profiles that occur down a slope, from the hilltop to the valley floor.*
 - ii) *They occur on hill slopes where the geology/parent material is uniform*
 - iii) *They occur on hill slopes where there is no marked difference in climate from the top to the bottom of the slope.*
 - iv) *The soil and water can and do move downslope.*
 - v) *The downslope flow sequence is an important determinant of soil variability, as the factors of soil formation differ from top to bottom, resulting in the development of different soil types.*
 - vi) *The variations in soil profile that occur down the slope are largely the result of changes in slope gradient.*
 - vii) *Each catena is, thus the result of the complex interrelationships between soil and slope processes and will be governed by the differing ratio of erosion to deposition occurring on different parts of the slope.*
2. How is the toposequence related to the soil catena?
- i) *Like the soil catena, the toposequence describes a soil association that can be defined in terms of topography, but does not necessarily imply the more strictly defined process-based linkage of a soil catena.*
 - ii) *They are however, sometimes used interchangeably.*
 - iii) *Toposequence models provide a conceptual understanding of soil and landscape relationships on a hillslope and are developed intuitively by soil surveyors' observations to assist with soil mapping and delineation of map units.*

UNIT 2 FACTORS OF SOIL FORMATION

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Factors of Soil Formation
 - 2.3.1.1 Parent Materials
 - 2.3.1.2 Topography
 - 2.3.1.3 Climate
 - 2.3.1.4 Living Organisms
 - 2.3.1.5 Time
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

The soil does not begin and end on the surface. It is much more complex. The soil is made up of layers called horizons. This sequence of horizons developed as a result of an intricate complex of interactions of processes and factors of soil formation. The factors of soil formation include parent material, relief or topography, organisms (including humans), climate and time. The process of soil formation is called soil genesis.

2.2 Objectives

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

- Enumerate and describe the factors of soil formation

2.3 Main Content

2.3.1 The Factors of Soil Formation

Soil forms layers or horizons, roughly parallel to the earth's surface, in response to five soil forming factors. The whole soil, from the surface to its lowest depths, develops naturally as a result of these five factors. The five factors are:

- 1) Parent material
- 2) Relief or topography
- 3) Organisms (including humans)

- 4) Climate
- 5) Time.

These soil forming factors continue to affect soils even on “stable” landscapes. Materials are deposited on their surface, and materials are blown or washed away from the surface. Additions, removals, and alterations are slow or rapid, depending on climate, landscape position, and biological activity.

If a single parent material is exposed to different climates, then a different soil individual will form. If any one of the five factors is changed but the remaining four factors remain the same, a new soil will form. This process is called “soil genesis”. It is thought that roughly 95 percent of the world’s soils have been moved or transported to their present location. Only 5 percent of the world’s soils are “residual soils” or soils that formed in place from the existing parent material.

Self-Assessment Exercise

What is soil genesis?

2.3.1.1 Parent Material

Few soils weather directly from the underlying rocks. These “residual” soils have the same general chemistry as the original rocks. More commonly, soils form in materials that have moved in from elsewhere. Materials may have moved many miles or only a few feet. Windblown “loess” is common in the northern Nigeria and particularly, in the Sahara Desert. The material in which soils form is called “parent material.” In the lower part of the soils, these materials may be relatively unchanged from when they were deposited by moving water, ice, or wind. There are different kinds of parent materials, which may be igneous, sedimentary or organic in origin. All of the different kinds of parent material are subjected, in varying degrees, to the other four soil forming factors. All five of the soil forming factors are acting at the same time at different rates of speed and with different degrees of efficiency.

2.3.1.2 Topography

Most of locations on earth exhibit some relief or topography related to the type of landform that they occupy. A landscape location.

- 1) has an elevation either above or below another part of the landscape,
- 2) has a distinct shape (convex, concave or linear),
- 3) faces a specific compass direction, and
- 4) is only one component of the landscape.

These factors influence drainage, runoff, deposition, and erosion as well as the collection of solar energy. Slope and aspect affect the moisture and temperature of soil. Steep slopes facing the sun are warmer. Steep soils may be eroded and lose their topsoil as they form. Thus, they may be thinner than the more nearly level soils that receive deposits from areas upslope. Deeper, darker colored soils may be expected on the bottom land. The shape of the topography also contributes to how the slope disperses water. Concave-shaped slopes tend to concentrate water which causes more erosion and runoff. Convex-shaped slopes tend to disperse water more uniformly. Concave positions in flatter landscapes tend to collect water and these soils are more poorly drained and may have a water table near the surface.

The most common flat landscapes are those in wide valleys along rivers. The soils in these areas range from poorly drained to moderately well drained and have very limited runoff. During floods, soil material commonly is deposited in these landscape positions and erosion generally is not a concern. Erosion from surrounding slopes also results in additional depositions of soil material on the valley bottoms. These landscapes are often cooler because of cold air drainage from higher surrounding areas.

2.3.1.3 Climate

Climate directly and indirectly affects soil formation. Soils vary, depending on the climate. Temperature and moisture amounts cause different patterns of weathering and leaching. Less development occurs in drier areas because as water quickly moves into and through a soil it increases the rate of weathering of soil materials. For example, soluble materials such as organic matter, clay, and calcium carbonate and other salts are moved downward in a soil profile and sometimes out of a soil profile if enough water is available. In general terms, the depth at which soluble material occurs in a soil profile indicates the amount of water that the soil individual receives. Thus, a record of the average annual precipitation and average annual soil temperature on each site is important. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Also, in arid regions, wind plays a crucial role in soil formation by contributing to the redistribution of sand and other particles.

2.3.1.4 Living Organisms

Plants, animals (including humans) and micro-organisms, affect soil formation. Animals and micro-organisms mix soils and form burrows and pores.

The kinds of plants that grow on a soil impact the kind of plant residue that form and is incorporated into the soil. Plant roots open channels in the soils. Different types of roots have different effects on soils. Grass roots are “fibrous” near the soil surface and easily decompose, adding organic matter. Taproots open pathways through dense layers. Surface soil horizons are most affected by the kinds of plants that grow on a site. Needles, twigs, leaves, stems, and roots of plants are incorporated into the soil and broken down by the different kinds of organisms that live in the soil, changing the spatial and temporal dynamics of surface soils. Different kinds of plants produce materials that are acidic and others produce material that is alkaline. This too changes the kind of soil that forms on a site.

Micro-organisms affect chemical exchanges between roots and soil. They are present in all soils, and they occur in extremely large numbers. One teaspoon of soil contains many millions of tiny, microscopic microorganisms. These organisms assist in the breakdown of soil parent material, organic matter, and other weathering products contained in the soil. They also produce substances that help plants absorb nutrients and water from the soil.

Animals and micro-organisms mix soils and form burrows and pores. Humans can mix the soil so extensively that the soil material is again considered parent material. Other organisms such as worms that burrow into the soil create little channels that assist in the movement of water and air into and through soil. Burrowing animals such as voles, moles, and ground squirrels mix the soil as they dig homes which also helps to move water and air into the soil profile.

It is however, noteworthy that the native living organisms depends on climate, topography, and biological factors plus many soil factors such as soil density, depth, chemistry, temperature, and moisture.

2.3.1.5 Time

Time is the last of the five soil forming factors to consider. However, this does not mean that it is not important. It takes time for all these factors to interactively result in different types of soils. Over time, soils exhibit features that reflect the other forming factors. Soil formation processes are continuous. Recently deposited material, such as the deposition from

a flood, exhibits no features from soil development activities. The previous soil surface and underlying horizons become buried. The time clock resets for these soils. Terraces above the active floodplain, while genetically similar to the floodplain, are older land surfaces and exhibit more development features.

Young soils are usually easy to recognize because they have little or weak soil horizon development and the horizons, commonly, are indistinct. The soil parent material and the intensity of weathering have not yet produced highly visible evidence such as clay or carbonate movement and deposition which form subsoil horizons. Normally, soil scientists think of soil development in terms of soil age. Older soils have more and stronger horizon development than do younger soils. Young soils are weakly developed and have indistinct soil horizons while older (mature) soils are strongly developed and have well defined soil horizons.

An often-asked question is, “How long does it take to form an inch of topsoil?” This question has many different answers but most soil scientists agree that it takes at least 100 years and it varies depending on climate, vegetation, and other factors. In a wet, hot climate soil horizons will form fairly quickly compared to those in cold, dry environments. Therefore, soils in cold, dry climates develop rather slowly in comparison. It is not just the amount of time that determines the degree of soil development but also the parent material, climate, vegetation, and intensity of soil-forming factors during that time.

Self-Assessment Exercise

List the factors of soil formation.

2.4 Conclusion

When mapping soils, a soil scientist looks for areas with similar soil-forming factors to find similar soils. The colors, texture, structure, and other properties are described. Soils with the same kind of properties are given taxonomic names. Understanding the spatial dynamics of the factors of soil formation would consequently enable the prediction of spatial and temporal distribution of soils within an area, informing proper land use planning.

2.5 Summary

From this unit, you have learnt about the factors of soil formation. Some of the key things learnt include the following;
The factors of soil formation, which include:

- Parent material
- Topography
- Climate
- Living organisms
- Time

2.6 Tutor-Marked Assignment

1. Discuss the factors of soil formation.
2. What will be the findings of the following studies?
 - a) Two soils formed from limestone deposits, one in the cold climates of Netherlands and the other in the hot tropical climate of Nigeria.
 - b) Soils in two locations where all factors of soil formation are similar.

2.7 References/Further Reading/Web Resources

White, R.E. (2006) Principles and practice of soil science: The soil as a natural resource (4th Ed.). Malden, USA: Blackwell Publishing

2.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. What is soil genesis?

Soil genesis is the process of soil formation.

2. List the factors of soil formation.

*i) Climate ii) Living organisms iii) Relief/topography iv) Parent
Materials v) Time*

UNIT 3 THE SOIL-LANDSCAPE AND THE FACTORS OF SOIL FORMATION

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3 Main Content
 - 3.3.1 Relationship between Soil-Landscape and The Factors of Soil Formation
 - 3.3.2 Soil-Landscape, Factors of Soil Formation and Soil Mapping
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

Soils form on different landscapes. The process of soil formation on those landscapes is moderated by the factors of soil formation. The varying intensities of the actions of these factors across the landscape results in the formation of soils with extensive spatial variability. However, the nature of the landscape also, to a large extent, controls the how these factors operate on the landscape, and consequently, the nature and degree of variability of the resultant soils. There is therefore, a close link between the soil and the landscape, hence, the soil-landscape. Given the fact that the soil is usually not directly visible, it is not easy to map directly. Soil-landscape mapping can consequently be employed as a proxy for soil mapping.

3.2 Objectives

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

- Describe how the soil-landscape is related to the factors of soil formation

3.3 Main Content

3.3.1 Relationship Between Soil-Landscape and The Factors of Soil Formation

Soils form an almost complete skin over the earth, broken only by oceans and other water bodies and by mountains that have yet to develop a soil

cover. When you walk through your garden or through fields there is always this amazing carpet, called soil, beneath your feet. But how do soils form? Well, there are five main contributors that interact to produce soils: **parent rocks and sediments, climate, landscape (topography), living organisms (including plants and animals) and time**. Around the world the influence of these soil forming factors will be different from one country to another and this is why there are many different soils in the world.

Parent material is one of the most important factors that influence the type of soil develops. Just as we humans all have parents, so also do soils have parent material from which and/or on which they develop. In some cases, soils develop directly from the rock which lies beneath them. Gradually the rock will break down into smaller pieces under the effects of rainfall, snow, freezing and thawing, intermittent increase and decrease in temperature, etc.; and these smaller pieces break down even further to produce soil. This fragmented rock forms the skeletal material of soils. If the rock is very hard, it can take hundreds of years just to form one centimeter of soil. If soils form on loose materials such as desert sand dunes or on more or less loose deposits, deeper soils can form quite quickly. The parent rock or sediment is the main factor responsible for the texture of the soil (i.e., whether the soil is sandy, loamy or clayey) and is also important in determining whether the soil is acid or basic and how rich it is in nutrients.

Climate is the other most important soil forming influence, alongside parent material. It determines the rate of breakdown of the parent rock and thus how quickly the soil will get deeper. The two main climatic elements that influence soil formation are temperature and rainfall. Higher temperatures increase the rate at which breakdown of the underlying rock takes place and thus also the release of nutrients into the soil. Rainfall and snow melt are also important in breaking down rock to form soil and in the distribution of nutrients in the soil. In hot, wet climates such as the tropics, soils tend to be deep, whereas in the cold Arctic areas, soils tend to be thin and poorly developed.

Landscape generally affects the depth or thickness of soils. Steep slopes such as occur on the sides of hills and mountains generally have shallow soils because soil that does develop is regularly washed down the hillsides into the valleys below. The steep sides of mountains may lack soils altogether and be bare. By comparison flat land such as occurs in valley bottoms, flood plains of rivers or just low-lying plains will have deeper soils. These flatter areas often receive sediments washed off the slopes above, which makes the flat land soils deeper. Consequently, within a locality, there is a direct link between the soil and the landscape, as the landscape may also moderate the impact of the other factors. For instance,

the side of the hill facing the sun usually has higher temperature; the windward side of the mountain has higher rainfall than the leeward side; higher elevation has lower temperature than lower elevation. The nature of the landscape determines the type of plants and animals that can survive therein. The wet valleys may support plants like rice and sedges, and animals like crabs, but not crops like maize and cassava, and animals like monkeys and squirrels; the reverse is usually the case for drier upland regions of the landscape. The parent materials on the steep slopes are usually in situ materials, whereas, in the valleys, you have more of transported materials. The soils on slopes are usually younger, when compared to the soils on relatively level landscapes. Hence, at a local scale, the landscape may provide insight into the spatial distribution of soil.

A close relationship between soil type and **vegetation** tends to develop as soils begin to form. Vegetation plays an important part in the formation of soils from solid rock. The acids released by the roots of some plants act to breakdown the rock on which the soil is forming. The vegetation on a soil is particularly important in supplying the soil with precious organic matter. There is often a close relationship between the vegetation and the soil, the vegetation supplying its dying remains to the soil and the soil converting them into nutrients so the vegetation can continue to survive and develop in years ahead. Different types of vegetation give rise to different forms of organic matter in soils.

Organisms, of which there are millions and millions in the soil, play vital roles in soil development and in enabling the soil to perform its many ecosystem functions. Organisms begin to set up their home in the soil from the moment soils begin to form. Their main role is to deal with the recycling of organic matter and the release of nutrients, but they do other important things, such as, creating pores and building the architecture of the soil. Earthworms, for example, make channels in the soil through which roots can move and water can flow to other parts of the soil.

Human influences can have far reaching effects on soils. Farmers have cultivated and tended their soils for centuries; and farmed soils differ in many respects to those under natural vegetation, Arable soils, for instance, have a thicker topsoil due to ploughing and more nutrients because of added fertilizers. In most cases mankind has managed the soils well. In some parts of the world, though, soils have been damaged by human interference. For example, cutting down of parts of the tropical rainforest and cultivation of crops on steep slopes have led to soil erosion, which in some cases is irreversible.

It takes a long **time** for soils to develop from rock and from existing sediments. A few world soils, such as those on the old landscapes of South

Africa, are millions of years old. Most world soils are, however, much younger because periods of geological turbulence such as mountain building, earthquakes and ice ages have meant that soil formation has to begin again.

Self-Assessment Exercise

How does topography moderate other soil forming factors, even while affecting soil formation?

3.3.2 Soil-Landscape, Factors of Soil Formation and Soil Mapping

Soil-forming factors work at different levels and influence soil genesis at different scales. Climate and organisms are more 'active' factors, whereas relief and parent material dominate the initial state of soil formation. Time, in contrast, controls the overall rate at which soil formation takes place. Different factors can overlap and vary in their intensity, or might even be complemented by more specific factors, like wildfires, dust deposition, that periodically influence the formation of soil.

The factors of soil formation provide the basis for understanding soil genesis and soil mapping. In 1883, the Russian pedologist Dokuchaev put forward the famous theory on soil-forming factors, i.e., soil is formed over time as a consequence of climatic (CL), parent material (P), and biological processes (O), which he demonstrated that soils are products of soil-forming factors. Jenny (1941) further developed this, by adding topographic relief as a factor, into a soil-forming function:

$$S = f(\text{CLORPT...})$$

This equation suggests that, by looking for changes in these factors as the landscape is traversed, one can identify boundaries between different bodies of soils. The formulation has been used by a lot of soil investigators as a conceptual soil-forming model for understanding soil-landscape patterns within a region. Many studies have tried to quantitatively formalize the equation.

Based on a review of various quantitative approaches to making digital soil maps, McBratney et al. (2003) proposed a quantitative framework suitable for digital mapping and modeling of soil classes and properties, i.e., the well-known SCORPAN model. SCORPAN is an empirical model, and both factors and soil predictions are spatially and temporally explicit. The alphabets represent: S = soil [other or previously measured properties of the soil at a point], C = climate [climatic properties of the environment at a point], O = organisms [including land cover and natural vegetation, fauna or human activity], R = relief [topography, landscape

attributes], P = parent material [lithology], A = age [the time factor] and N = spatial or geographic position.

It is however noteworthy that, as mentioned earlier, soil mapping based on the factors of soil formation, is scale-dependent. From the global or continental scale, climate would be the predominant factor as soils in cold (temperate) climate would be very different from soils in very hot (tropical) regions. The living organisms, including vegetation, depend largely on the climatic dynamics as temperate regions support organisms that are drastically different from those of humid tropical regions, which also differs from those of arid regions. Organisms consequently has a continental scale. Parent materials operate on the local scale, and topography/landscape at even more local scale. In fact, Baskan et al. (2016) reported that topography/relief is the most important factor for soil formation, as it affects how water and energy were added to and/or lost from the soil.

Consequently, when trying to map soils within a locality, acquiring the geologic map representing the parent materials in the area may be the first step. Subsequently, the topography/landscape within the coverage of each geologic formation can be mapped. This soil-landscape model will enable the generation of a soil-landscape map that can serve as a proxy for the initial soil map, especially given the fact that soils and soil variation can hardly be viewed directly either visually or on remote-sensed data (satellite imageries or aerial photographs).

Self-Assessment Exercise

How can you use your knowledge of the soil forming factors to map soils?

3.4 Conclusion

Soil formation is a complex process brought about by the interaction of several different influences, including increasingly the influence of man. Soil is a vital, precious, yet fragile commodity which needs to be understood and managed intelligently. We need to work with nature to ensure soils are allowed to develop, and are sustained, not destroyed. Indeed, there are concerns that the pressures being put on our soils by human use, for example to produce more and more food, may be damaging our soils. There is consequently the need to map the spatial extent and capability of soils. Mapping the soil-landscape, in conjunction with the other factors of soil formation, will provide the much-needed insight into the nature and extent of the different soil types within an area. The CLORPT model by Jenny provided the basis for soil delineation. This was further developed into the SCORPAN model by McBratney. These

models, alongside the soil-landscape model, are very important tools for understanding soil genesis and the spatio-temporal dynamics of soils.

3.5 Summary

From this unit, you have learnt about the soil-landscape and the factors of soil formation. Some of the key things learnt include the following;

- Relationship between soil-landscape and the factors of soil formation
- Soil-landscape, factors of soil formation and soil mapping

3.6 Tutor-Marked Assignment

1. How is the soil-landscape related to the factors of soil formation?
2. How can a good knowledge of soil-landscape and the factors of soil formation help in soil mapping?

3.7 References/Further Reading/Web Resources

Baskan, O., Orhan Dengiz, O. and Gunturk, A. (2016) Effects of toposequence and land use-land cover on the spatial distribution of soil properties. *Environmental Earth Sciences* 75: 448. DOI 10.1007/s12665-016-5301-6

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3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. How does topography moderate other soil forming factors, even while affecting soil formation?

For instance, the side of the hill facing the sun usually has higher temperature; the windward side of the mountain has higher rainfall than the leeward side; higher elevation has lower temperature than lower elevation. The nature of the landscape determines the type of plants and animals that can survive therein. The wet valleys may support plants like rice and sedges, and animals like crabs, but not crops like maize and cassava, and animals like monkeys and squirrels; the reverse is usually the case for drier upland regions of the landscape. The parent materials on the steep slopes are usually in situ materials, whereas, in the valleys, you have more of transported materials. The soils on slopes are usually younger, when compared to the soils on relatively level landscapes. Hence, at a local scale, the landscape may provide insight into the spatial distribution of soil.

2. How can you use your knowledge of the soil forming factors to map soils?

By looking for changes in these factors as the landscape is traversed, one can identify boundaries between different bodies of soils. The formulation has been used by a lot of soil investigators as a conceptual soil-forming model for understanding soil-landscape patterns within a region.

UNIT 4 EFFECTS OF THE TOPOGRAPHY ON SOIL- LANDSCAPE AND ECOSYSTEM VARIABILITY

Unit Structure

- 4.1 Introduction
- 4.2 Objectives
- 4.3 Main Content
 - 4.3.1 Effect of Topography on Soil Variability
 - 4.3.1.1 Effects on Soil Morphology
 - 4.3.1.2 Effects on Soil Physical Properties
 - 4.3.1.3 Effects on Soil Chemical Properties
 - 4.3.2 Effect of Topography on Ecosystem Variability
 - 4.3.3 Soil-Landscape as a Proxy for Soil Mapping Units
- 4.4 Conclusion
- 4.5 Summary
- 4.6 Tutor-Marked Assignment
- 4.7 References/Further Reading/Web Resources
- 4.8 Possible Answers to Self-Assessment Exercise(s) within the content

4.1 Introduction

Topography plays a crucial role in soil formation and the determination of the spatial variability of soils and ecosystems. It affects the morphological, physical and chemical properties of the soil. In fact, it controls how the factors of soil formation interact with each other and the landscape, and consequently, the nature and degree of variability of the resultant soils. The resultant soil ecosystem variability is a reflection of the varying intensities of the actions of these factors of soil formation across the landscape. This close relationship between the soil and the landscape is what underscores the soil-landscape model. Given the fact that soil survey entails the division of varying landscapes into more or less distinct classes that require comparatively similar management practices, the soil-landscape can be used as a proxy for soil mapping and a tool for land use planning.

4.2 Objectives

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

- Explain the effect of topography on ecosystem variability
- Explain the effect of topography on soil variability
- Understand how terrain analysis is related to soil mapping

4.3 Main Content

4.3.1 Effect of Topography on Soil Variability

As mentioned earlier, according to Baskan et al. (2016), topography/relief is the most important factor for soil formation; it affects how water and energy are added to and/or lost from the soil.

4.3.1.1 Effects on Soil Morphology

Topography has an extensive impact on the nature and properties of soils. The variation of the soil colour is one of the more obvious sequences and is typical of many West Africa's soil-landscapes. Upland, well-drained soils are usually reddish-brown, the colour showing the presence of non-hydrated iron oxide in the soil. The iron is well dispersed and usually partly attached to the clay fraction, thus the clay itself appears red.

On the middle and lower parts of the slope, drainage is slower partly because of the moisture seeping down from the upper soils. These soils remain moist longer and dry out less frequently and less completely; this leads to an increasing degree of hydration of the iron. The red colour changes to brown or yellow; the hydrated iron oxides are mainly limonite and goethite. The colour changes are not sudden; there is a gradual change from the original reddish-brown of the upper soils to orange-brown and then to yellow-brown and sometimes brownish yellow on the lower slopes.

On the lowest slopes, where the drainage can be very poor and where parts or all of the soil is water logged, reduction of the iron and other soil compounds take place. Under this condition, bacteria obtain their oxygen from the oxygen-containing compounds and then these are reduced to other compounds. These waterlogged soils are usually bluish-grey, greenish-grey or even natural grey in colour. In this part of soil profile where the water table fluctuates mottling is likely to be produced.

As such, the lowland soils are usually poorly drained while the upland soils are well-drained. Similarly, in the poorly drained soils the predominant organisms are anaerobic in nature while the predominant species in well-drained soils are aerobic. Soil depth is also influenced by topography as soils along steeper slopes are shallow due to the impact of soil erosion while soils on valleys and plains are relatively deeper due to reduced erosion and deposition.

Self-Assessment Exercise

List four impacts on topography on soil morphology.

4.3.1.2 Effects on Soil Physical Properties

1. **Soil Texture:** Soil texture refers to the relative proportion of stone, gravel, sand, silt and clay in a specified quantity of soil. Due to the greater ease of erosion of silt than clay and sand, topography may have a greater impact on silt concentration in soils. As such, steeper slopes will have relatively lower silt than valleys due to erosion of fine earth fractions on the slopes and the deposition of the silt in the valleys and low-lying parts of the landscape. This ultimately changes the soil texture along the landscape. Indeed, the trend of percentage silt in the different physiographic positions of the landscape will reflect the density-dependent pattern of surface flow, transportation and deposition of soil materials from upland to lowland.
2. **Infiltration:** Infiltration is the downward entry of water from the surface into the soil profile. It is the key to soil and water conservation because it determines the amount of runoff over the soil surface during rainstorms. The relation between the rate of water supply to the soil and the rate of infiltration through it determine the distribution of such water between runoff and storage in the root zone. Slopes, particularly steeper slopes, characteristically have low infiltration rate and high runoff intensity. This invariably affects the water economy of the rooting zone of plants. Such soil will have difficulty in meeting the water needs for crop production where water is a major limiting factor. Greatest soil erosion, low infiltration, high runoff, and minimal soil development have also been reported for the shoulder of the landscape.
3. **Hydraulic Conductivity:** Hydraulic conductivity, which is a measure of the seepage of water into and through the soil under the influence of gravity, is usually higher in the lowland valleys. This may be due to the deposition of relatively fine materials/sediments, like silt, and coarser sediments like sand, that were eroded from the upland areas. As such, the vertical flow of water would be considerably less than in the upland parts of the landscape as it may have a relatively higher clay concentration. This also indicates that soil moisture content is highly influenced by slope position.

Self-Assessment Exercise

List four soil properties that are affected by variation in topography.

4.3.1.3 Effects on Soil Chemical Properties

1. **Soil Organic Matter:** Soil organic matter is an important soil component that plays key roles in the functions of both natural ecosystems (greatly influencing soil structure, fertility, and water-holding capacity) and agricultural systems, in which it also affects food production and quality. It is also a reflection of the soil organic carbon concentration in the soil. Topography affects soil organic carbon through erosion and redistribution of fine soil particles and organic matter across landscape, and through water redistribution leading to varying leaching, infiltration, and runoff potentials. Also, the high organic carbon content of the wet lowlands may be attributed to the prevalent anaerobic conditions in the soils, which does not support the survival of the aerobic microorganisms that would ensure the rapid decomposition and mineralization of the organic matter. The reverse is the case in the well-drained aerobic soils of the upper slopes.
2. **Available Phosphorus:** The term available phosphorous (P) refers to the inorganic form, occurring in soil solution, which is almost exclusively, orthophosphate. In most soils, the main source of orthophosphate is organic matter. As such, given the relative accumulation and low decomposition rate of organic matter in the wet lowlands, it is expected that the lowlands would also have relatively higher available phosphorus concentration than the well-drained uplands.
3. **Total Nitrogen:** Nitrogen is one of the major nutrients required for the nutrition of plants. Of the total amount of nitrogen present in soils, nearly 95-99% is in the organic form and 1-5% in the inorganic form as ammonium and nitrates. Given the fact that the wet lowlands usually have higher organic matter, total nitrogen would also be higher in the wet lowlands than in the drier upland parts of the landscape. Moreover, nitrogen is usually highly soluble in water. As such, the dissolved nitrogen acquired as the runoff flows down the slope will ultimately be deposited in the valleys or plains, engendering higher nitrogen content.
4. **Zinc:** The Zinc content is usually high in the topsoil, decreasing down the profile. This correlates to the fact that organic matter is equally high in the topsoil, decreasing down the profile. This implies that a greater proportion of the zinc available in the soil is sourced from organic matter. Similarly, the wet lowlands, with relatively higher organic matter would also have higher zinc content. This may also correlate to the fact that organic matter has high cation exchange capacity with a net negative charge, providing the surface required for the adsorption of the positively charged zinc ion.

5. **Copper:** Copper distribution also correlate with organic matter distribution. It is expected to be higher in the wet low-lying valleys with high organic matter content.
6. **Iron:** The type of iron oxide present in the soil, as mentioned earlier, is considerably affected by topography. The reddish colour of upland soils is a result of the presence oxidized Fe (III) (Fe^{+++}). The predominant iron oxide in low wetlands is reduced Fe (II) (Fe^{++}), which gives the soil a bluish or greenish colour. It is also noteworthy that Fe^{+++} is not readily soluble, but when reduced to Fe^{++} , it is very soluble. As such, due to its high solubility, on the long run, it might be leached out of the soil, resulting in the grayish colour of a soil that is devoid of iron oxide.

Self-Assessment Exercise

List four soil chemical properties affected by topography.
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4.3.2 Effect of Topography on Ecosystem Variability

Topography profoundly affects abiotic conditions which, in turn, influence the structure, function and dynamics of ecological communities. Over large spatial and temporal scales, topography shapes climate regimes and influences diversification. At local scales, topography affects thermal, hydrologic and edaphic components of the ecosystem. In forests, local topographic heterogeneity is linked with a broad set of abiotic conditions (e.g., soil water availability, nutrient content and soil texture, microclimate, exposure, flood regimes) that can influence stand structure, dynamics and composition. Thus, the integrated impact of topography and soil on the landscape results in the development of diverse ecosystems. This can be buttressed with the toposequence/soil catena concept.

Traditional cropping system are using designed to take full advantage of local topographical features, toposequences, macro- and microrelief. This is because there is no land with optimal conditions to support every land use type. Thus, a combination of soil or landscape need to be matched with the requirements of a particular land use type to determine the optimal use of each parcel of land. Lowland swamps or valleys are suitable for swamp rice production, but are not suitable for maize. On the other hand, upland, well-drained soils are suitable for maize, but unsuitable for swamp rice.

Similarly, the ideal ecosystems for crabs are wet relatively wet soils that are usually waterlogged; earthworms would thrive in wet soils but not as much in submerged soils; both would not thrive effectively in dry upland soils. A squirrel or a monkey, on the other hand, would not thrive

effectively on these wetland soils. You may even find fishes in the valley wetlands, but they will absolutely not survive in the dry upland soils. Each species has a particular set of characteristic features of the landscape unit within which it can survive. As such, different parts of the landscape would support a different set of ecosystems, and by studying and delineating the landscape/topographic units, we can make projection on the kinds of ecosystems that can be found in specific regions.

Self-Assessment Exercise

List four components of the ecosystem that are affected by topography.

4.3.3 Soil-Landscape as A Proxy for Soil Mapping Units

The process of soil formation is moderated by the factors of soil formation. Although the development of soils depends primarily on geologic and climatic conditions, soils vary in their properties within and between landforms because of soil-forming factors. The magnitude of variation is determined by climate, topography and vegetation, but landform plays a significant role in modifying the effects of climate and vegetation cover.

For instance, the side of the hill facing the sun usually has higher temperature; the windward side of the mountain has higher rainfall than the leeward side; higher elevation has lower temperature than lower elevation. The nature of the landscape determines the type of plants and animals that can survive therein. The wet valleys may support plants like rice and sedges, and animals like crabs, but not crops like maize and cassava, and animals like monkeys and squirrels; the reverse is usually the case for drier upland regions of the landscape. The parent materials on the steep slopes are usually in situ materials, whereas, in the valleys, you have more of transported materials. The soils on slopes are usually younger, when compared to the soils on relatively level landscapes. Hence, at a local scale, the landscape may provide insight into the spatial distribution of soil.

Given the fact that the soil is usually not directly visible, it is not easy to map directly. Soil-landscape mapping can consequently be employed as a proxy for soil mapping. This underscores a paradigm of conceptual soil-landscape model, under the hypothesis that the location and distribution of soils in the landscape is predictable. Mapping soil-landscape relations at large spatial scales will be important, not only for understanding soil-environment interactions, but also for irrigation design, crop selection, agricultural input requirement decisions, and overall land suitability evaluation.

Self-Assessment Exercise

List the two factors of soil formation that are most affected by topography.

4.4 Conclusion

The art of soil survey and classification involves dividing soils of a varying landscape into more or less distinct classes that require comparatively similar management practices. The concept of soil-landscape relationship will consequently help to categorize highly variable soils into relatively distinct management zones. Indeed, soil mapping is more efficient if planned and focused on areas defined by soils and landscapes rather than land administrative boundaries.

4.5 Summary

From this unit, you have learnt about the effects of the topography on soil-landscape and ecosystem variability. Some of the key things learnt include the following:

- Effect of topography on soil variability
- Effect of topography on ecosystem variability
- Soil-landscape as a proxy for soil mapping units

4.6 Tutor-Marked Assignment

1. Discuss the effects of the soil-landscape on the:
 - a) Soil physical properties
 - b) Soil chemical properties
 - c) Ecosystem diversity.

4.7 References/Further Reading/Web Resources

Baskan, O., Orhan Dengiz, O. and Gunturk, A. (2016) Effects of toposequence and land use-land cover on the spatial distribution of soil properties. *Environmental Earth Sciences* 75: 448. DOI 10.1007/s12665-016-5301-6

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4.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List four impacts on topography on soil morphology.
 - i) *Upland soils are usually reddish in colour due to the oxidize nature of iron oxides*
 - ii) *Lowland soils are usually bluish-grey, greenish-grey or even natural grey in colour due to the reduced condition of the iron oxides and their eventual leaching out of the soil profile.*
 - iii) *Due to an increasing degree of hydration of the iron, midslope soils change from the reddish colours seen in uplands to orange-brown and then to yellow-brown and sometimes brownish yellow.*
 - iv) *Lowland and gentle-sloping fields are usually deeper than steeper slopes due to the differential effects of erosion and deposition.*
2. List three soil properties that are affected by variation in topography.
 - i) *soil texture* ii) *Soil infiltration* iii) *Hydraulic conductivity* iv) *Soil moisture content*
3. List four soil chemical properties affected by topography.
 - i) *Soil organic matter* ii) *Available Phosphorus* iii) *Total nitrogen* iv) *Zinc*
4. List four components of the ecosystem that are affected by topography.
 - i) *Climate regimes/ microclimate* ii) *Hydrology/soil water availability* iii) *Nutrient content* iv) *Soil texture*
5. List the two factors of soil formation that are most affected by topography.
 - i) *Climate* ii) *Living organisms, particularly, vegetation*

MODULE 3 DIGITAL REMOTE SENSING

Unit 1	Remote Sensing Concept
Unit 2	The Electromagnetic Spectrum
Unit 3	Interaction of Electromagnetic Radiation With the Atmosphere and the Earth Surface
Unit 4	Types of Remote Sensing
Unit 5	Elements of Image Interpretation
Unit 6	Digital Image Classification

UNIT 1 REMOTE SENSING CONCEPT

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Remote Sensing and its Applications
 - 1.3.2 Components of Remote Sensing
 - 1.3.3 Advantages and Limitations of Remote Sensing
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

Remote sensing is defined as the science and art of obtaining information about an object, area, or phenomenon through the analyses of data acquired by a sensor that is not in direct contact with the target of interest. Remote sensing is a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computers, electronics, telecommunication, etc., all of which are integrated to act as one complete system. Agriculture, meteorology, oceanography, ecology, cartography, botany, geomorphology and geology are just a few of the disciplines which have been transformed by this technology. The components of the remote sensing system include the sun as a source of energy; emission of sun's energy; interaction of solar energy with atmospheric elements; interaction of sunlight with terrestrial features; terrestrial radiation of the earth's element; collection of information/data; data acquisition by the earth station; interpretation and analysis; and application domain of the

acquired data. It however has some advantages and limitations, some of which would be explored in the course of your studies in this unit.

1.2 Objectives

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

- Explain the concept of remote sensing
- Outline the agricultural and allied applications of remote sensing
- Outline the elements of remote sensing
- Outline the advantages of remote sensing
- Outline the limitations of remote sensing

1.3 Main Content

1.3.1 Remote Sensing and Its Applications

Remote sensing is defined as the science and art of obtaining information about an object, area, or phenomenon through the analyses of data acquired by the sensor that is not in direct contact with the target of interest. This can be done by the use of either recording or real-time sensing device(s) mounted on aircraft, spacecraft, satellite or ship. Consequently, remote sensing enables us to acquire information about a phenomenon, object or surface while at a distance from it.

Remote sensing is a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computers, electronics and telecommunication, etc., all of which are integrated to act as one complete system.

Agriculture, meteorology, oceanography, ecology, cartography, botany, geomorphology and geology are just a few of the disciplines which have been transformed by this technology. The primary application of remote sensing include:

1. **Analyzing the condition of rural roads:** Remote sensing makes it possible to analyze the conditions of rural road and infrastructures. This can be performed in great details within a very short span of time at very limited financial cost. It saves a lot of time and money from transporters.
2. **Creating a base map for visual reference:** Nowadays many modern mapping technologies are based on remote sensing, including Google maps, open street maps, Bing maps, NASA's Globe view, etc.
3. **Computing snow pack:** Snow melt ratio can be easily understood by using remote sensing technology. NASA uses LIDAR along with a spectrometer in order to measure the absorption of sunlight.

4. **Collecting earth's pictures from space:** Many space organizations have a collection containing images of the earth. Interesting patterns of earth's geometry including atmosphere, oceans, land, etc. can be seen in it. EO-1, Terra, Landsat, etc., are used to collect these data.
5. **Controlling forest fires:** Information acquired by satellites using remote sensing enables firefighters to be dispatched on time and over correct locations so the damage from such fires can be minimized.
6. **Detecting land use and land cover:** Remote Sensing technologies are used to determine various physical properties of land, as well as what the land is being used for (land use). The specific applications include natural resource and land use classification and management, wildlife habitat monitoring and protection, urban data collection, expansion, planning and mapping, natural resource extraction activities, etc.
7. **Estimating forest supplies:** Forests are a valuable resource provider and it balances the various important earth systems. These functions include source of paper, packaging, construction materials, carbon sink, etc. Various applications of remote sensing in Forestry include collection of forest data and monitoring the forest cover, vegetation types, density and their measurement, and mapping of forests. MODIS, AVHRR, and SPOT are regularly used to measure the increment/decrement in global forests.
8. **Locating construction and building alteration:** Tax revenue agencies use satellite data in several countries. They locate signs of wealth using this technology. Early in the year of 2013, there were 15000 swimming pools (unclaimed to steal taxes) in those countries.
9. **Figuring out fraud insurance claims:** Many insurance companies use Landsat's red and infrared channels to figure out vegetation growth in particular land. This information can be used to verify seeded crops and fight against crop insurance fraud.
10. **Observing climate changes:** Satellites such as CERES, MODIS, AMSRE, TRMM, and MOPITT has made it possible to observe climate changes from up above the skies. It is also possible to compare past climate situation with the current one.
11. **Predicting potential landslides:** Landslides cause noticeable death and wealth loss around the globe. INSAR uses interferometry remote sensing technique for providing an early warning regarding potential landslides.
12. **Oceans and Coastal Monitoring:** This includes ocean current pattern, regional circulation identification and monitoring, Storm forecasting, ocean water temperature, gases, and pressure monitoring, phytoplankton and corals diversity and concentration, fisheries surveillance, marine diversity assessment, oil spills and

its prediction in extent and effects, shipping navigation, routing, and traffic monitoring, coastal vegetation mapping, etc.

13. **Hydrological and Sea Ice applications:** These include river and delta change, flood, and lake ice mapping and their monitoring, drainage basin mapping and watershed modelling, wetland mapping and monitoring, snow pack, ice and its thickness measurement and their monitoring, iceberg and glacier dynamics detection and monitoring, meteorological / global climate change research and pollution monitoring in hydrosphere.
14. **Geological applications of remote sensing:** These include structural mapping, sand and gravel aggregate exploration, mineral exploration, geo-botanical mapping, sedimentation and geo-hazard mapping and their monitoring.
15. **Agriculture:** Agriculture is an important source of income and livelihood in most countries. Satellites and airborne images are used to map, classify the crops and soil, examining and monitoring their healthiness, etc. Agricultural applications include crop classification, crop yield estimation, mapping of soil characteristics and soil management practices, monitoring of the crops and soils, and irrigation scheduling in standing crops.

Application of remote sensing in agriculture include:

1. **Identifying crop conditions:** Satellite imagery and normalized difference vegetation index (NDVI) technologies are used in order to monitor global food supplies.
2. **Increasing precision in farming:** The health of crops can be measured using remote sensing applications, reducing wasteful expenditure on fertilizer, money and time.
3. **Determining the soil moisture content:** Active and passive sensors of satellites in space are used in order to determine soil moisture content. Many earth sciences such as water cycle, flood, and drought are based on the content of soil moisture.
4. **Crop production forecasting:** Remote Sensing is used to predict crop production and yield over a given field and determine how much of the crop will be harvested under specific conditions. The researcher can predict the crop quantity that will be produced in given farmland over a given period of time.
5. **Determining crop damage and crop progress:** In the event of crop damage or crop progress, remote sensing technology can be used to penetrate the farmland and determine exactly how much of a given crop has been damaged and/or is under stress and the progress of the remaining crops in the farm.
6. **Crop identification:** Crop species can also be identified using remote sensing technology. This is more so, when they display unexpected/mysterious features. The location can be ascertained to facilitate sample collection for further studies.

7. **Crop condition analysis and stress detection:** Remote sensing technology plays an important role in the assessment of crop health condition and the extent to which the crop has withstood stress. This data can be then used to determine the quality of the crop.
8. **Drought monitoring:** Remote sensing technology is used to monitor the weather patterns including the drought patterns over a given area. The information is used to forecast the rainfall patterns of an area and also tell the time difference between the current and the next rainfall which can be helpful to keep track of the drought.
9. **Water content determination of the field crop:** Apart from determining the soil moisture content, remote sensing also plays an important role in the estimation of the water content in the field crops.
10. **Crop health analysis:** Health analysis of a crop can also be determined, which helps in determining the overall crop yield.

Self-Assessment Exercise

List five applications of remote sensing technology.

1.3.2 Elements of Remote Sensing

Remote Sensing Systems consist of a number of elements. The elements range from solar radiation to the application of imageries for public problems, through various stages (Figure 6).

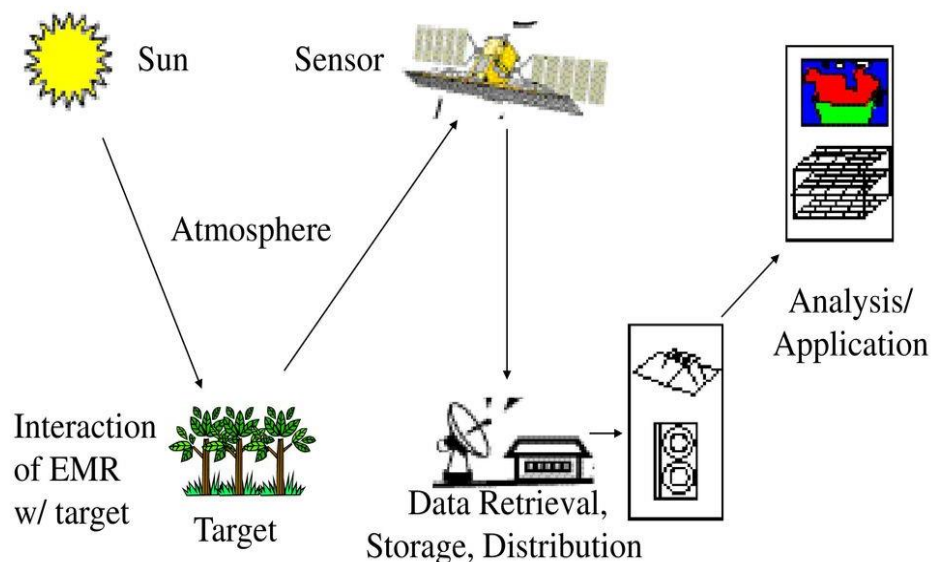


Figure 6: Components of Remote Sensing Systems

1. **Sun as a Source of Energy:** Sun is the prime source of energy to the world. It is the resource for all activities of the life forms.

2. **Emission of Sun's Energy:** Solar energy is emitted into the space. The emission is in the form of various electromagnetic waves. It consists of gamma rays to radio waves (short wave length). This band of rays is called the 'electromagnetic radiation' (EMR).
3. **Interaction of Solar Energy with Atmospheric Elements:** When the solar energy passes through the atmosphere, many elements await to meet the energy. A portion of the '*electromagnetic radiation*' is absorbed by carbon di oxide, ozone, moisture and dust and reflected back. So, the balance of electromagnetic radiation reaches the earth's surface as sunlight.
4. **Interaction of Sunlight with Terrestrial Features:** Electromagnetic waves in sunlight have different wave lengths. A number of bands can be identified based on the wave lengths. These bands of radiation fall on the objects of the earth and get reflected, differently by different objects. The reflectance varies according to the wave length. Through such reflectance, various wave lengths help in remote sensing to identify various elements over the earth. Thus, the spectral reflectance from the earth, in fact earth objects, are of many thousand types.
5. **Terrestrial Radiation of the Earth's Element:** The solar energy, along with the energy already stored in the elements on the earth, are radiated back into the atmosphere. Any object, with a temperature of about 0°K (273°C) will emit energy. Thus, all objects over the earth have temperatures above 0o K and therefore emit energy at varying levels.
6. **Collection of Information/Data:** The energy thus reflected and emitted by the earth's features are recorded by cameras and sensors fitted onto the various platforms. The cameras record the energy in films and the sensors convert the energy into electrical signals and send them to the earth's receiving stations.
7. **Data Acquisition by the Earth Station:** The electrical pulses from the remote sensors are converted into 'digital' numbers. Each point or picture element gets different (pixel) digital numbers. Thus, a satellite image is composed different digital values or pixels.
8. **Interpretation and Analysis:** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
9. **Application:** - The final element of the remote sensing process is achieved when we apply the information, we extracted from the imagery of the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

Self-Assessment Exercise

List five elements of remote sensing.

1.3.3 Advantages and Limitations of Remote Sensing

The sun is the major source of energy, radiation and illumination. At any given moment the sun is bombarding the earth with a variety of wavelengths of electromagnetic radiation, including visible light, infrared, radio and microwaves. Detection and discrimination of surface features means detecting and recording of radiant energy reflected or emitted by surface.

Different features return different amount and kind of energy in different bands of the electromagnetic spectrum, incident upon it. This unique property depends on the property of material (structural, chemical and physical), surface roughness, angle of incidence, intensity and wavelength of radiant energy. Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation.

These spectral characteristics, if ingeniously exploited, can be used to distinguish one thing from another or to obtain information about shape, size and other physical and chemical properties. Thus, to understand remote sensing, it is important to first understand the basics of electromagnetic radiation (EMR).

1.3.3.1 Advantages of Remote Sensing

1. Remote sensing can cover and identify very large areas in less time.
2. Remote sensing is an inexpensive and constructive method for creating maps
3. Remote sensing makes data collection over a variety of scales and resolutions easy.
4. There is no limitation on the amount of data that can be collected from a single remotely sensed image.
5. Remotely sensed data can be processed and analyzed using GIS tools and that data can be utilized for various application.
6. Passive remote sensing does not disturb or affect the targeted object.
7. Large data can be collected through remote sensing which minimizes the extent and magnitude of fieldwork required.
8. Remote sensing can repeat coverage over course of time.
9. It is easier to monitor floods, earthquakes, volcanic eruptions, storms or forest fire using remote sensing.

1.3.3.2 Limitations of Remote Sensing

1. Remote sensing is expensive for smaller or specific areas.

2. Remote sensing needs special trained personnel to use this technology.
3. Powerful electromagnetic radiation (EMR) used in active remote sensing systems may affect the target.
4. The image may sometimes be affected by other phenomena and introduce error to the result.
5. It is easier to introduce human error during data collection and calibration.
6. Different models need to be prepared regularly to gain precision and preparation of models is sometimes time consuming.
7. The information provided by remote sensing data may not be complete and may be temporary and need to be corrected regularly.

Self-Assessment Exercise

List four advantages and four limitations of remote sensing.
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1.4 Conclusion

Remote sensing is a technology that is very essential to the effective survey of soils, landscape and ecosystem. This technology has immense agricultural, environmental and natural resources assessment, monitoring, mapping and other allied applications. The free availability of much of these data is also an added advantage as it will inform sustainable natural resources use and management.

1.5 Summary

From this unit, you have learnt about the remote sensing concept. Some of the key things learnt include the following;

- Remote sensing and its applications
- Elements of remote sensing
- Advantages and limitations of remote sensing

1.6 Tutor-Marked Assignment

1. What is remote sensing?
2. List five agricultural and five non-agricultural applications of remote sensing.
2. Briefly describe the elements of remote sensing.

1.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The

International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. *Agri-India TODAY* 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List five applications of remote sensing technology.
 - i) *Analyzing the condition of rural roads*
 - ii) *Locating construction and building alteration*
 - iii) *Oceans and coastal monitoring*
 - iv) *Drought monitoring*
 - v) *Increasing precision in farming*
2. List five elements of remote sensing.
 - i) *Sun as a Source of Energy*
 - ii) *Emission of Sun's Energy*
 - iii) *Interaction of Solar Energy with Atmospheric Elements*
 - iv) *Interaction of Sunlight with Terrestrial Features*
 - v) *Terrestrial Radiation of the Earth's Element*

3. List four advantages and four limitations of remote sensing.

<i>SN</i>	<i>Advantages</i>	<i>Limitations</i>
a.	<i>Remote sensing can cover and identify very large areas in less time.</i>	<i>Remote sensing is expensive for smaller or specific areas.</i>
b.	<i>Remote sensing is an inexpensive and constructive method for creating maps</i>	<i>Remote sensing needs special trained personnel to use this technology.</i>
c.	<i>Remote sensing makes data collection over a variety of scales and resolutions easy.</i>	<i>Powerful electromagnetic radiation (EMR) used in active remote sensing systems may affect the target.</i>
d.	<i>There is no limitation on the amount of data that can be collected from a single remotely sensed image.</i>	<i>The image may sometimes be affected by other phenomena and introduce error to the result.</i>

UNIT 2 THE ELECTROMAGNETIC SPECTRUM

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Electromagnetic Radiation
 - 2.3.2 Electromagnetic Spectrum
 - 2.3.3 Electromagnetic Radiation Quantities
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

Electromagnetic energy is the foundation of remote sensing. It is the energy source required to transmit information from the target to the sensor. Electromagnetic radiation is one of the fundamental forms of energy in the universe, which consists of an electric wave and a magnetic wave at right angles, both perpendicular to the direction of propagation. Electromagnetic energy is a crucial medium that is described as an electromagnetic spectrum, which consists of many of the basic forms of energy in the universe. On this spectrum, many forms exist that describe energy in a specific region of the electromagnetic spectrum. These are visible light, radio-waves, microwaves, infra-red, ultraviolet rays, x-rays and gamma rays. Humans only see within the visible light region of the electromagnetic spectrum (red, green and blue). They cannot see x-rays, infrared, ultraviolet, etc. The human eyes (as well as the eyes of most animals) are the first known remote sensors, as they can observe and evaluate an object without being in direct contact with the object simply by capturing and interpreting signals received via the light reflected off the target object. That is how we manage to see things. As such, it is the sense of sight that is replicated by humans in the form of remote sensing, with the extended ability to sense beyond just the visible light. However, not all regions of the electromagnetic spectrum are used in remote sensing, like, gamma rays, x-rays and radio waves.

2.2 Objectives

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

- Describe the electromagnetic spectrum
- Outline the parts of the electromagnetic spectrum used in remote sensing

2.3 Main Content

2.3.1 Electromagnetic Radiation

Electromagnetic radiation is one of the fundamental forms of energy in the universe. It consists of an electric wave (E) and a magnetic wave (M) at right angles, both perpendicular to the direction of propagation (Figure 7).

Electromagnetic radiation is a dynamic form of energy that propagates as wave motion at a velocity of light (C).

$C = 3 \times 10^{10}$ (m/s) (where C = speed of light, m = meter, s = seconds)

Electromagnetic energy radiates in accordance with the basic wave theory. This theory describes the Electromagnetic energy as traveling in a harmonic sinusoidal fashion at the velocity of light.

$$c = f \times \lambda$$

(Where, f is frequency, λ is wavelength and c is velocity)

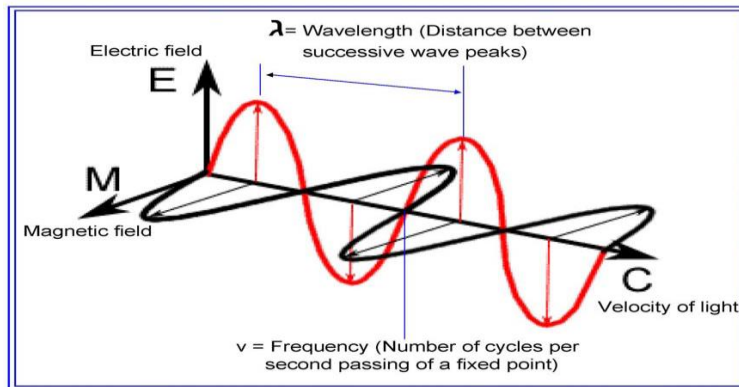


Figure 7: Schematic diagram of electromagnetic radiation

Although many characteristics of electromagnetic energy are easily described by wave theory, another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that Electromagnetic radiation is composed of many discrete units called photons/quanta. The energy of quantum is:

$$Q = h \times \frac{c}{\lambda}$$

(Where Q is the energy of quantum, h is plank's constant)

Hence, from equation 1

$$Q = \frac{h \times f}{3} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots$$

Self-Assessment Exercise

Outline the formulae for computing the speed of light and quantum energy.

2.3.2 Electromagnetic Spectrum

Electromagnetic energy is the energy source required to transmit information from the target to the sensor. It is a crucial medium that is described as an electromagnetic spectrum (Figure 8). Many of the basic forms of energy in the universe are related as part of the electromagnetic spectrum. On this spectrum, many forms exist that describe energy in a specific region of the electromagnetic spectrum. These are visible light, radio-waves, microwaves, infra-red, ultraviolet (uv) rays, x-rays and gamma rays.

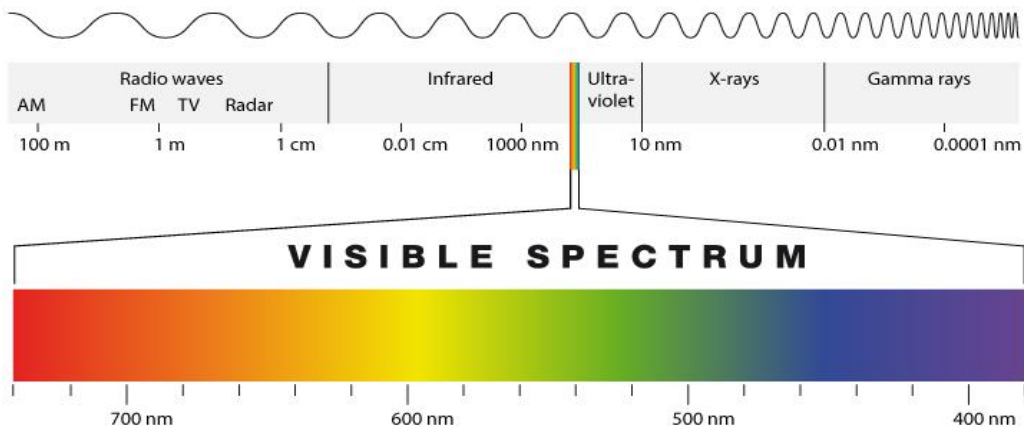


Figure 8: Electromagnetic spectrum

This spectrum is an overview of the continuum of electromagnetic energy from extremely short wavelengths (cosmic gamma rays) to extremely long wavelengths (radio and television waves). Note that as the wavelengths of energy decrease, the frequency increases. These divisions are not absolute and definite; overlapping may occur (Table 1).

Table 1: Divisions of the electromagnetic spectrum and their application in remote sensing

Region Name	Wavelength	Comments
Gamma Ray	< 0.03 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
X-ray	0.03 to 30 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
Ultraviolet	0.03 to 0.4 micrometers	Wavelengths from 0.03 to 0.3 micrometers absorbed by ozone in the Earth's atmosphere.
Photographic Ultraviolet	0.3 to 0.4 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Visible	0.4 to 0.7 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Reflected Infrared	0.7 to 3.0 micrometers	Available for remote sensing the Earth. Near Infrared 0.7 to 0.9 micrometers. Can be imaged with photographic film.
Thermal Infrared	3.0 to 14 micrometers	Available for remote sensing the Earth. This wavelength cannot be captured with photographic film. Instead, sensors are used to image this wavelength band.
Microwave or Radar	0.1 to 100 centimeters	Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that actively emit microwaves.
Radio	> 100 centimeters	Not normally used for remote sensing the Earth.

Self-Assessment Exercise

List the electromagnetic spectrum regions that are not normally used in remote sensing.

2.3.3 Electromagnetic Radiation Quantities

- **Radiant energy (Q)** is the energy carried by electromagnetic radiation. Radiant energy causes the detector element of the sensor to respond to electromagnetic radiation in some appropriate manner. Unit of Radiant Energy Q is Joule.
- **Radiant Flux (Φ) (Phi)** is the time rate of the flow of radiant energy. Unit of Radiant flux is Joule/Second or Watt (W).
- **Irradiance (E)** is the Radiant flux intercepted by a plane surface per unit area of the surface. It arrives at the surface from all

directions within a hemisphere over the surface. Unit of Irradiance E is W/m^2 or Wm^{-2} (Watt per square meter).

- **Radiance (L)** is defined as the radiant flux per unit solid angle (leaving an extended source in a given direction) per unit projected area of the source in that direction. The concept of radiance is intended to correspond to the concept of brightness. The projected area in a direction which makes an angle θ (Theta) with the normal to the surface of area A is $A\cos\theta$. Unit for Radiance is $\text{Wm}^{-2}\text{sr}^{-1}$.
- **Spectral Reflectance ($\rho(\lambda)$)** is the ratio of reflected energy to incident energy as a function of wavelength.
- **Spectral Signature** are the values of the spectral reflectance of objects averaged over different, well defined wavelength intervals. Using the spectral signature as a diagnostic feature, objects or features can be distinguished from each other.

Self-Assessment Exercise

List five electromagnetic radiation quantities.

2.4 Conclusion

For different reasons, certain regions of the electromagnetic spectrum are not available for remote sensing. These regions include the gamma rays, x-rays and radio waves. Further assessment indicates that even within the regions that are available for remote sensing, specific wavelength intervals are either blocked or absorbed in the atmosphere before it gets to the target. These need to be evaluated further, in line with what is regarded as the atmospheric window.

2.5 Summary

From this unit, you have learnt about the electromagnetic spectrum. Some of the key things learnt include the following;

- Electromagnetic radiation
- Electromagnetic spectrum
- Electromagnetic radiation quantities

2.6 Tutor-Marked Assignment

1. Write short notes on
 - a) Electromagnetic radiation
 - b) Electromagnetic spectrum
2. List five electromagnetic radiation quantities and describe two.

2.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

2.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Outline the formulae for computing the speed of light and quantum energy.

$$c = f \times \lambda$$

(Where, f is frequency, λ is wavelength and c is velocity = 3×10^{10})

$$Q = h \times \frac{c}{\lambda}$$

(Where Q is the energy of quantum, h is plank's constant)

2. List the electromagnetic spectrum regions that are not normally used in remote sensing.

i) Gamma rays (< 0.03 nm)

ii) X-rays (0.03 – 30 nm)

iii) Ultraviolet radiations (30 – 300 nm) iv) Radio waves (> 100 cm)

3. List five electromagnetic radiation quantities.

i) Radiant energy (Q)

ii) Radiant Flux (Φ) (Φ)

iii) Irradiance

(E) iv) Radiance (L)

v) Spectral Reflectance

UNIT 3 INTERACTION OF ELECTROMAGNETIC RADIATION WITH THE ATMOSPHERE AND THE EARTH SURFACE

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3 Main Content
 - 3.3.1 Interaction of Electromagnetic Radiation with the Atmosphere
 - 3.3.2 Interaction of Electromagnetic Radiation with the Earth Surface
 - 3.3.3 Data Detection and Output
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

We see an object with our eyes because light energy from the sun, the moon or an electric lamp interacts with the target object, and are reflected towards us. Our eyes capture the reflected light, enabling our brain to interpret the data and draw conclusions. It is noteworthy that once light interacts with an object, the nature of the light is changed, implying that the nature of the light that our eyes capture is different from that of the original light that hit the object. It is this change that enable us to see and understand that different objects differ from each other. For instance, when you have a black and white object lying side by side in the dark, and you shine a torchlight on them, they will get the same or similar amount of light, but you will see two different things. This is because the black object absorbed all the light that hit it, enabling you to see black, while the white object reflected all radiations, enabling you to see the white. If the object appeared red, then this means that it absorbed the blue and green sections of the visible light and reflected red, which is why your eyes see red. With these at the back of your mind, in this unit you will learn how electromagnetic radiation interacts with both the atmosphere and the objects on the earth surface, enabling the remote sensing process.

3.2 Objectives

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

- Discuss the interaction between electromagnetic radiation and the atmosphere
- Discuss the interaction between electromagnetic radiation and the earth surface

3.3 Main Content

3.3.1 Interaction of Electromagnetic Radiation with the Atmosphere

The sun is the source of radiation; and electromagnetic radiation (EMR) from the sun that is reflected by the earth and detected by the satellite or aircraft-borne sensor must pass through the atmosphere twice, once on its journey from the sun to the earth and once after being reflected by the surface of the earth back to the sensor. Interactions of the direct solar radiation and reflected radiation from the target with the atmospheric constituents interfere with the process of remote sensing and are called as “Atmospheric Effects”.

The atmospheric constituents scatter and absorb the radiation, modify the radiation reflected from the target by attenuating it. Both scattering and absorption vary in their effect from one part of the spectrum to the other. The solar energy is subjected to modifications by several physical process as it passes the atmosphere, viz. scattering, absorption and refraction.

- **Atmospheric Scattering:** Scattering is the redirection of electromagnetic radiation by particles suspended in the atmosphere or by larger molecules of atmospheric gases or water vapor. The amount of scattering depends upon the size and abundance of particles, the wavelength of radiation and depth of the atmosphere through which the energy is traveling which varies both in time and over season thus scattering will be uneven spatially and will vary from time to time. Scattering reduces image contrast and changes spectral signature of ground objects as seen by the sensor.
- **Atmospheric Absorption:** The gas molecules present in the atmosphere strongly absorb the electromagnetic radiation passing through the atmosphere in certain spectral bands. Mainly three gases are responsible for most of the absorption of solar radiation, viz. ozone, carbon dioxide and water vapor. Absorption relatively reduces the amount of light that reaches our eye making the scene look relatively duller.
- **Atmospheric Windows:** The atmosphere selectively transmits energy of certain wavelengths. The spectral bands for which the

atmosphere is relatively transparent are known as “Atmospheric Windows”. In the visible part transmission is mainly affected by ozone absorption and by molecular scattering.

- **Refraction:** The phenomenon of refraction that is bending of light at the contact between two media also occurs in the atmosphere as the light passes through the atmospheric layers of varied clarity, humidity and temperature.

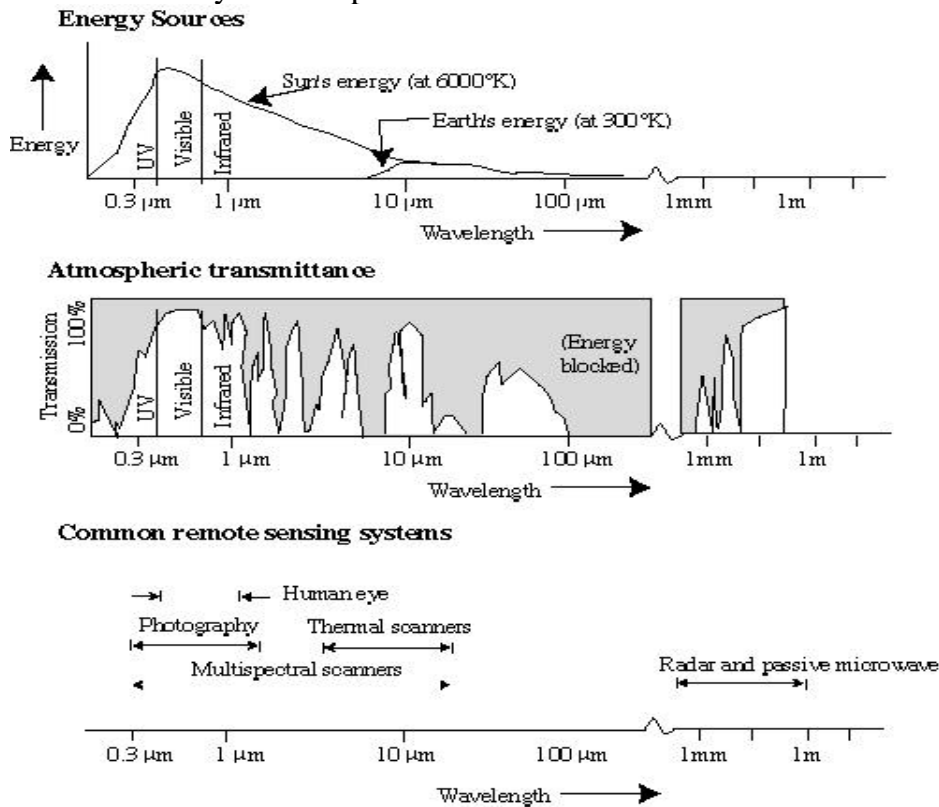


Figure 9: Dynamics of the electromagnetic spectrum

Self-Assessment Exercise

List four classes of interaction between electromagnetic radiations with the atmosphere.

3.3.2 Interaction of Electromagnetic Radiation with the Earth Surface

Radiation from the sun, when incident upon the earth’s surface, is either reflected by the surface, transmitted into the surface or absorbed and emitted by the surface. The electromagnetic radiation, on interaction, experiences a number of changes in magnitude, direction, wavelength, polarization and phase. These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, colour and spectral signature). The spectral band from 0.3 μm to 3 μm is known as the

reflective region. In this band, the radiation sensed by the sensor is that due to the sun, reflected by the earth's surface.

- **Reflection:** Of all the interactions in the reflective region, surface reflections are the most useful and revealing in remote sensing applications. Reflection occurs when a ray of light is redirected as it strikes a non-transparent surface. The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence and reflection.
- **Transmission:** Transmission of radiation occurs when radiation passes through a substance without significant attenuation. For a given thickness, or depth of a substance, the ability of a medium to transmit energy is measured as transmittance (τ). $\tau = \text{transmitted radiation/incident radiation}$.

Self-Assessment Exercise

List four classes of interaction between electromagnetic radiations with the earth surface.

3.3.3 Data Detection and Output

The most important component of a remote sensing is the sensor/detector, which records the variation of radiant energy reflected or emitted by objects or surface material. Different types of sensors are sensitive to different parts of the electromagnetic spectrum. The function of recording system is to convert the energy detected by sensor into a form which can be perceived. This is done by dividing the incoming energy by beam splitters and filters into different wavelength bands and then converting energy in each wavelength band into electrical signal. The electrical signal is processed to give radiometric data for each band, which is recorded in digital format.

Self-Assessment Exercise

What is the most important component of remote sensing?

3.4 Conclusion

The solar energy is subjected to modifications by several physical process as it passes the atmosphere, viz. scattering, absorption and refraction. On the other hand, the radiation sensed by the sensor after sunlight has interacted with the target object is moderated by reflection, transmission and/or absorption. The sensor/detector is the most important component of a remote sensing as it records the variation of radiant energy reflected or emitted by objects enabling its assessment and evaluation.

3.5 Summary

From this unit, you have learnt about the interaction of electromagnetic radiation with the atmosphere and the earth surface. Some of the key things learnt include the following;

- Interaction of electromagnetic radiation with the earth surface
- Interaction of electromagnetic radiation with the atmosphere

3.6 Tutor-Marked Assignment

1. Discuss the interactions between electromagnetic radiations and
 - a) the atmosphere.
 - b) the earth surface.

3.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

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Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List four classes of interaction between electromagnetic radiations with the atmosphere.
i) Atmospheric scattering ii) Atmospheric absorption
iii) Atmospheric Transmission iv) Refraction
2. List four classes of interaction between electromagnetic radiations with the earth surface.
i) Reflection ii) Absorption iii) Transmission iv) Emission
3. What is the most important component of remote sensing?
The most important component is the sensor/detector, which records the variation of radiant energy reflected or emitted by objects or surface material.

UNIT 4 TYPES OF REMOTE SENSING

Unit Structure

- 4.1 Introduction
- 4.2 Objectives
- 4.3 Main Content
 - 4.3.1 Types of Remote Sensing
 - 4.3.2 Types of Remote Sensors
 - 4.3.2.1 Classification Based on the Mode of Operation and the Output
- 4.4 Conclusion
- 4.5 Summary
- 4.6 Tutor-Marked Assignment
- 4.7 References/Further Reading/Web Resources
- 4.8 Possible Answers to Self-Assessment Exercise(s) within the content

4.1 Introduction

Remote sensing can be viewed different perspectives. In terms of the types of remote sensing, we have three types, namely, optical (visible and reflective infrared), thermal infrared and microwave remote sensing. Sensors can be looked at from two perspectives, viz: mode of operation and the output (imaging and non-imaging sensors) and source of the electromagnetic radiation (active and passive sensors). The remote sensing platform on their parts can be classified into, ground-based platforms, air-borne platforms and satellites.

4.2 Objectives

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

- Describe the types of remote sensing
- Enumerate and describe the types of remote sensors
- Enumerate and describe the types of remote sensing platforms

4.3 Main Content

4.3.1 Types of Remote Sensing

Remote sensing can be broadly classified into three types with respect to the wavelength region and type of sensor involved for data acquisition; viz. Optical (Visible and Reflective Infrared), Thermal Infrared and Microwave.

- **Optical Remote Sensing:** This involves the use of visible part of the electromagnetic spectrum. Energy emitted from the sun is used for visible and reflective infrared remote sensing. The International Commission on Illumination has defined the visible spectrum to be from 0.38 to 0.79 μm . The human eye has its peak sensitivity at 0.55 microns, which is approximately the peak of the emission curve of the sun. Remote sensing data obtained in the visible and reflective infrared regions mainly depends on the reflectance of objects on the ground surface. Therefore, information about objects can be obtained from the spectral reflectance.
- **Thermal Infrared Remote Sensing:** The source of radiant energy used in thermal infrared remote sensing is the object itself. This is because any object with a temperature above absolute zero (i.e., 0 K, or -273°C) emits electromagnetic radiation, usually with a peak at about 10 μm .
- **Microwave Remote Sensing:** In microwave region, there are two types of microwave remote sensing, passive and active. In passive microwave remote sensing, the microwave radiation emitted from an object is detected. With regards to active microwave remote sensing, the source of electromagnetic radiations and the detector are placed on the sensor.

Self-Assessment Exercise

List the different types of remote sensing.

4.3.2 Types of Remote Sensors

4.3.2.1 Classification Based on The Mode of Operation and the Output

The common remote sensing systems are of two types, Imaging (image forming) and non-Imaging (non-image forming). Image-forming systems are again of two types, framing type and scanning type.

- **Imaging Sensors:** Data from these sensors can be processed to produce an image of an area, within which smaller parts of the sensor's whole view are resolved visually.
- **Framing systems are those that snap an image**, much like a common film camera or a digital camera. An image is formed on a focal plane and stored via chemical or electronic means.

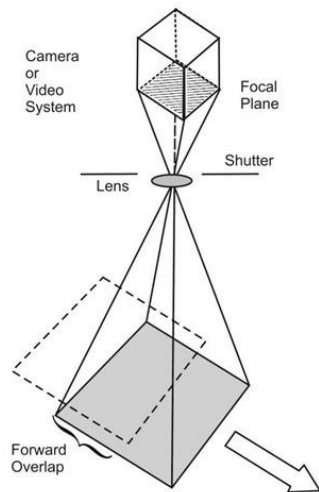


Figure 10: Framing sensor

- **Scanning systems** (like those on the Landsat Satellite System) consist of a small number of detectors—from one to 32. The sensor is swept from side to side, typically via an oscillating mirror, while the system flies along a track. The image is built up by the combined motion of the optic and the platform (aircraft or satellite). Such sensors are called "whiskbroom" sensors.

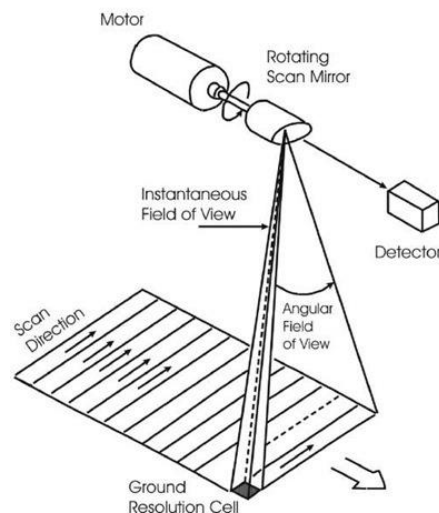


Figure 11: Scanning sensor

Non-imaging Sensors: These are usually hand-held devices that register only a single response value, with no finer resolution than the whole area viewed by the sensor, and therefore no image can be made from the data. These single values can be referred to as a type of "point" data.

4.3.2.2 Classification Based on the Source of The Electromagnetic Radiation

A sensor is the device that gathers energy (EMR or others), converts it into a signal and presents it in a form suitable for obtaining information

about the target under investigation. Sensors used for remote sensing can be broadly classified into passive and active depending on the source of energy.

- **Active sensors** use their own source of energy to illuminate earth surface and a part of it is reflected and received to gather information.
- **Passive sensors** do not have their own source of energy. Instead, they receive solar electromagnetic energy reflected from the target surface or energy emitted from the surface itself. Hence, with the exception of thermal sensors, passive sensors cannot be used at night time. Energy that is naturally emitted (e.g., thermal energy) can be detected day or night, as long as the amount of energy is large enough to be recorded.

Self-Assessment Exercise

List the classes of remote sensors based on

- a) Mode of operation and the output
- b) Source of the electromagnetic radiation

4.3.3 Types of Remote Sensing Platforms

Platforms refer to the structures or vehicles on which remote sensing instruments are mounted (Figure 12). The platform on which a particular sensor is housed determines a number of attributes, which may dictate the use of particular sensors. These attributes include: distance the sensor is from the object of interest, periodicity of image acquisition, timing of image acquisition, and location and extent of coverage. There are three broad categories of remote sensing platforms: ground based, airborne, and satellite.

- **Ground based:** A wide variety of ground-based platforms are used in remote sensing. Some of the more common ones are hand held devices, tripods, towers and cranes. Instruments that are ground-based are often used to measure the quantity and quality of light coming from the sun or for close range characterization of objects. For example, to study properties of a single plant or a small patch of grass, it would make sense to use a ground-based instrument.
- **Airborne:** Airborne platforms were the sole non-ground-based platforms for early remote sensing work. The first aerial images were acquired with a camera carried aloft by a balloon in 1859. Balloons are rarely used today because they are not very stable and the course of flight is not always predictable, although small balloons carrying expendable probes are still used for some meteorological research.

At present, airplanes are the most common airborne platform. Nearly the whole spectrum of civilian and military aircrafts are used for remote sensing applications. When altitude and stability requirements for a sensor are not too demanding, simple, low-cost aircraft can be used as platforms. However, as requirements for greater instrument stability or higher altitudes become necessary, more sophisticated aircraft must be used.

Helicopters are usually used for low altitude applications where the ability to hover is required. Helicopters are quite expensive to operate and they are typically used only when needed. Nevertheless, the recent introduction of unmanned aerial vehicles (UAV), also called drones, has greatly improved the acquisition of high-quality aerial photographs at relatively cheaper costs.

- **Satellite:** The most stable platform aloft is a satellite, which is space-borne. The first remote sensing satellite was launched in 1960 for meteorology purposes. Now, over a hundred remote sensing satellites have been launched and more are being launched every year. The Space Shuttle is a unique spacecraft that functions as a remote sensing satellite and can be reused for a number of missions. Satellites can be classified by their orbital geometry and timing. Two orbits commonly used for remote sensing satellites are geostationary and Sun-synchronous.
- **Geostationary Satellites:** These have a period of rotation equal to that of Earth (24 hours) so the satellite always stays over the same location on Earth. Communications and weather satellites often use geostationary orbits with many of them located over the equator. The Space Shuttle uses an equatorial orbit with an inclination of 57 degrees.
- **Sun Synchronous Satellites:** These have orbits with high inclination angles, passing nearly over the poles. Orbits are timed so that the satellite always passes over the equator at the same local sun time. In this way the satellites maintain the same relative position with the sun for all of its orbits. Many remote sensing satellites are Sun synchronous which ensures repeatable sun illumination conditions during specific seasons. Because a Sun synchronous orbit does not pass directly over the poles, it is not always possible to acquire data for the extreme Polar Regions. The frequency at which a satellite sensor can acquire data of the entire Earth depends on sensor and orbital characteristics.

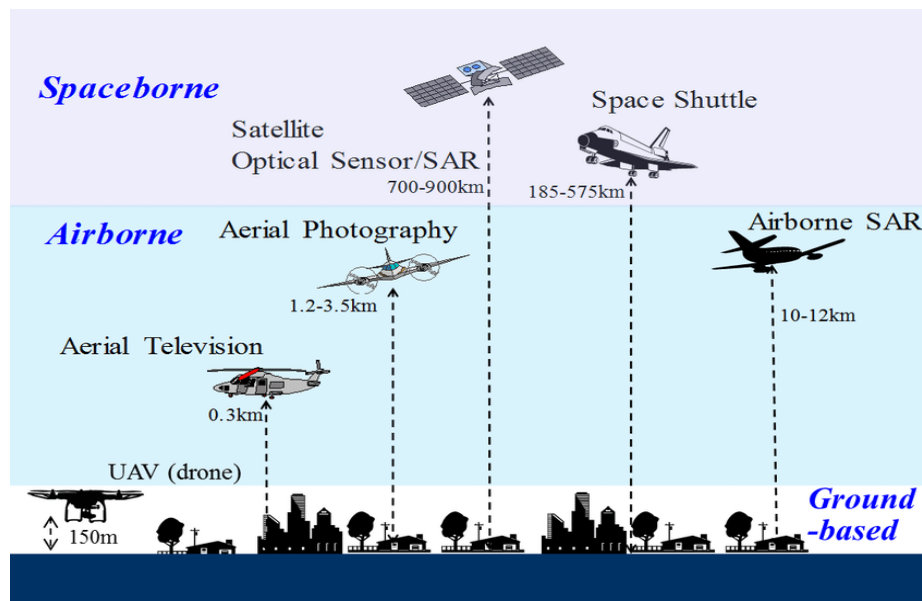


Figure 12: Remote sensing platforms

Self-Assessment Exercise

List the three types of remote sensing platforms.

4.4 Conclusion

Each of these platforms and/or sensors have their advantages and limitations. However, the shortcomings of one may be the strong points of the other. For instance, satellite imageries usually have cloud cover issues which make them unreliable in the humid tropics where cloud cover is usually persistent and dense; but it supports continuous data collection without stoppage, which makes them very good for monitoring change. Drone images are, on their parts, cloudless as they are flown below the cloud, and the researcher is at liberty to select the best possible time for data capture; however, it is impossible to fly a drone non-stop, as is possible for satellites. Data from different sources can consequently be complementary. As such air-borne sensor data generated from drones, when used in tandem with satellite imageries, will provide more useful and accurate information than would have been acquired when only one data source is used.

4.5 Summary

From this unit, you have learnt about the types of remote sensing. Some of the key things learnt include the following;

- Types of remote sensing
- Types of remote sensors
- Types of remote sensing platforms

4.6 Tutor-Marked Assignment

1. List the types of remote sensing
2. Classify remote sensors based on the source of the electromagnetic radiation.
3. Briefly discuss the types of remote sensing platforms.

4.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

4.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List the different types of remote sensing.
 - i) Optical (Visible and Reflective Infrared) remote sensing*
 - ii) Thermal (Infrared) remote sensing*
 - iii) Microwave remote sensing*
2. List the classes of remote sensors based on
 - a) Mode of operation and the output
 - i) Imaging sensors* *ii) Non-imaging sensors*
 - b) Source of the electromagnetic radiation
 - i) Active sensors* *ii) Passive sensors*
3. List the three types of remote sensing platforms.
 - i) Ground-based platforms* *iii) Air-borne platforms* *iii) Space-borne platforms*

UNIT 5 ELEMENTS OF IMAGE INTERPRETATION

Unit Structure

- 5.1 Introduction
- 5.2 Objectives
- 5.3 Main Content
 - 5.3.1 Human Vision
 - 5.3.1.1 Interpretation Elements
 - 5.3.2 Stereoscopic Vision
- 5.4.0 Conclusion
- 5.5 Summary
- 5.6 Tutor-Marked Assignment
- 5.7 References/Further Reading/Web Resources
- 5.8 Possible Answers to Self-Assessment Exercise(s) within the content

5.1 Introduction

Qualitative principles of remote sensed data analysis underscore information extraction based on visual image analysis or interpretation of the data. This is the most intuitive way to extract information from remote sensing images. It is based on man's ability to relate colours and patterns in an image to real world features. This can be viewed from the perspective of human vision (the ability of a person to draw conclusions from visual observations) and stereoscopic vision (viewing two images that are separated so that the left sees the left image and the right eye sees the right image, enabling the perception of a 3-D image from the photographs). The method used depends on the kinds of information that the researcher wants to extract from the photographs. In terms of image interpretation, the interpretation elements of note are tone/hue, texture, shape, size, pattern, site and association. These would be treated in greater details in this section

5.2 Objectives

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

Discuss the elements of image interpretation

5.3 Main Content

5.3.1 Human Vision

Human vision goes a step beyond perception of colour: it deals with the ability of a person to draw conclusions from visual observations. In analyzing a picture, typically you are somewhere between the following two situations: direct and spontaneous recognition, or using several clues to draw conclusions by a reasoning process (logical inference).

Spontaneous recognition refers to the ability of an interpreter to identify objects or phenomena at first glance. From Figure 13, an agronomist would immediately recognize the pivot irrigation systems with their circular shape. The agronomist would be able to do so because of earlier (professional) experience. Similarly, most people can directly relate an aerial photo to their local environment. The quote from people that are shown an aerial photograph for the first time “I see because I know” refers to spontaneous recognition.



Figure 13: Satellite image of an area in Spain (circular features are pivot irrigation systems).

Logical inference means that the interpreter applies reasoning. In the reasoning the interpreter will use his/her professional knowledge and experience. Logical inference is, for example, concluding that a rectangular shape is a swimming pool because of its location in a garden and near to a house. Sometimes, logical inference alone cannot help in image interpretation, so that field observations are required. Consider the aerial photograph in Figure 14. Would you be able to interpret the material and function of the white mushroom-like objects? A field visit would be required for most people to relate the different features to elements of a house or settlement.



Figure 14: Mud huts of Labbezanga near the Niger river. Photo by Georg Gerster, 1972.

Self-Assessment Exercise

How does one use human vision to analyze a picture?

5.3.1.1 Interpretation Elements

When dealing with image data, visualized as photograph, a set of terms is required to express and define characteristics present in a photograph. These characteristics are called interpretation elements and are used, to define interpretation keys, which provide guidelines on how to recognize certain objects. The following interpretation elements are distinguished: tone/hue, texture, shape, size, pattern, site and association.

- **Tone** refers to the relative brightness or colour of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Variations in tone also allow the elements of shape, texture, and pattern of objects to be distinguished.
- **Shape** refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural targets, while natural features are generally more irregular in shape.
- **Size** of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. A quick approximation of target size can direct interpretation to an appropriate result more quickly.
- **Pattern** refers to the spatial arrangement of visibly discernible objects. Typically, an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern.

- **Texture** refers to the arrangement and frequency of tonal variation in particular areas of an image. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation.
- **Shadow** is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings.
- **Association** takes into account the relationship between other recognizable objects or features in proximity to the target of interest. The identification of features that one would expect to associate with other features may provide information to facilitate identification.
- **Site** relates to the topographic or geographic location. A typical example of this interpretation element is that backswamps can be found in a floodplain but not in the centre of a city area. Similarly, a large building at the end of a number of converging railroads is likely to be a railway station—we would not expect a hospital at this site.

Having introduced these interpretation elements you may have noticed a relation with the spatial extent of the feature to which they relate.

- Tone or hue can be defined for a single pixel;
- Texture is defined for a neighboring group of pixels, not for single pixels.
- The other interpretation elements relate to individual objects or a combination of objects.

The simultaneous and often implicit use of all these elements is the strength of visual image interpretation.

In standard image classification only 'hue' is applied, which explains the limitations of automated methods compared to visual image interpretation.

Self-Assessment Exercise

List five elements of image interpretation.

5.3.2 Stereoscopic Vision

The impression of depth encountered in the real world can also be realized by images of the same object that are taken from different positions. Such a pair of images (photographs or digital images) is separated and observed at the same time by both eyes. These give images on the retinas of the viewer's eyes, in which objects at different positions in space are

projected on relatively different positions. We call this stereoscopic vision. Pairs of images that can be viewed stereoscopically are called stereograms. Stereoscopic vision is explained here because the impression of height and height differences is important in the interpretation of both natural and man-made features from image data. Under normal conditions the human eye can focus on objects between 150mm distance and infinity. In doing so we direct both eyes to the object (point) of interest. This is known as convergence, and is how humans normally see in three dimensions. To view the stereoscopic model formed by a pair of overlapping photographs, the two images have to be separated so that the left and right eyes see only the left and right photographs, respectively. In addition, one should not focus on the photo itself but at infinity.

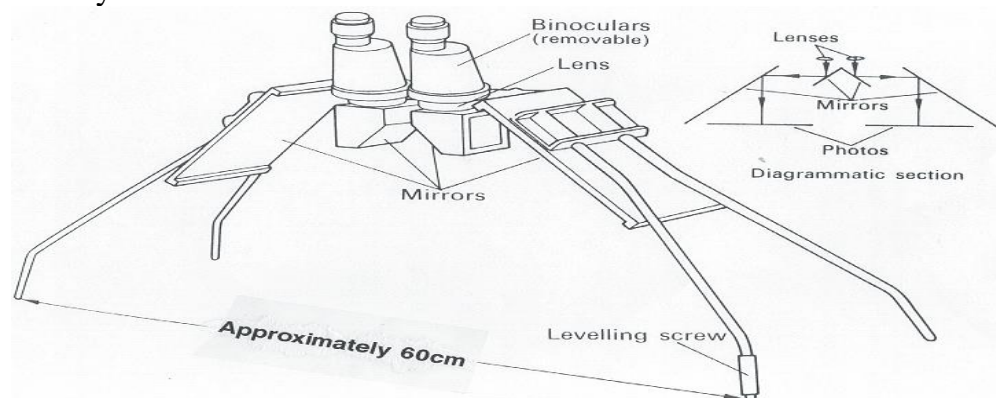


Figure 15: The mirror stereoscope enables stereoscopic vision of stereograms. Each photo is projected only onto one eye.

Self-Assessment Exercise

What is the major application of stereoscopic vision in image classification?

5.4 Conclusion

Visual image interpretation of a satellite imagery or an aerial photograph requires the use of image tone/hue, texture, shape, size, pattern, site and association to manually delineate the boundaries evident in the image. On the other hand, if variation in elevation or altitude is required for the boundary delineation operation, stereoscopic vision has to be employed, requiring the use of instruments called stereoscopes. It is however, noteworthy that these operations are cumbersome, time-consuming and subjective. They also require a good background knowledge of the site and the processes/features under observation. Digital image classification (using a computer and GIS software) enables us to automate this process. It should however be noted that unlike visual image interpretation, standard image classification uses only 'hue' in boundary delineation. This is the major limitation of automated methods.

5.5 Summary

From this unit, you have learnt about the elements of image interpretation. Some of the key things learnt include the following;

- Human vision
- Stereoscopic vision
- Interpretation elements

5.6 Tutor-Marked Assignment

1. Write short notes on
 - a) Human vision
 - b) Stereoscopic vision.
2. Briefly describe five elements of image interpretation.

5.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

5.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. How does one use human vision to analyze a picture?
By employing the techniques of
i) Spontaneous recognition ii) Logical inference
2. List five elements of image interpretation.
i) Tone ii) Shape iii) Size iv) Pattern v) Texture
3. What is the major application of stereoscopic vision in image classification?
To get the impression of height and height differences.

UNIT 6 DIGITAL IMAGE CLASSIFICATION

Unit Structure

- 6.1 Introduction
- 6.2 Objectives
- 6.3 Main Content
 - 6.3.1 Principle of image classification
 - 6.3.1.1 Image space
 - 6.3.1.2 Feature space
 - 6.3.2 Image classification
 - 6.3.2.1 Image classification process
- 6.4 Conclusion
- 6.5 Summary
- 6.6 Tutor-Marked Assignment
- 6.7 References/Further Reading/Web Resources
- 6.8 Possible Answers to Self-Assessment Exercise(s) within the content

6.1 Introduction

Visual image interpretation is qualitative in nature. On the other hand, quantitative principles of remote sensed data analysis are mostly based on information extraction based on semi-automatic processing by the computer. In this process the (human) operator instructs the computer to perform an interpretation according to certain conditions. These conditions are defined by the operator. Image classification is one of the techniques in the domain of digital image interpretation. Other techniques include automatic object recognition and scene reconstruction. In this study guide, we will focus on image classification. Image classification is based on the different spectral characteristics of different materials on the Earth's surface. It is a process that operates in the feature space. Here, only 'hue' is applied in image classification, which is its major limitation. The major tools employed are the image space and the feature space.

6.2 Objectives

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

- Outline the principle of image classification
- Describe the process of digital image classification

6.3 Main Content

6.3.1 Principle of Image Classification

6.3.1.1 Image Space

A digital image is a 2D-array of elements. In each element the energy reflected or emitted from the corresponding area on the Earth's surface is stored. The spatial arrangement of the measurements defines the image or image space. Depending on the sensor, data are recorded in n bands (**Figure 16**). Digital image elements are usually stored as 8-bit DN-values (range: 0–255).

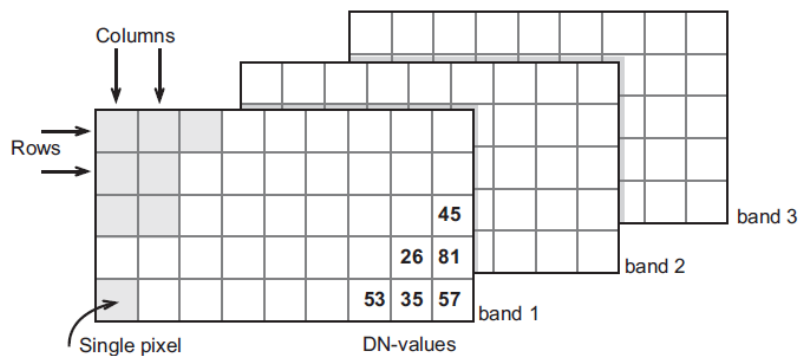


Figure 16: The structure of a multi-band image.

6.3.1.2 Feature Space

In one pixel, the values in (for example) two bands can be regarded as components of a two-dimensional vector, the feature vector. An example of a feature vector is (13, 55), which tells that 13 DN and 55 DN are stored for band 1 and band 2 respectively. This vector can be plotted in a two-dimensional graph.

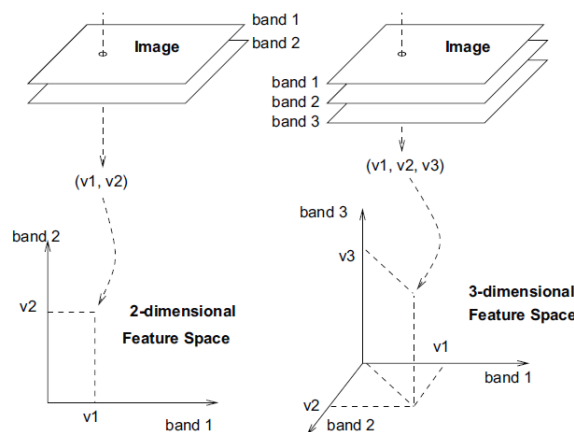


Figure 17: Plotting of the values of a pixel in the feature space for a two and three band image.

Similarly, this approach can be visualized for a three-band situation in a three-dimensional graph. A graph that shows the values of the feature vectors is called a feature space, or also feature space plot or scatter plot. Figure 17 illustrates how a feature vector (related to one pixel) is plotted in the feature space for two and three bands, respectively. Two-dimensional feature space plots are most common.

Note that plotting values is difficult for a four- or more-dimensional case, even though the concept remains the same. A practical solution when dealing with four or more bands is that all the possible combinations of two bands are plotted separately. For four bands, this already yields six combinations: bands 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and bands 3 and 4.

Plotting the combinations of the values of all the pixels of one image yields a large cluster of points. Such a plot is referred to as a scatterplot (Figure 18). A scatterplot provides information about the combinations of pixel values that occur within the image. Note that some combinations will occur more frequently and can be visualized by using intensity or colour.

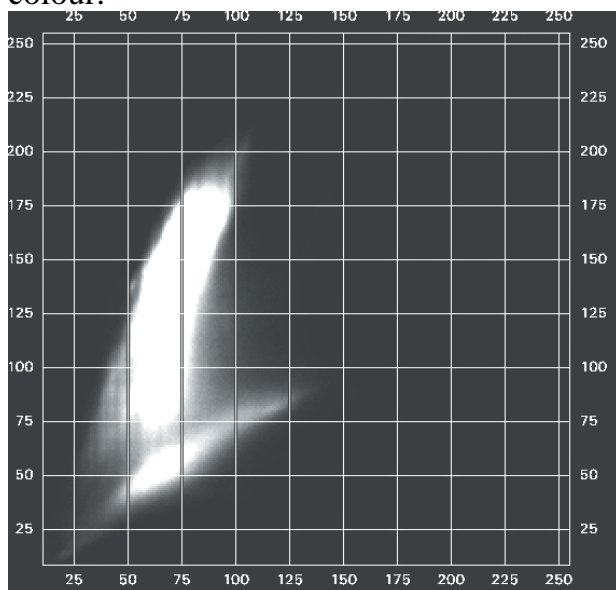


Figure 18: Scatterplot of two bands of a digital image. Note the units (DN-values) along the x and y-axes. The intensity at a point in the feature space is related to the number of pixels at that point.

Distances and clusters in the feature space

Distance in the feature space is expressed as ‘Euclidian distance’ and the units are DN (as this is the unit of the axes). In a two-dimensional feature space, the distance can be calculated according to Pythagoras’ theorem. In the situation of Figure 19, the distance between (10, 10) and (40, 30) equals the square root of $(40 - 10)^2 + (30 - 10)^2$. For three or more dimensions, the distance is calculated in a similar way.

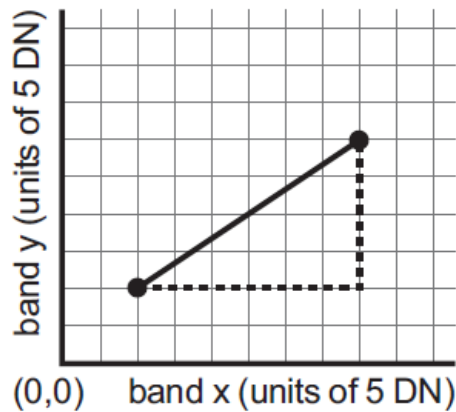


Figure 19: Euclidian distance between the two points is calculated using Pythagoras' theorem.

Self-Assessment Exercise

What are the principles of image classification based on?

6.3.2 Image Classification

The scatterplot shown in Figure 19 gives information about the distribution of corresponding pixel values in two bands of an image. Figure 20 shows a feature space in which the feature vectors have been plotted for six specific land cover classes (grass, water, trees, etc.). Each cluster of feature vectors (class) occupies its own area in the feature space. Figure 20 shows the basic assumption for image classification: a specific part of the feature space corresponds to a specific class. Once the classes have been defined in the feature space, each image pixel can be compared to these classes and assigned to the corresponding class.

Classes to be distinguished in an image classification need to have different spectral characteristics. This can, for example, be analyzed by comparing spectral reflectance curves. Figure 20 also illustrates the limitation of image classification: if classes do not have distinct clusters in the feature space, image classification can only give results to a certain level of reliability.

The principle of image classification is that a pixel is assigned to a class based on its feature vector, by comparing it to predefined clusters in the feature space. Doing so for all image pixels results in a classified image. The crux of image classification is in comparing it to predefined clusters, which requires definition of the clusters and methods for comparison. Definition of the clusters is an interactive process and is carried out during the training process. Comparison of the individual pixels with the clusters takes place using classifier algorithms.

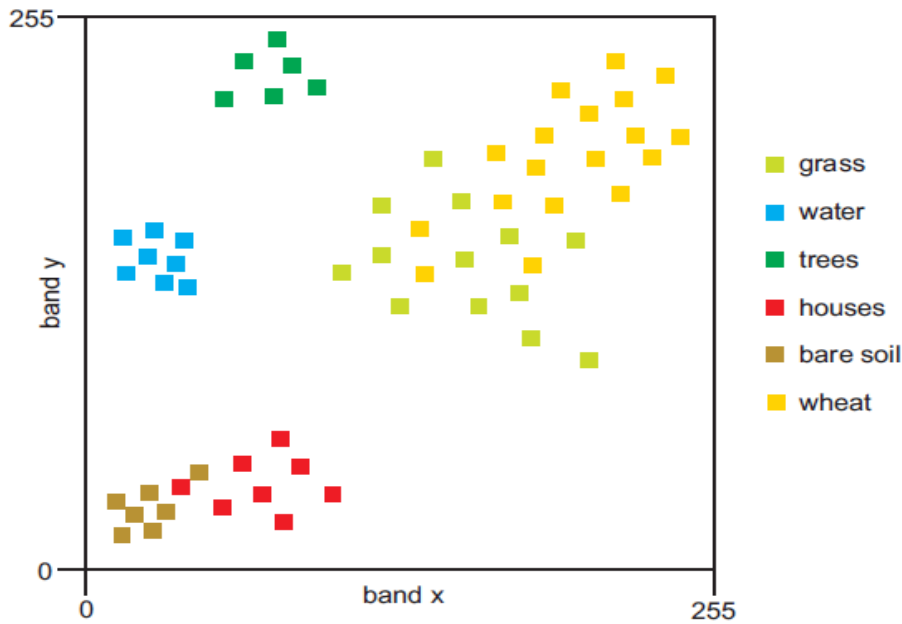


Figure 20: Feature space showing the respective clusters of six classes; note that each class occupies a limited area in the feature space.

Self-Assessment Exercise

What is the basis of image classification?

6.3.2.1 Image Classification Process

The process of image classification (Figure 21) typically involves five steps:

1. Selection and preparation of the image data. Depending on the cover types to be classified, the most appropriate sensor, the most appropriate date(s) of acquisition and the most appropriate wavelength bands should be selected.

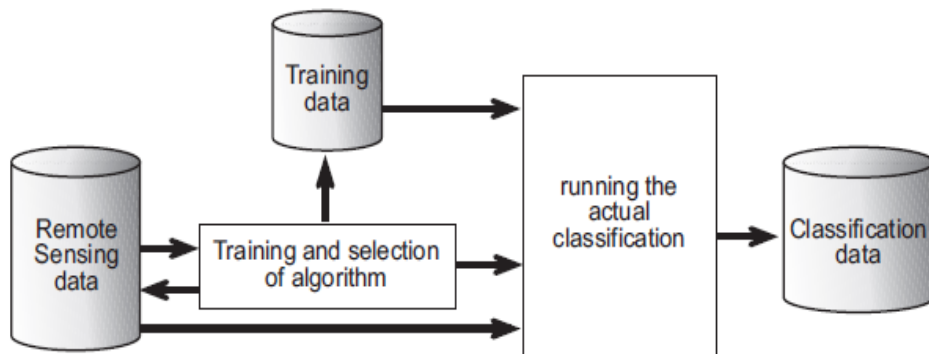


Figure 21: The classification process; most important component is the training in combination with selection of the algorithm.

2. Definition of the clusters in the feature space. Here two approaches are possible: supervised classification and unsupervised classification. In a supervised classification, the operator defines the clusters during the training process; in an unsupervised classification a clustering algorithm automatically finds and defines a number of clusters in the feature space.
3. Selection of classification algorithm. Once the spectral classes have been defined in the feature space, the operator needs to decide on how the pixels (based on their DN-values) are assigned to the classes.
4. Running the actual classification. Once the training data have been established and the classifier algorithm selected, the actual classification can be carried out. This means that, based on its DN-values, each individual pixel in the image is assigned to one of the predefined classes (Figure 22).
5. Validation of the result. Once the classified image has been produced its quality is assessed by comparing it to reference data (ground truth). This requires selection of a sampling technique, generation of an error matrix, and the calculation of error parameters.

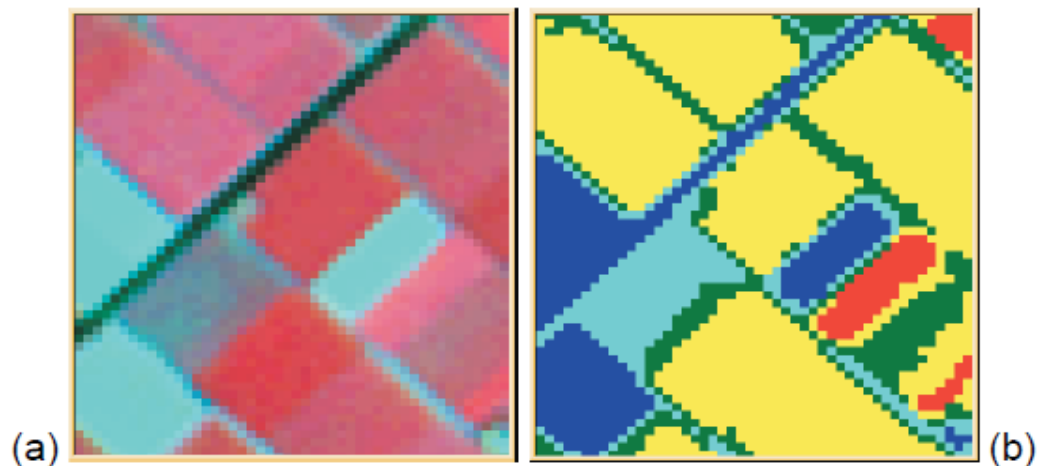


Figure 22: The result of classification of a multispectral image (a) is a raster in which each cell is assigned to some thematic class (b).

Self-Assessment Exercise

List the five steps of image classification.

6.4 Conclusion

Application of image classification is found in many regional scale projects. In Asia, the Asian Association of Remote Sensing (AARS) is generating various land cover datasets based on (un)supervised classification of multispectral satellite data. In the Africover project (by

the Food and Agriculture Organization, FAO), image classification techniques are being used to establish a pan-African land cover dataset. The European Commission requires national governments to verify the claims of farmers related to subsidized crops. These national governments employ companies to make a first inventory, using image classification techniques, which is followed by field checks.

6.5 Summary

From this unit, you have learnt about the digital image classification. Some of the key things learnt include the following;

- Principle of image classification
 - Image space
 - Feature space
- Image classification
- Image classification process

6.6 Tutor-Marked Assignment

1. Discuss the principles of image classification.
2. What are the processes involved in image classification?

6.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

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MODULE 4 GEOGRAPHIC INFORMATION SYSTEM (GIS)

Unit 1	Data Models
Unit 2	Coordinate Systems
Unit 3	Download and Installation of Open-Source GIS Software

UNIT 1 DATA MODELS

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Overview of the Geographic Information System
 - 1.3.2 Data Models
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

Maps are essential supporting tool in the decision-making process. Mapmaking is not a new enterprise. It is virtually as old as human civilization, dating back to the times of the Pharaohs and earlier. Modern developments in computerization and Geographic information system (GIS) have, however, improved the efficiency and ease of the map making process. In fact, the GIS performs these tasks better and faster than do the old manual methods. The geographic information system (GIS) is a computer-based system for capturing, storing, checking, and displaying data related to positions on Earth's surface. The GIS works with two data models, namely, raster and vector data. A map generated using GIS is a product of several layers of vector and/or raster data, which are all combined in a map layout.

1.2 Objectives

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

- Define geographic information system (GIS)
- Discuss the essence of the cartographic data models
- List open-source and commercial GIS software applications

1.3 Main Content

1.3.1 Overview of The Geographic Information System

The introduction of modern technologies has led to an increased use of computers and information technology instead of manual methods in all aspects of spatial data handling. The software technology used in this domain is the geographic information systems (GIS).

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation. This enables people to more easily see, analyze, and understand patterns and relationships.

In short, geographic information system gives us the power to create maps, integrate information, visualize scenarios, solve complicated problems, present powerful ideas and develop effective solutions like never before. It is an effective supporting tool in the decision-making process. Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods.

Self-Assessment Exercise

What is geographic information system?
--

1.3.2 Data Models

Conversion of real-world geographical variation into discrete objects is done through data models. It represents the linkage between the real-world domain of geographic data and computer representation of these features. Data models are of two types: Raster and Vector.

- **Raster model:** In raster type of representation of the geographic data, a set of cells located by coordinate is used; each cell is independently addressed with the value of an attribute. Each cell contains a single value. One set of cells and associated values is a layer.
- **Vector model:** There are three different geometric classes of vector data model, viz. the point representing location, line giving the length and polygon giving information about the perimeter or area of a geographic data. Vector data model uses line segments or points represented by their explicit 'x', 'y' coordinates to identify locations. Discrete objects are formed by connecting line segments to form areas (polygons) as defined by the line segments. Vector data models require less storage space, outputs are appreciable,

estimation of area/perimeters is accurate and editing is faster and convenient as compared to raster model.

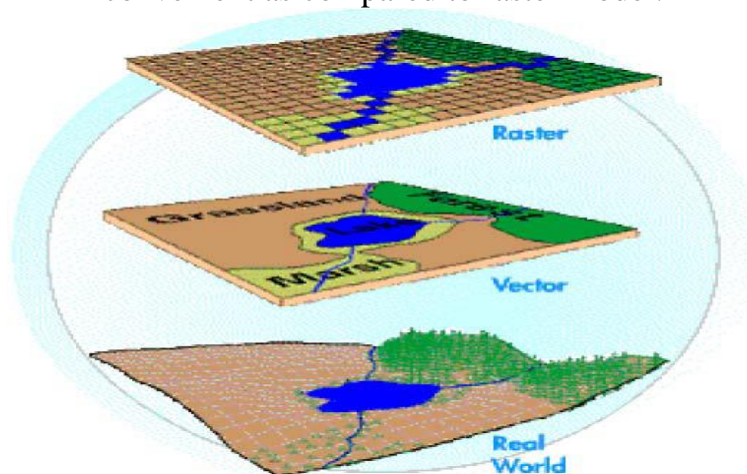


Figure 23: Data models

Self-Assessment Exercise

List the types of data models.

1.3.3 Mapping with Geographic Information Systems

In a GIS system, data is imported, analyzed and displayed in layers (a grouping of data of a particular level of classification, e.g., roads, rivers, buildings, soil types, vegetation, elevation data, etc.). The concept of layers is to be found in both vector and raster models. The layers can be combined with each other in various ways to create new layers that are a function of the individual ones. The characteristic of each layer within layer-based GIS is that all locations with each layer may be said to belong to a single areal region or cell, whether it be a polygon bounded by lines in vector system, or a grid cell in a raster system.

Once all the desired data have been entered into a GIS system, they can be combined to produce a wide variety of individual maps, depending on which data layers are included. One of the most common uses of GIS technology involves comparing natural features with human activity. For instance, GIS maps can display what man-made features are near certain natural features or which homes and businesses are in areas prone to flooding.

With GIS technology, researchers can also look at change over time. They can use satellite data to study topics such as land cover change over a seasonal or multi-year timescale. One important use of time-based GIS technology involves creating time-lapse photography that shows processes occurring over large areas and long periods of time.

GIS technology sometimes allows users to access further information about specific areas on a map. A person can point to a spot on a digital map to find other information stored in the GIS about that location. For example, a user might click on a location to find out the soil type, soil pH, base saturation or land use types predominant in that region.

GIS technology makes updating maps much easier than updating maps created manually. Updated data can simply be added to the existing GIS program. A new map can then be printed or displayed on screen. This skips the traditional process of drawing a map, which can be time-consuming and expensive.

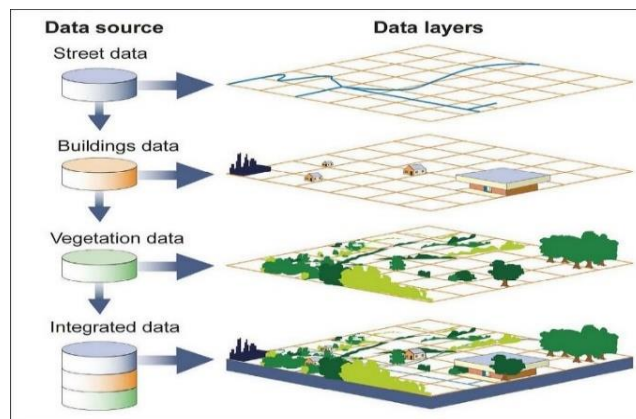


Figure 24: Data layers in a geographic information system

Self-Assessment Exercise

What is the value of layers in geographic information systems?

1.3.4 Geographic Information System (Gis) Software

These are computer (and sometimes tablet and phone) applications/software that enable us to manipulate and analyze spatial data. We have open-source (available for free download and use) and commercial (has to be paid for, or requires periodic subscription) GIS software. Examples of both types are shown in Table 2.

Table 2: Open-source and Commercial GIS Applications

S/N	GIS SOFTWARE	
	Commercial	Open-source (Free)
1	ArcGIS (Esri)	QGIS 2 (Quantum GIS)
2	ERDAS Imagine	QGIS 3 (Quantum GIS)
3	Geomedia (Hexagon Geospatial)	gVSIG (Generalitat Valenciana Sistemas de Información Geográfica)

4	MapInfo Professional (Pitney Bowes)	GRASS GIS (Geographic Resources Analysis Support System GIS)
5	Global Mapper (Blue Marble)	ILWIS (Integrated Land and Water Information Management)
6	Manifold GIS (Manifold)	SAGA GIS (System for Automated Geoscientific Analyses)
7	Smallworld (General Electric)	GeoDa (Geographic Dara) – for data exploration in statistics.
8	Bentley Map	Whitebox GAT (Geospatial Analysis Toolbox). Replacement for Terrain Analysis System (TAS) – a tool for hydro-geomorphic applications
9	MapViewer and Surfer (Golden Software)	MapWindow
10	Maptitude (Caliper Corporation)	uDig (User-friendly Desktop Internet-oriented GIS)
11	SuperGIS (Supergeo Technologies)	OpenJump GIS (JAVA Unified Mapping Platform)
12	IDRISI (Clark Laboratories)	FalconView
13	AutoCAD Map 3D (Autodesk)	OrbisGIS
14	Tatuk GIS	Diva GIS
15	MicroImages (TNTgis)	FlowMap is a freeware application designed to analyze and display flow data.

Self-Assessment Exercise

List four open-source and four commercial GIS software.

1.4 Conclusion

GIS technology makes the map-making process easy and efficient. A new map can then be printed or displayed on screen. This skips the traditional process of drawing a map, which can be time-consuming and expensive. Furthermore, with GIS, even old analog maps can be digitized and subsequently, updated. Also, remote sensed data are easier to handle, analyze and manage in a GIS – particularly for very large areas. Finally, the acquisition or subscription costs for GIS applications was originally problematic as the commercial software are usually very costly. Luckily, this problem has been largely taken care of by the current availability of

open-source GIS applications that are available for free download and use.

1.5 Summary

From this unit, you have learnt about the data models. Some of the key things learnt include the following;

- Overview of the geographic information system
- Data models
- Mapping with geographic information systems
- Geographic information system (GIS) software

1.6 Tutor-Marked Assignment

1. Define the term, Geographic Information System.
2. Discuss the GIS data models.
3. List five open-source and five commercial GIS software.

1.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. What is geographic information system?
Geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface.
2. List the types of data models.
i) Raster model ii) Vector model
3. What is the value of layers in geographic information systems?
Being that layers are generated to represent individual groups of data of similar nature (e.g., lines, points, polygons or pixels), several layers can be combined to generate a map in which points, lines, polygons and even pixels are presented.
4. List four open-source and four commercial GIS software.

<i>S/N</i>	<i>Commercial</i>	<i>Open-source</i>
<i>i.</i>	<i>ArcGIS (Esri)</i>	<i>SAGA GIS (System for Automated Geoscientific Analyses)</i>
<i>ii.</i>	<i>ERDAS Imagine</i>	<i>QGIS (Quantum GIS)</i>
<i>iii.</i>	<i>Geomedia (Hexagon Geospatial)</i>	<i>gVSIG (Generalitat Valenciana Sistemas de Información Geográfica)</i>
<i>iv.</i>	<i>MapInfo Professional (Pitney Bowes)</i>	<i>GRASS GIS (Geographic Resources Analysis Support System GIS)</i>

UNIT 2 COORDINATE SYSTEMS

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Geographic Coordinate Systems
 - 2.3.2 Geographic (Datum) Transformations
 - 2.3.3 Projected Coordinate Systems
 - 2.3.3.1 Types of Map Projections
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

The earth is spherical in shape. As such, a map that effectively represents the features of locations on the earth surface should also be spherical in shape. If all the maps of the earth that are produced and used today are drawn on a globe, then they would all be relatively accurate. Unfortunately, most maps drawn on a paper that can be spread out on a flat surface. To throw more light on the problem, spread a piece of paper on your desk. Buy an orange, slice it in such a way that the furthestmost part of the peel is not sliced through. Cut the left and right halves in same way. Remove the pulp of the orange, leaving behind the peels, with its four segments still linked in the middle. Spread the peel over the paper. You will notice that while the middle may spread perfectly on the paper, the upper and lower ends have gaps in-between. Therein lies the problem of the cartographer. The Orange is the earth, but you are expected to draw your map on a flat paper. This effectively introduces a lot of errors in the mapping process. This is where geographic and projected coordinate systems become relevant. The geographic coordinate systems depict the locations as is to be expected on the globe. The projected coordinate systems are mathematical computations that approximate the geographic coordinate system on a flat surface, minimizing the inherent errors.

2.2 Objectives

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

- Describe the geographic coordinate systems
- Describe the projected coordinate systems

2.3 Main Content

A **coordinate system** is a method for identifying the location of a point on the earth. Most coordinate systems use two numbers, a **coordinate**, to identify the location of a point. Each of these numbers indicates the distance between the point and some fixed reference point, called the **origin**. The first number, known as the X value, indicates how far left or right the point is from the origin. The second number, known as the Y value, indicates how far above or below the point is from the origin. The origin has a coordinate of 0, 0.

Longitude and latitude are a special kind of coordinate system, called a **spherical coordinate system**, since they identify points on a sphere or globe. However, there are hundreds of other coordinate systems used in different places around the world to identify locations on the earth. All of these coordinate systems place a grid of vertical and horizontal lines over a flat map of a portion of the earth.

2.3.1 Geographic Coordinate Systems

A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid). The spheroid defines the size and shape of the earth model, while the datum connects the spheroid to the earth's surface.

A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's center to a point on the earth's surface. The angles often are measured in degrees (or in grads). The following illustration shows the world as a globe with longitude and latitude values:

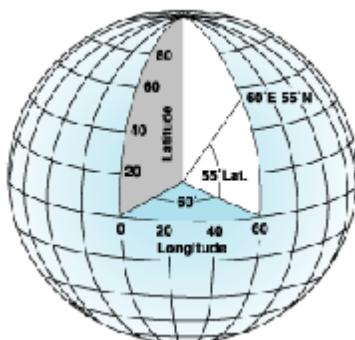


Figure 25: A Representation of the Earth and the Geographic Coordinates In the spherical system, horizontal lines, or east–west lines, are lines of equal latitude, or parallels. Vertical lines, or north–south lines, are lines of equal longitude, or meridians. These lines encompass the globe and form a gridded network called a graticule.

The line of latitude midway between the poles is called the equator. It defines the line of zero latitude. The line of zero longitude is called the prime meridian. For most GCSs, the prime meridian is the longitude that passes through Greenwich, England. The origin of the graticule (0,0) is defined by where the equator and prime meridian intersect.

Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS). Latitude values are measured relative to the equator and range from -90° at the south pole to $+90^\circ$ at the north pole. Longitude values are measured relative to the prime meridian. They range from -180° when traveling west to 180° when traveling east. If the prime meridian is at Greenwich, then Australia, which is south of the equator and east of Greenwich, has positive longitude values and negative latitude values.

It may be helpful to equate longitude values with x and latitude values with y. Data defined on a geographic coordinate system is displayed as if a degree is a linear unit of measure. This method is basically the same as the Plate Carrée projection. A physical location will usually have different coordinate values in different geographic coordinate systems.

Self-Assessment Exercise

What is a geographic coordinate system?

2.3.2 Geographic (Datum) Transformations

If two datasets are not referenced to the same geographic coordinate system, you may need to perform a geographic (datum) transformation. This is a well-defined mathematical method to convert coordinates between two geographic coordinate systems. As with the coordinate systems, there are several hundred predefined geographic transformations that you can access. It is very important to correctly use a geographic transformation if it is required. When neglected, coordinates can be in the wrong location by up to a few hundred meters. Sometimes no transformation exists, or you have to use a third GCS like the World Geodetic System 1984 (WGS84) and combine two transformations.

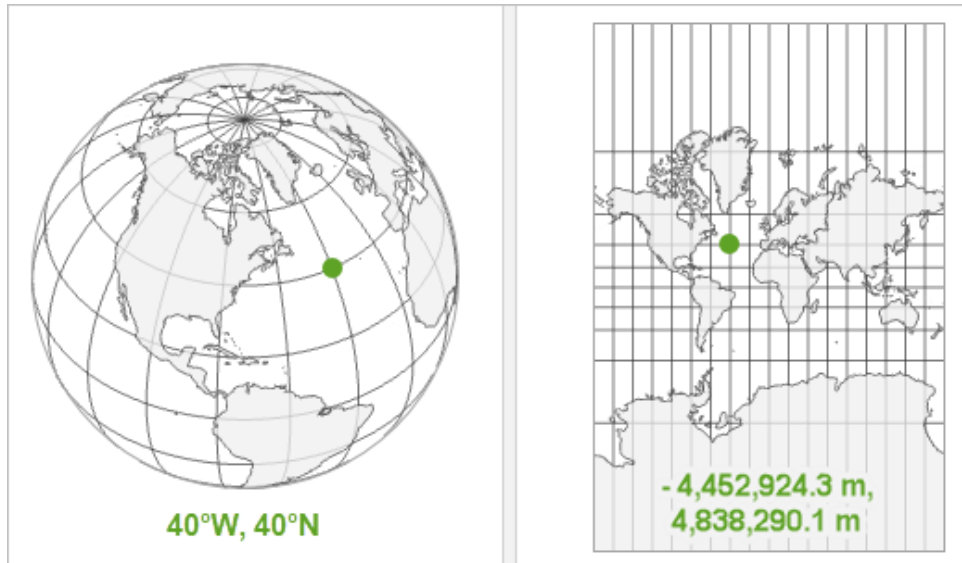


Figure 26: Geographic Coordinate System Measured in Angular Units Vs. a Projected Coordinate System Measured in Linear Units.

2.3.3 Projected Coordinate Systems

A projected coordinate system (PCS) is defined on a flat, two-dimensional surface. Unlike a GCS, a PCS has constant lengths, angles, and areas across the two dimensions. A PCS is always based on a GCS that is based on a sphere or spheroid. In addition to the GCS, a PCS includes a map projection, a set of projection parameters that customize the map projection for a particular location, and a linear unit of measure.



Figure 27: A Map Representative of The Globe Earth Spread on a Flat Surface

The surface of the earth is curved but maps are flat. To convert feature locations from the spherical earth to a flat map, the latitude and longitude coordinates from a geographic coordinate system must be converted, or projected, to planar coordinates. A map projection uses mathematical

formulas to convert geographic coordinates on the spherical globe to planar coordinates on a flat map.

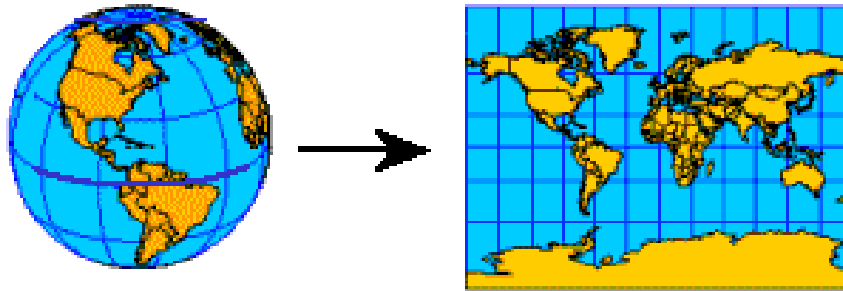


Figure 28: The Globe Earth Projected onto a Flat Surface

A projected coordinate system is a reference system for identifying locations and measuring features on a flat (map) surface. It consists of lines that intersect at right angles, forming a grid. Projected coordinate systems, which are based on Cartesian coordinates, have an origin, an x and a y axis, and a unit for measuring distance.

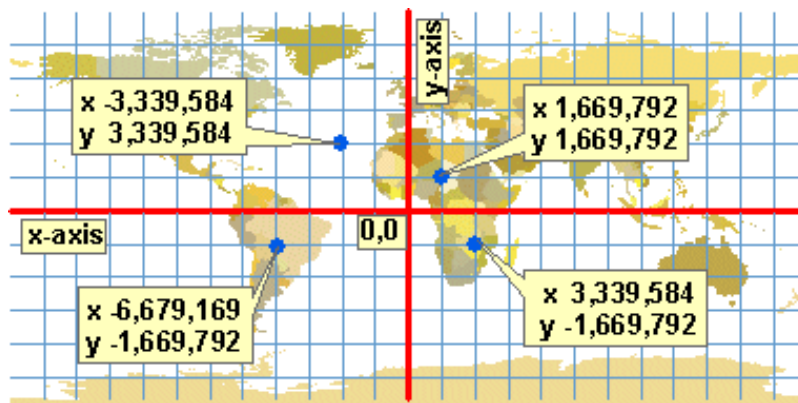


Figure 29: A Representation of the Cartesian Coordinates System

The origin of the projected coordinate system (0,0) commonly coincides with the center of the map. This means that x and y coordinate values will be positive only in one quadrant of the map (the upper right). On published maps, however, it is desirable to have all the coordinate values be positive numbers.

To offset this problem, mapmakers add two numbers to each x and y value. The numbers are big enough to ensure that all coordinate values, at least in the area of interest, are positive values. The number added to the x coordinate is called a false easting. The number added to the y coordinate is called a false northing.

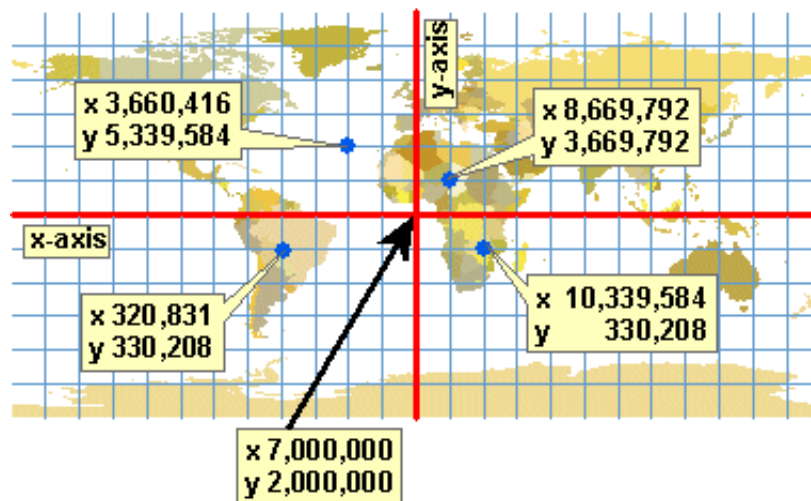


Figure 30: Converting the Projected Coordinates into Positive Values

Self-Assessment Exercise

Differentiate between a geographic coordinate system and a projected coordinate system.

2.3.3.1 Types of Map Projections

Mathematical formulas are used to convert a three-dimensional geographic coordinate system to a two-dimensional flat projected coordinate system. The transformation is referred to as a *map projection*. Map projections usually are classified by the projection surface used, such as conic, cylindrical, and planar surfaces. Depending on the projection used, different spatial properties will appear distorted. Projections are designed to minimize the distortion of one or two of the data's characteristics, yet the distance, area, shape, direction, or a combination of these properties might not be accurate representations of the data that is being modeled. There are several types of projections available. While most map projections attempt to preserve some accuracy of the spatial properties, there are others that attempt to minimize overall distortion instead, such as the *Robinson* projection. The most common types of map projections include:

1. **Equal area projections:** These projections preserve the area of specific features. These projections distort shape, angle, and scale. The *Albers Equal Area Conic* projection is an example of an equal area projection.
2. **Conformal projections:** These projections preserve local shape for small areas. These projections preserve individual angles to describe spatial relationships by showing perpendicular graticule lines that intersect at 90-degree angles on the map. All of the angles are preserved; however, the area of the map is distorted.

The *Mercator* and *Lambert Conformal Conic* projections are examples of conformal projections.

3. **Equidistant projections:** These projections preserve the distances between certain points by maintaining the scale of a given data set. Some of the distances will be true distances, which are the same distances at the same scale as the globe. If you go outside the data set, the scale will become more distorted. The *Sinusoidal* projection and the *Equidistant Conic* projection are examples of equidistant projections.
4. **True-direction or azimuthal projections:** These projections preserve the direction from one point to all other points by maintaining some of the great circle arcs. These projections give the directions or azimuths of all points on the map correctly with respect to the center. Azimuthal maps can be combined with equal area, conformal, and equidistant projections. The *Lambert Equal Area Azimuthal* projection and the *Azimuthal Equidistant* projection are examples of azimuthal projections.

Self-Assessment Exercise

List the four major types of map projections.

2.4 Conclusion

For places within the vicinity of the equator, the geographic coordinate system can to a great degree of accuracy represent the location on a flat map. The further north or south you go, the greater the degree of inaccuracy of the generated map. While the regions around the equator will be largely accurate, the northernmost and southernmost regions will appear to be much larger than they really are. This why the projected coordinate systems are very relevant. The most widely used projected coordinate system is the Universal Transverse Mercator (UTM). The system divides the globe into 60 longitudinal projection zones numbered 1 to 60 starting at 180°W, 20 latitudinal zones spanning the latitudes 80°S to 84°N and denoted by the letters C to X, omitting the letter O. The UTM zone for Nigeria ranges from 31N through 32N to 33N.

2.5 Summary

From this unit, you have learnt about the coordinate systems. Some of the key things learnt include the following;

- Geographic coordinate systems
- Geographic (datum) transformations
- Projected coordinate systems
- Types of map projections

2.6 Tutor-Marked Assignment

1. Differentiate between geographic coordinate systems and projected coordinate systems.
2. In one sentence, state why geographic (datum) transformation is important.
3. Describe the major types of map projections.

2.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. *Agri-India TODAY* 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

2.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. What is a geographic coordinate system?
*A **coordinate system** is a method for identifying the location of a point on the earth. A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the earth.*
2. Differentiate between a geographic coordinate system and a projected coordinate system.

S/N	Geographic Coordinate System	Projected Coordinate System
i.	<i>It defines the locations of features on a model of the earth.</i>	<i>It contains a GCS, but it converts that GCS into a flat surface, using math (the projection algorithm) and other parameters.</i>
ii.	<i>It is shaped like a globe — spherical.</i>	<i>It is flat</i>
iii.	<i>Its units are angular, usually degrees</i>	<i>Its units are linear, most commonly in meters.</i>
iv.	<i>Does not have constant lengths, angles, and areas across</i>	<i>has constant lengths, angles, and areas across the two dimensions</i>
v.	<i>It is 3-dimensional</i>	<i>It is 2-dimensional</i>

3. List the four major types of map projections.
 - i) *Equal area projections*
 - ii) *Conformal projections*
 - iii) *Equidistant projections*
 - iv) *True-direction or azimuthal projections*

UNIT 3 DOWNLOAD AND INSTALLATION OF OPEN-SOURCE GIS SOFTWARE

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3 Main Content
 - 3.3.1 Download and Installation of QGIS
 - 3.3.1.1 Download of QGIS
 - 3.3.1.2 Installation of QGIS
 - 3.3.2.1 Download and Installation of GRASS GIS
 - 3.3.2.2 Download of GRASS GIS
 - 3.3.2.3 Installation of GRASS GIS
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

There are a lot of open-source software that are available for free download and use. In this course, we are going to use two of them, namely: Quantum Geographic Information System (QGIS) and Geographic Resources Analysis Support System Geographic Information System (GRASS GIS). There are some degrees of integration between both software. Some of the tools in GRASS GIS can be accessed with QGIS. For now, however, we will focus on hydrologic and geomorphic mapping with GRASS GIS and cartography with QGIS.

3.2 Objectives

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

- Be able to download QGIS software
- Be able to download GRASS GIS software
- Be able to install both GIS software

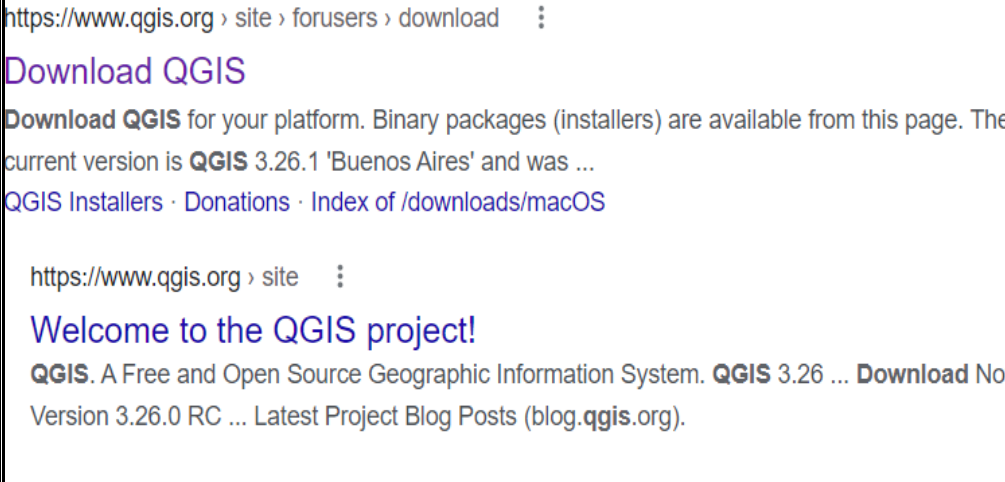
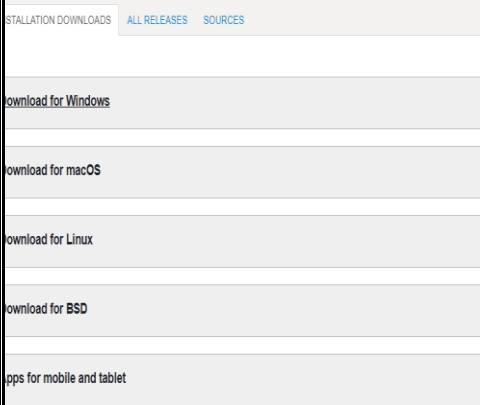
3.3 Main Content

3.3.1 Download and Installation of QGIS

QGIS is a free and open-source geographic information system that can be used to create, modify, visualize, analyze and publish geographic information on Windows, Mac, Linux, BSD and mobile devices. We will

focus on its use with Windows devices (most computers, besides Apple and Linux).

3.3.1.1 Download of QGIS

<p>Copy and paste following website (https://www.qgis.org/en/site/forusers/download.html) in your internet browser and press the “Enter” key on your keyboard.</p>	
<p>If the website does not load appropriately, then, maybe the online directory has been updated. In that case, search for “QGIS download” on google search or any other search engine.</p>	
<p>The following (or variations of it) may show up on the top of the search results.</p>	
 <p>https://www.qgis.org › site › forusers › download</p> <p>Download QGIS</p> <p>Download QGIS for your platform. Binary packages (installers) are available from this page. The current version is QGIS 3.26.1 'Buenos Aires' and was ...</p> <p>QGIS Installers · Donations · Index of /downloads/macOS</p> <p>https://www.qgis.org › site</p> <p>Welcome to the QGIS project!</p> <p>QGIS. A Free and Open Source Geographic Information System. QGIS 3.26 ... Download No Version 3.26.0 RC ... Latest Project Blog Posts (blog.qgis.org).</p>	
<p>Click on the “Download QGIS” link and it will take you to the same website that mentioned on item 1 (if the website is yet to be updated).</p>	
<p>Whichever option works, the following page will be loaded:</p>  <p>INSTALLATION DOWNLOADS ALL RELEASES SOURCES</p> <p>download for Windows</p> <p>download for macOS</p> <p>download for Linux</p> <p>download for BSD</p> <p>apps for mobile and tablet</p>	<p>Click on the leftward arrow (←) in front of the device type. (I am using a Windows device, so I would click on the arrow in front of “Download for Windows”). The appropriate information will be loaded with the other options still listed below it.</p>
<p>The image on item 6 may be automatically exposed as the default, in which case you do not need to click on the arrow – now downward-pointing (▼) to expose what is already exposed.</p>	

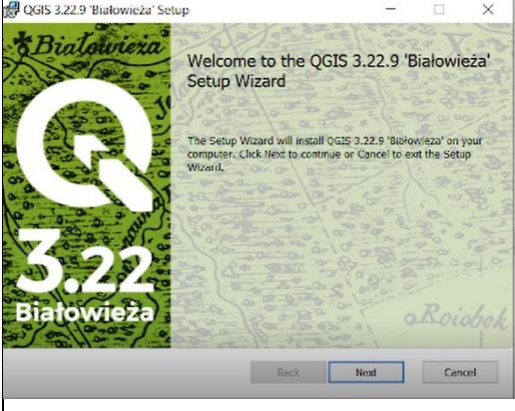
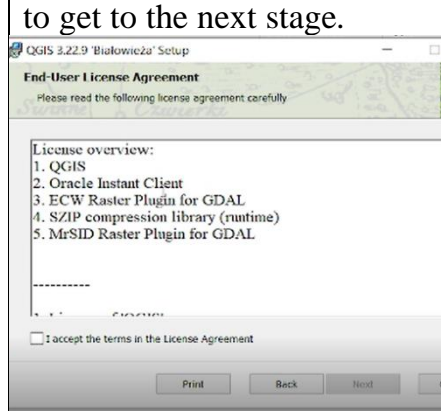

<p>If you click that arrow, you will revert back to a webpage reflecting the image above.</p>	
<p>If the tab, “INSTALLATION DOWNLOAD” is selected as it usually, automatically, is, you may have two options listed under two headings Latest release (richest on features): Long term release (most stable): Select the option under “Long term release”, as this is usually more stable.</p>	<p>Once it begins to download after clicking on the appropriate option, the following window appears</p>  <p>If you have the wherewithal, please donate, if not, click “Close this message” to return back to the download window.</p>
<p>Given the fact that the software is being continually updated, if you need an older version (for instance the version we used in this tutorial “3.24”), select the tab, “All releases”</p>	<p>Click on “here” in front of the appropriate option, maybe the first option previous releases of QGIS are still available here</p>

<p>INSTALLATION DOWNLOADS ALL RELEASES SOURCES</p> <p>Previous releases of QGIS are still available here - including older releases for OS X and older releases are available here and for OS X here.</p> <p>Plugins for QGIS are also available here.</p>																																																	
<p>1. This will take you to a database with a long list of the different versions of the software index of/downloads</p>	<p>2. Click on the link to download.</p>																																																
<table border="1"> <thead> <tr> <th>Name</th> <th>Last modified</th> <th>Size</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>Parent Directory</td> <td>-</td> <td>-</td> <td>-</td> </tr> <tr> <td>qgis.zip</td> <td>2018-09-24 23:24</td> <td>81K</td> <td></td> </tr> <tr> <td>QGIS-1.4.0-L-No-GrassSetup.exe</td> <td>2017-12-02 20:29</td> <td>29M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.5.0-13926-Setup.exe</td> <td>2017-12-02 20:29</td> <td>73M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.5.0-14093-Setup.exe</td> <td>2017-12-02 20:30</td> <td>77M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.5.0-14095-Setup.exe</td> <td>2017-12-02 20:30</td> <td>77M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.5.0-14109-Setup.exe</td> <td>2017-12-02 20:30</td> <td>77M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.5.0-14307-Setup.exe</td> <td>2017-12-02 20:30</td> <td>76M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.6.0-14615-Setup.exe</td> <td>2017-12-02 20:31</td> <td>77M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.7.0-b55a00e73-Setup.exe</td> <td>2017-12-02 20:31</td> <td>92M</td> <td></td> </tr> <tr> <td>QGIS-OSGeo4W-1.7.0-b55a00e73-Setup.exe.md5</td> <td>2017-12-02 20:31</td> <td>73</td> <td></td> </tr> </tbody> </table> <p>Scroll down to find the appropriate one.</p>	Name	Last modified	Size	Description	Parent Directory	-	-	-	qgis.zip	2018-09-24 23:24	81K		QGIS-1.4.0-L-No-GrassSetup.exe	2017-12-02 20:29	29M		QGIS-OSGeo4W-1.5.0-13926-Setup.exe	2017-12-02 20:29	73M		QGIS-OSGeo4W-1.5.0-14093-Setup.exe	2017-12-02 20:30	77M		QGIS-OSGeo4W-1.5.0-14095-Setup.exe	2017-12-02 20:30	77M		QGIS-OSGeo4W-1.5.0-14109-Setup.exe	2017-12-02 20:30	77M		QGIS-OSGeo4W-1.5.0-14307-Setup.exe	2017-12-02 20:30	76M		QGIS-OSGeo4W-1.6.0-14615-Setup.exe	2017-12-02 20:31	77M		QGIS-OSGeo4W-1.7.0-b55a00e73-Setup.exe	2017-12-02 20:31	92M		QGIS-OSGeo4W-1.7.0-b55a00e73-Setup.exe.md5	2017-12-02 20:31	73		
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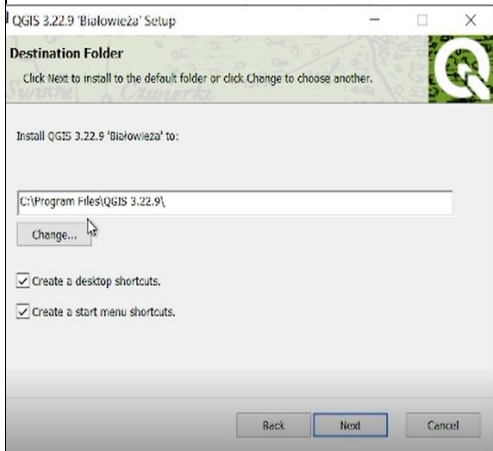
Self-Assessment Exercise

Show evidence of downloaded QGIS software (an image of the downloaded software in a folder).

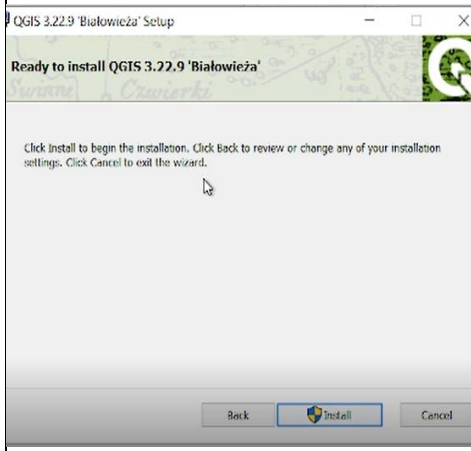
3.3.1.2 Installation Of QGIS

<p>1. Double-click on the downloaded software to load the installation window (or right-click on the downloaded software and select “install” in the context menu).</p>	
<p>2. The install window is automatically loaded</p>	<p>3. Click “Next” in the bottom righthand side of the window to get to the next stage.</p>
	
<p>4. Accept the license agreement by highlighting the appropriate box and click the “Next” button.</p>	

. You are taken to the next window. Accept the default settings and click “Next”



. The next window is the actual installation window. Click the “Install” button.

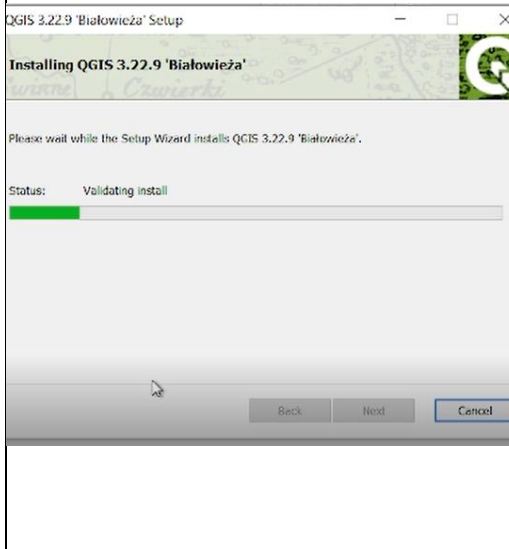


. The software prepares to install



. Your window may go blank with a prompt requiring you to confirm whether you want to allow the application to make some changes in your system. Click the “Yes” button to commence the actual installation. information will be loaded with the other options still listed below it.

. The installation commences



. When the installation is complete, a new window pops up. Click the “Finish” button to conclude the installation.



Self-Assessment Exercise

Show evidence of successful QGIS installation (an image of the open QGIS window).

3.3.2 Download and Installation of Grass GIS

GRASS GIS offers powerful raster, vector, and geospatial processing engines in a single integrated software suite. It includes tools for terrain and ecosystem modeling, hydrology, visualization of raster and vector data, management and analysis of geospatial data, and the processing of satellite and aerial imagery. It comes with a temporal framework for advanced time series processing and a Python API for rapid geospatial programming. GRASS GIS has been optimized for performance and large geospatial data analysis.

3.3.2.1 Download of Grass GIS

. Double-click on the downloaded software to load the installation window (or right-click on the downloaded software and select “install” in the context menu).

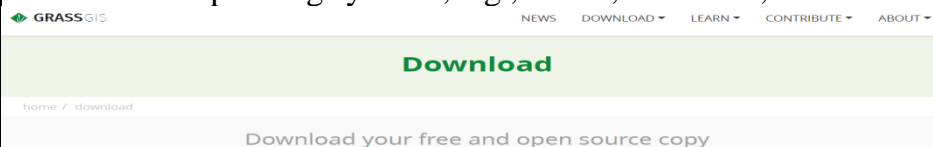
. If the website does not load appropriately, then, maybe the online directory has been updated. In that case, search for “GRASS GIS download” on google search or any other search engine.

. The following (or variations of it) may show up on the top of the search results.

[https://grass.osgeo.org > download](https://grass.osgeo.org/download) ⋮
[Download - Grass GIS - OSGeo](#)
 Download your free and open source copy ... **GRASS GIS** for Linux. **Download GRASS GIS** packages for your favorite Linux distribution. **Download ...**
[GRASS GIS for Windows](#) · [Linux](#) · [Mac](#) · [Data](#)


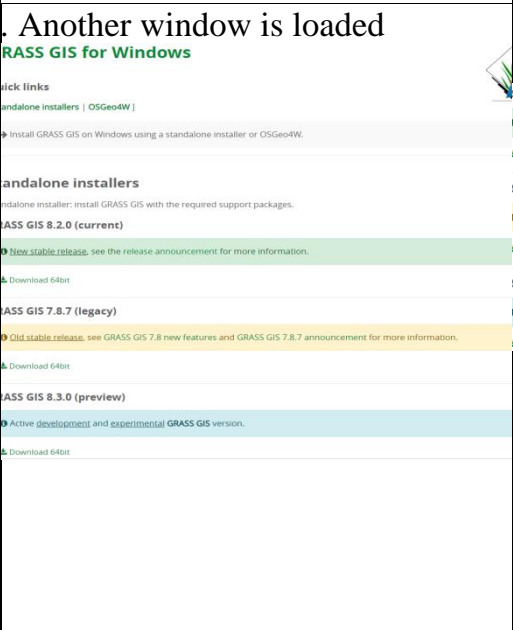
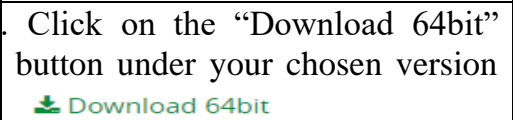
[https://grass.osgeo.org > download > windows](https://grass.osgeo.org/download/windows) ⋮
[download - windows - Grass GIS - OSGeo](#)
 Active development and experimental GRASS GIS version. Download 64bit. OSGeo4W.

. Click on the “Download Grass GIS - OSGeo” link and it will take you to the same website that mentioned on item 1 (if the website is yet to be updated). The image below is a snapshot of the top of the online directory. When you scroll down, you will find the software versions for different operating systems, e.g., Linux, Windows, etc.



. Scroll down until you find “GRASS GIS for Windows” or the version that suits your need.

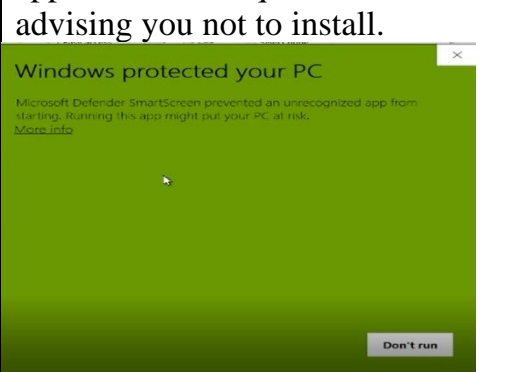
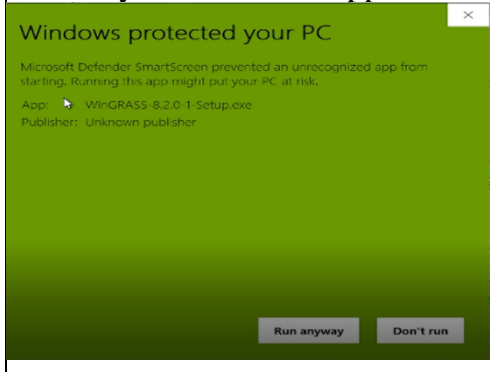
. Click on the “DOWNLOAD” button on the screen.

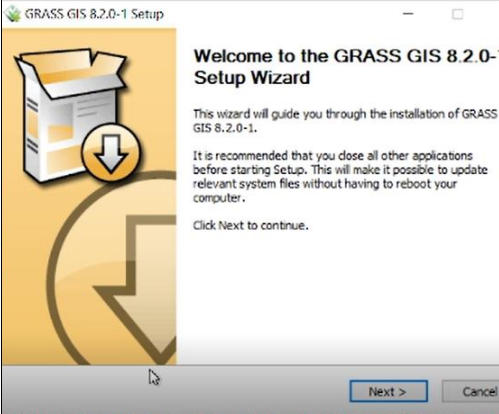
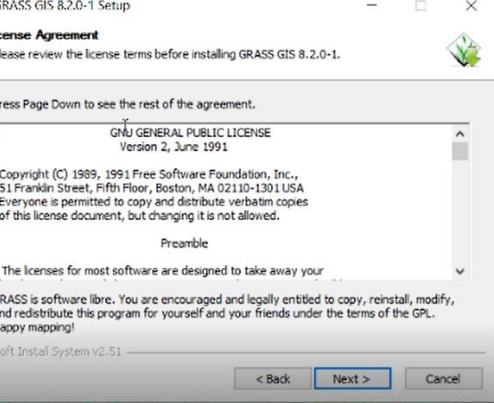
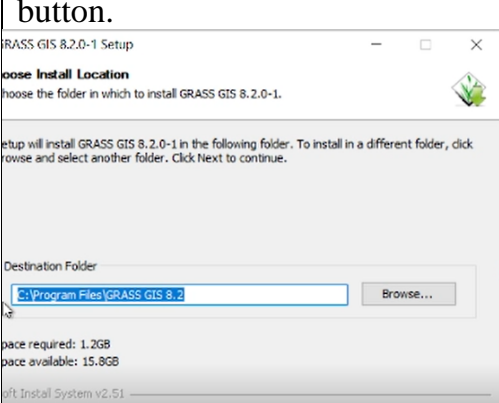
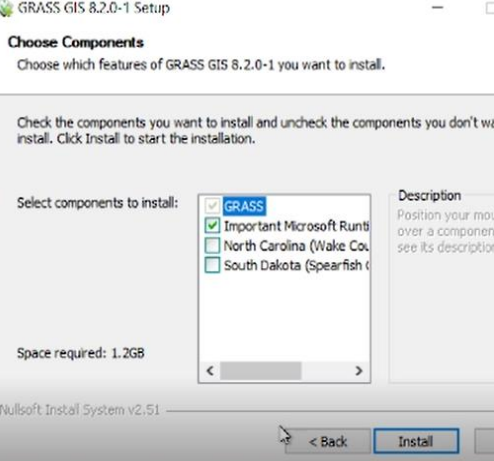
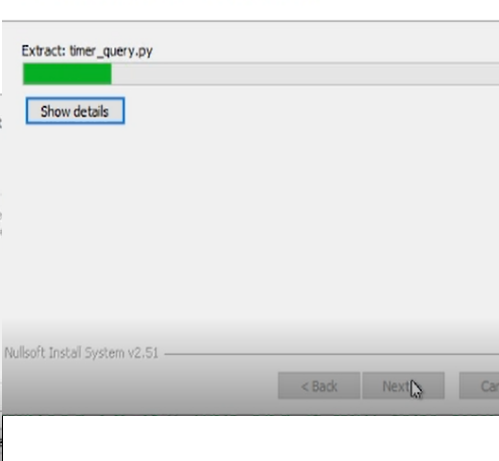
	<p style="text-align: center;">DOWNLOAD</p>
<p>Another window is loaded</p> 	<p>On the window you may see three major download options</p> <p>You may preferably go for the current version. If you choose, you may download the legacy (older) version. You should not download the preview version because it is not yet fully developed.</p>
<p>Click on the “Download 64bit” button under your chosen version</p> 	<p>The Download process automatically begins.</p>

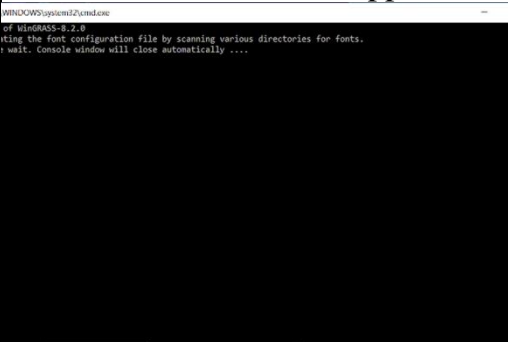
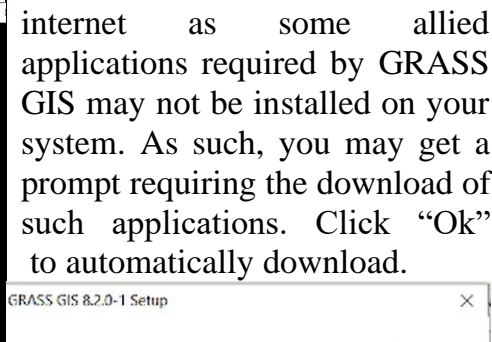
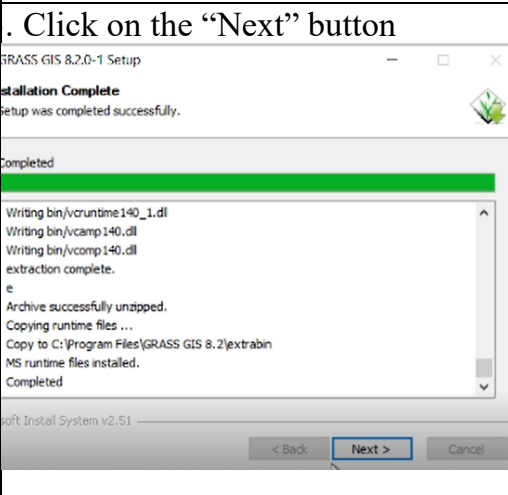
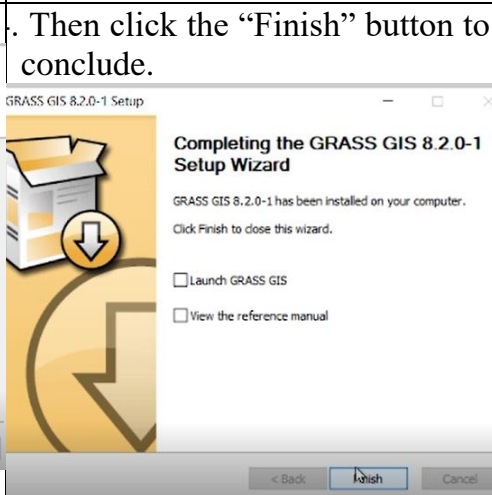
Self-Assessment Exercise

Show evidence of downloaded GRASS GIS software (an image of the downloaded software in a folder).

3.3.2.2 Installation of Grass GIS

<p>1. Double-click on the downloaded software to load the installation window (or right-click on the downloaded software and select “Open” or “Run as administrator” in the context menu).</p>	
<p>2. You may get a prompt warning you that the source of the application is questionable and advising you not to install.</p> 	<p>3. Click in the “More information” link in the loaded prompt to enable you the run the application</p> 
<p>Click on “Run anyway” the load the actual installation window.</p>	

<p>Run anyway Don't run</p>	
<p>Note that for most people you may not be required to go through this stage, so you may actually skip from stage 1 to stage 5.</p>	
<p>5. Your window may go blank with a prompt requiring you to confirm whether you want to allow the application to make some changes in your system. Click the “Yes” button to commence the actual installation. Information will be loaded with the other options still listed below it.</p>	<p>6. It loads the installation window. Click the “Next” button</p> 
<p>7. The license agreement window appears. Click the “Next” button.</p>	<p>8. No need to change the installation directory so click the “Next” button.</p>
	
<p>9. Accept default installation settings by clicking on the “Install” button.</p>	<p>10. The installation process begins</p>
	

<p>. It may momentarily load a dark window, which soon disappears.</p>	<p>. Note that while installing, you should be connected to the internet as some allied applications required by GRASS GIS may not be installed on your system. As such, you may get a prompt requiring the download of such applications. Click “Ok” to automatically download.</p>
	
<p>. Click on the “Next” button</p>	<p>. Then click the “Finish” button to conclude.</p>
	

Self-Assessment Exercise

Show evidence of successful GRASS GIS installation (an image of the open QGIS window).

3.4 Conclusion

Having installed these software packages, in subsequent units, we will use them to run some spatial analysis and generate map products.

3.5 Summary

From this unit, you have learnt about the download and installation of open-source GIS software. Some of the key things learnt include the following;

- How to download QGIS software
- How to install QGIS software
- How to download GRASS GIS software
- How to install GRASS GIS software

3.6 Tutor-Marked Assignment

1. Show evidence of download and installation of QGIS software
2. Show evidence of download and installation of GRASS GIS software

3.7 References/Further Reading/Web Resources

For audiovisual tutorials on the download and installation of QGIS and GRASS GIS software packages and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

QGIS Download

<https://www.youtube.com/watch?v=AvKpkFqS30c&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=1>

QGIS Installation

<https://www.youtube.com/watch?v=fRjGxExGM9o&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=3>

GRASS GIS Download

<https://www.youtube.com/watch?v=j-03WXwgiO0&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=4>

GRASS GIS Installation

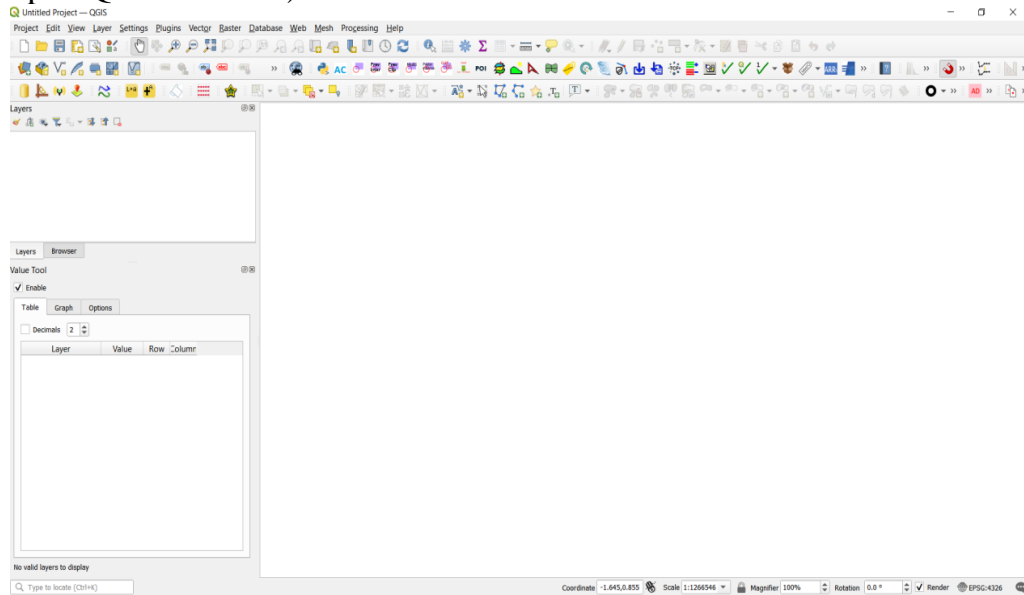
<https://www.youtube.com/watch?v=iFndfBGM8HI&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=5>

3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Show evidence of downloaded QGIS software (an image of the downloaded software in a folder).



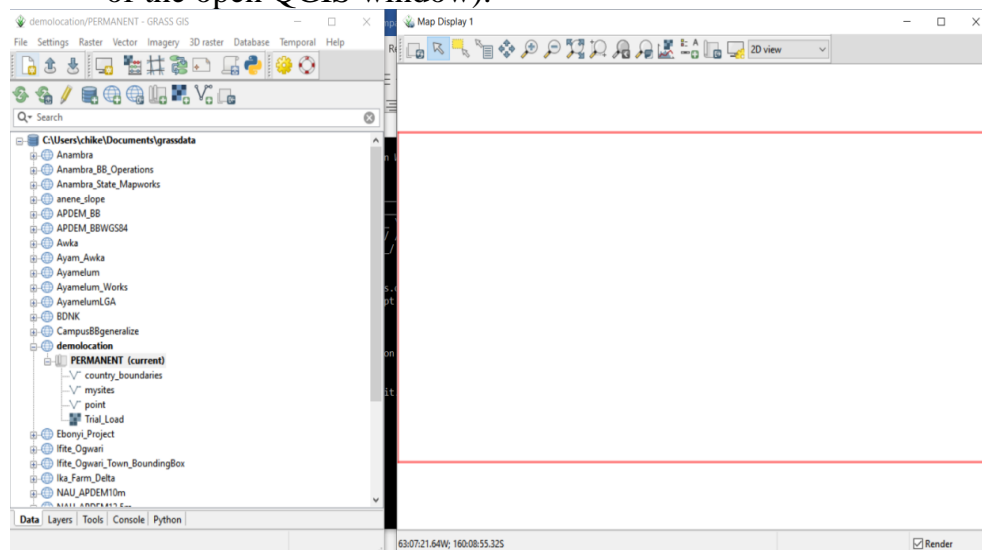
2. Show evidence of successful QGIS installation (an image of the open QGIS window).



3. Show evidence of downloaded GRASS GIS software (an image of the downloaded software in a folder).



4. Show evidence of successful GRASS GIS installation (an image of the open QGIS window).



MODULE 5 GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

Unit 1	Satellite Navigation
Unit 2	Importance of the GNSS
Unit 3	Download and Installation of GNSS Applications

UNIT 1 SATELLITE NAVIGATION

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Satellite Navigation
 - 1.3.2 Geographical Positioning System
 - 1.3.3 Other Global Navigation Satellite Systems
 - 1.3.3.1 Global Navigation Satellite System (GLONASS)
 - 1.3.3.2 BeiDou Navigation Satellite System
 - 1.3.3.3 Galileo
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

The geographic coordinates, as reflected in the geographic coordinate system, enable us to determine the location of any particular point on the earth surface. The location is a function of the longitude and latitude of the site. Each location on the earth surface has a unique longitude and latitude. As such, if I record the longitude and latitude (geographic coordinates) of my house in Nigeria and send it to a friend in the Netherlands who has never been to Nigeria, he would be able to locate my house without any further directive from me. The device that enables him to do that is called the global navigation satellite systems (GNSS) device. The GNSS is a system that uses satellites to provide autonomous geo-spatial positioning, giving a measurement of the longitude, latitude and altitude at any given site. The first and most popular GNSS satellites is the global positioning system (GPS) launched by the US. Other subsequently GNSS satellite constellations are Russia's Global Navigation Satellite System (GLONASS), China's BeiDou Navigation

Satellite System (BDS) and the European Union's Galileo. These GNSS systems have been used extensively all over world. Some of its applications will be explored in this section.

1.2 Objectives

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

- Discuss satellite navigation
- Explain the meaning of geographical positioning system
- List and briefly discuss other global navigation satellite systems

1.3 Main Content

1.3.1 Satellite Navigation

Satellite Navigation is based on a global network of satellites that transmit radio signals from medium earth orbit. A satellite navigation system is a system that uses satellites to provide autonomous geo-spatial positioning. It allows small electronic receivers to determine their location (longitude, latitude, and altitude/elevation) to high precision (within a few centimeters to meters) using time signals transmitted along a line of sight by radio from satellites. The system can be used for providing position, navigation or for tracking the position of something fitted with a receiver (satellite tracking).

It is a burgeoning technology, which provides unequalled accuracy and flexibility of positioning for navigation, surveying and GIS data capture. It provides continuous three-dimensional positioning 24 hours per day throughout the world. The three-dimensional nature of GNSS measurements also allows us to determine horizontal as well as vertical displacement at the same time and place. The GNSS technology has a tremendous number of applications in GIS data collection, surveying, and mapping.

Several GNSS systems exist, namely, the United States' Global Positioning System (GPS), Russia's Global Navigation Satellite System (GLONASS), China's BeiDou Navigation Satellite System (BDS) and the European Union's Galileo. Of all these, users of Satellite Navigation are most familiar with the 31 Global Positioning System (GPS) satellites developed and operated by the United States.



Figure 31: GNSS Satellites and their Orbits

Self-Assessment Exercise

List four global satellite navigation systems (GNSS).

1.3.2 Geographical Positioning System (GPS)

The GPS uses constellation of up to 32 satellites, continuously orbiting earth and computers to compute positions anywhere on earth (Figure 32). These were first launched in 1978. The GPS is based on satellite ranging. That means the position on the earth is determined by measuring the distance from a group of satellites in space. In order to understand GPS basics, the system can be categorized into five logical steps:

- (1) Triangulation from the satellite is the basis of the system
- (2) To triangulate, the GPS measures the distance using the travel time of the radio message
- (3) To measure travel time, the GPS need a very accurate clock
- (4) Once the distance to a satellite is known, then we need to know where the satellite is in space
- (5) As the GPS signal travels through the ionosphere and the earth's atmosphere, the signal is delayed.

To compute a position in three dimensions we need to have four satellite measurements. The GPS uses a trigonometric approach to calculate the positions, The GPS satellites are so high up that their orbits are very predictable and each of the satellites is equipped with a very accurate atomic clock.

The introduction of modern technologies has led to an increased use of computers and information technology instead of manual methods in all aspects of spatial data handling. The software technology used in this domain is geographic information systems (GIS).

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation. This enables people to more easily see, analyze, and understand patterns and relationships.

In short geographical information system gives power to create maps, integrate information, visualize scenarios, solve complicated problems, present powerful ideas and develop effective solutions like never before. It can be said as supporting tool for decision making process. Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods.



Figure 32: GPS Satellites and their Orbits

Self-Assessment Exercise

List the five logical steps that the GPS system is categorized into.

1.3.3 Other Global Navigation Satellite Systems

1.3.3.1 Global Navigation Satellite System (GLONASS)

GLONASS was first launched in 1982 by the formerly Soviet, and now Russian Federation. It is a space-based satellite navigation system that provides a civilian radionavigation-satellite service and is also used

by the Russian Aerospace Defense Forces. GLONASS has had full global coverage since 1995 and with 24 active satellites.

1.3.3.2 Beidou Navigation Satellite System

BeiDou Navigation Satellite System was first launched in 2000 by China. It started as the now-decommissioned Beidou-1, an Asia-Pacific local network on the geostationary orbits. The second generation of the system BeiDou-2 became operational in China in December 2011. The BeiDou-3 system is proposed to consist of 30 Medium Earth Orbit (MEO) satellites and five geostationary satellites (IGSO). A 16-satellite regional version (covering Asia and Pacific area) was completed by December 2012. Global service was completed by December 2018. On 23 June 2020, the BDS-3 constellation deployment was fully completed after the last satellite was successfully launched at the Xichang Satellite Launch Center.

1.3.3.3 Galileo

Galileo was first launched in 2011 by the European Union Space Agency (ESA). The European Union and the European Space Agency agreed in March 2002 to introduce their own alternative to GPS, called the Galileo Positioning System. Galileo became operational on 15 December 2016. The estimated cost of installation for the 30 Medium Earth Orbit (MEO) satellites was €10,000,000,000. Galileo was designed to be compatible with the modernized GPS system. Receivers are able to combine the signals from both Galileo and GPS satellites to greatly increase the accuracy of navigation. The full Galileo constellation currently consists of 24 active satellites, the last of which was launched in December 2021.

Self-Assessment Exercise

How many satellites does the full Galileo constellation currently consists of?

1.4 Conclusion

To effectively measure the location of a site, the GNSS receiver must receive GNSS signal from at least four satellites. Luckily most GNSS satellites are available for use freely. More so, irrespective of the fact that there are currently four major GNSS systems, they were all designed in such a way that they are largely compatible with each other. As such, no matter where you are on earth, at any particular moment, you are likely to receive GNSS signals, unless you are in a densely forested area or inside a house.

1.5 Summary

From this unit, you have learnt about satellite navigation. Some of the key things learnt include the following;

- Satellite navigation
- Geographical positioning system (GPS)
- Global navigation satellite system (GLONASS)
- BeiDou navigation satellite system
- Galileo

1.6 Tutor-Marked Assignment

1. What is geographic satellite navigation system (GNSS)
2. List the four main GNSS and discuss two of them.

1.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List four global satellite navigation systems (GNSS).
 - i) *United States' Global Positioning System (GPS),*
 - ii) *Russia's Global Navigation Satellite System (GLONASS),*
 - iii) *China's BeiDou Navigation Satellite System (BDS)*
 - iv) *European Union's Galileo*
2. List the five logical steps that the GPS system is categorized into.
 - (1) *Triangulation from the satellite is the basis of the system*
 - (2) *To triangulate, the GPS measures the distance using the travel time of the radio message*
 - (3) *To measure travel time, the GPS need a very accurate clock*
 - (4) *Once the distance to a satellite is known, then we need to know where the satellite is in space*
 - (5) *As the GPS signal travels through the ionosphere and the earth's atmosphere, the signal is delayed.*
3. How many satellites does the full Galileo constellation currently consists of?
It consists of 24 active satellites.

UNIT 2 IMPORTANCE OF THE GNSS

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Importance of the GNSS
 - 2.3.2 Global Earth Observation System of Systems (GEOSS)
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

Global Navigation Satellite Systems (GNSS) are now an integral part of all aspects of our lives. They play a crucial part in logistics and transportation; asset tracking and security; industry and agriculture; smartphones and semi-automated cars; and surveying and monitoring of natural/environmental resources. They also enable the sustenance of the nine societal benefits of the Global Earth Observation System of Systems (GEOSS), which will be discussed subsequently.

2.2 Objectives

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

- Explain the importance of the GNSS

2.3 Main Content

2.3.1 Importance of The Gns

Global Navigation Satellite Systems (GNSS) are now an integral part of all aspects of our lives. GNSS positioning, navigation and timing services has found several potential applications, from individuals and families to schools and industries. Furthermore, recent cross-disciplinary scientific research is now opening up the value of the navigation signals to a wider market, especially the Earth Observation (EO) community, who are using them to solve problems in new and novel ways. Some of these include:

1. **Logistics and transportation:** GNSS enable real-time access to the location of items for delivery. When products are ordered, the manufacturer, the logistics company, and the buyer can track the movement of the items, through dispatch right to their delivery. It

is also used extensively in the transport industry, such as rail, aviation, and marine transportation. On rail transport, you can track the location of all locomotives and cars, map the position of other trains and minimize accidents, delays, etc. Without GNSS, pilots will be lost in the air. From departure, enroute, and navigating unseen atmospheric conditions to the landing, GNSS systems guide the entire aviation system. The same also applies to marine transport. Captains can know their exact location and bearing via GNSS-enabled methods. For road transportation, it is an integral part of vehicle navigation systems for route planning; in aviation, GNSS devices are crucial for navigation and precision landing, working, whereas, in the maritime industry, both stand alone and integrated navigation systems are essential.

2. **Asset tracking and security:** Everyone knows what a car GPS tracker is, and this is one primary application of GNSS surveillance systems. With GNSS, you can confirm the location of your vehicle in case of theft and track it to its location. Beyond cars, luggage misplacement at the airport is often a common issue and can be avoided by monitoring devices.
3. **Wearables:** Currently, there are several smartwatches and health monitors that can track an individual's movement. They also alert and call for help during health crises or accidents and then enable the person's position to be located. Fitness trackers also make use of GNSS solutions. Further applications of GNSS include monitoring kids' locations at parks, monitoring convicts, looking after older patients with degenerative diseases, etc.
4. **Industry and agriculture:** GNSS have also found application in industry and agriculture. This ranges from monitoring incoming trucks to increasing the efficiency of farm machinery. It extends to soil monitoring, livestock tracking, forest management, and precision farming.
5. **Smartphones and semi-automated cars:** GNSS have found a massive application with smartphones and cars. This covers GPS-enabled maps for self-driving cars. GNSS has seen the most widespread use currently in smartphone devices. You can easily access the best routes with less traffic and know about the nearest hotels, eateries, etc. Self-driving cars are becoming more common and all this has a heavy reliance on positioning systems.
6. **Surveying:** Similarly, GNSS devices have found tremendous application domains in land, hydrographic, geologic, land cover, soil surveys, etc.

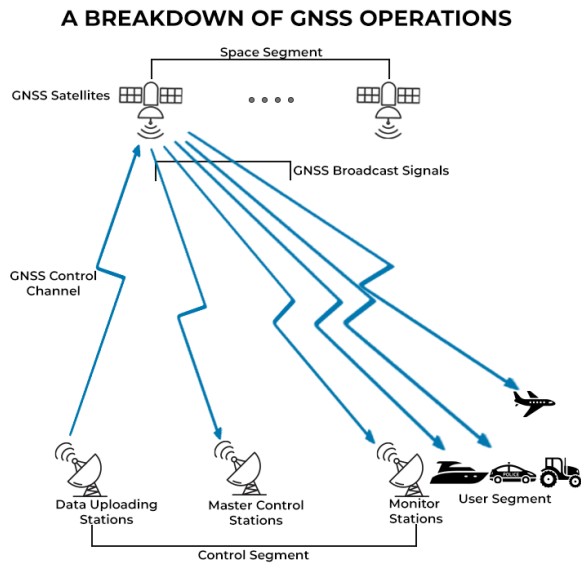


Figure 33: GNSS Controls and Some Applications

Self-Assessment Exercise

List four industries that use the GNSS systems.

2.3.2 Global Earth Observation System of Systems (GEOSS)

Group on Earth Observations is an intergovernmental organization responsible for coordinating and improving earth observations through the creation of the Global Earth Observation System of Systems (GEOSS). GEOSS is building links between content providers for global observing systems and providing support for the development of new systems where gaps currently exist. It simultaneously addresses nine areas of critical importance to people and society, for which GNSS is of fundamental importance.



The benefits of GNSS for GEOSS

Figure 34: Nine Societal Benefits of GEOSS for which GNSS is Fundamentally Important

DISASTERS:

A new understanding of volcanic and seismic events and precursors has been brought about by precise (millimeter scale) monitoring of the earth's crust in vulnerable areas. GNSS buoys are becoming an important part of tsunami early warning systems. GNSS navigation allows emergency relief to be delivered –especially in areas with little or no mapping. GNSS Reflectometry is able to provide information on the extent and depth of flooding.

HEALTH:

GNSS positioning enables individual patients, staff or equipment to be monitored, and response teams directed more efficiently. The Galileo Search and Rescue Service will provide a two-way link between victims and rescuers.

The conditions that enable communicable diseases to propagate can be monitored using GNSS techniques: e.g., water levels and humidity, biomass, animal movement.

ENERGY:

The logistics of delivering the raw materials, and safely disposing of waste are now governed by GNSS.

Smart-Grids need sub millisecond coordinated timing to work efficiently, this can only be provided by GNSS.

GNSS Reflectometry techniques can produce scatterometry models to assist in the optimum positioning of off-shore wind farms.

**CLIMATE
WEATHER:**

& The two areas are very similar, weather is a short to medium-term commentary, whereas climate is the analysis of long-term (at least 30 years) statistics.

GNSS Radio Occultation - measuring the refraction of GNSS signals to either a monitoring satellite in a lower orbit, or ground receiver, provides information about the temperature and the water vapour content of the atmosphere. As the geometry of the transmitting satellite and the receiver change, it is possible to scan different layers of the atmosphere in almost real time.



GNSS positioning can be used to monitor the height, speed and extent of glaciers. Reflectometry can give information about the depth and type of snow or ice.

WATER:

Precise measurement of vertical movements of the Earth's surface by GNSS, enables the precise calibration of tide gauges for monitoring sea-level variation in coastal waters. GNSS buoys provide tidal and sea-level variations beyond these areas. Ocean surface height and roughness / sea-state, can also be calculated from the reflected signals picked up by adapted GNSS receivers.

ECOSYSTEMS:

GNSS Reflectometry offers the potential for monitoring vegetation and biomass. It also has an important role in providing information for global monitors such as: carbon modelling, greenhouse gas emission inventories and deforestation control.

AGRICULTURE:

GNSS contributes to drought early warning systems through improved climate data, soil moisture monitoring, monitoring of lake and reservoir levels, vegetation growth and stress monitoring of vegetation.

GNSS assists Precision Agriculture – enabling precise application of seed, fertilizer, water and pest control even in low visibility and night-time working.

BIODIVERSITY:

The use of GNSS Telemetry for tracking migratory species, gives important information about the feeding and resting patterns, and even the health of individual animals.

GNSS Reflectometry can monitor vegetation and even provide the data for modelling biomass, an important factor in calculating greenhouse gas emissions and deforestation.

Self-Assessment Exercise

List five application domains of GNSS systems.

2.4 Conclusion

GNSS has so much to offer in connected technology. The future is bright and full of amazing innovations. Soon enough, we will have a widespread network of smart devices that can sense, locate, anticipate and prepare for specific situations. Smart phones are just a precursor; there is more to come.

2.5 Summary

From this unit, you have learnt about the importance of the GNSS. Some of the key things learnt include the following;

- Importance of the GNSS
- Global earth observation system of systems (GEOSS)

2.6 Tutor-Marked Assignment

1. Discuss the importance of the GNSS?
2. Under what condition have you personally used it?

2.7 References/Further Reading/Web Resources

Kerle, N., Janssen, L.L.F. & Huurneman, G.C. (Eds.) (2004) Principles of Remote Sensing: An Introductory Textbook. Enschede: The International Institute for Geo-Information Science and Earth Observation (ITC). 250 pp.

Khargharia, R. (2021) An Overview on Remote Sensing: Principle and Applications. Agri-India TODAY 1(5): 12-14.

Marghany, M. (2016) Environmental Applications of Remote Sensing. ExLi4EvA Publisher.

Shekar, S. and Xiong, H. (2008) Encyclopedia of GIS. New York, USA: Springer.

2.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List four industries that use the GNSS systems.
 - i) *Logistics and transportation*
 - ii) *Asset tracking and security*
 - iii) *Agriculture*
 - iv) *Smartphones and semi-automated cars*

2. List five application domains of GNSS systems.
 - i) *Disaster/hazard assessment and rescue mission*
 - ii) *Exploration and management of energy*
 - iii) *Assessment and monitoring of climate/weather dynamics*
 - iv) *Assessment of ecosystem dynamics and biodiversity*
 - v) *Agriculture*

UNIT 3 **DOWNLOAD AND INSTALLATION OF GNSS APPLICATIONS**

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3 Main Content
 - 3.3.1 Download and Installation of GNSS Applications for Android Devices
 - 3.3.2 Download and Installation of GNSS Applications for Ipad and Iphone Devices
 - 3.3.3 Record Geographic Coordinates
 - 3.3.3.1 Record Geographic Coordinates with Android Devices
 - 3.3.3.2 Record Geographic Coordinates with Ipad or Iphone Devices
 - 3.3.4 Save Geographic Coordinates in Excel
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

Gnss Receivers Are The Core Product For Satellite Positioning. They Convert Signals From Visible Satellites Into A Position On Earth. The Number Of Visible Satellites Is Dependent On The Number Of Constellations The Receiver Is Compatible With, Such As Gps, Glonass, Galileo And Beidou. The Greater The Number Of Satellites Whose Signals The Receiver Can Receive, The Greater The Precision Of The Measured Coordinates. Unfortunately, These Receivers Are Not Readily Available. Luckily, Most Smart Phones Currently Have In-Built Gps Or Gnss Receivers. As Such, Geographic Coordinates Can Be Captured With Phones And Tablets. Also, Due To Recent Technological Advancements, A Lot Of Gnss Applications Compatible To Tablets And Android Phones Have Been Developed. We Are Going To Download, Install And Use Some Of These Applications In This Unit.

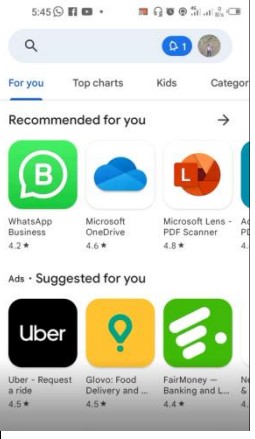
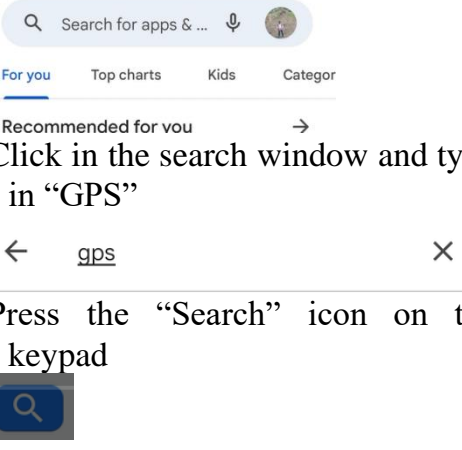
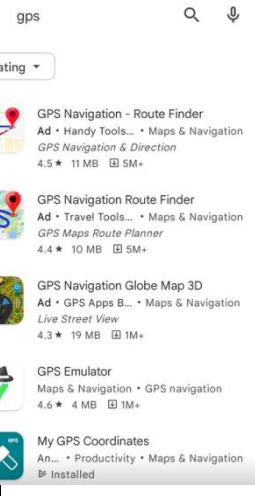
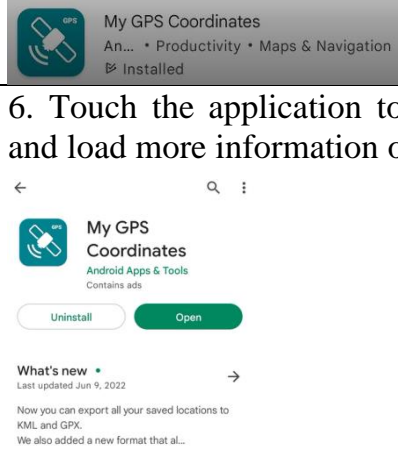
3.2 Objectives

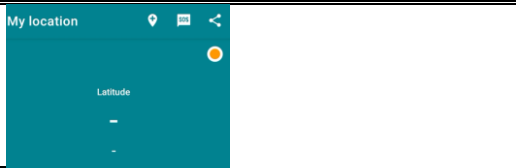


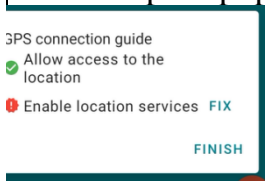
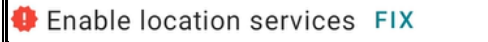
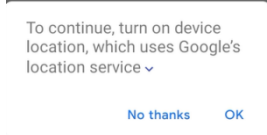



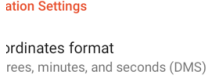
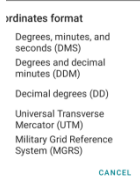
By The End Of This Unit, You Will Be Able To:

- Download And Install of Gnss Applications
- Collection Of Geographic Coordinates Using Gnss Applications

3.3 Main Content

3.3.1 Download and Installation of GNSS Applications for Android Devices

<p>1. Load the Google Play Store application in your android device -</p> <p>2. The google play store opens, displaying an array of applications.</p> 	<p>3. You can see the “Search for app...” window at the top of the screen</p> <p>Click in the search window and type in “GPS”</p> <p>Press the “Search” icon on the keypad</p> 
<p>A long list of GPS-related application is loaded</p> 	<p>5. Scroll up and down to find an appropriate application. In this tutorial, we will select “My GPS Coordinate”</p> <p>6. Touch the application to select and load more information on it.</p> 
<p>7. Press the “Install” button. (In this tutorial, you see it as “uninstall” because I have already installed the application. As such, when an application is installed the button changes to from “Install” to “Uninstall”)</p>	<p>8. The screen is momentarily blank</p>

<p>Uninstall</p>	
<p>3. The following image is momentarily loaded</p> 	
<p>0. Touch the location icon on the top righthand side of the screen.</p> 	<p>1. A new prompt pops up.</p> 
<p>2. Press “FIX” in front of “Enable location services”. This may not pop up if the location service is already switched on in your android device.</p> 	<p>3. A new message pops up.</p> 
<p>4. Press the “Ok” button to load a new window.</p> 	<p>5. The coordinates are loaded.</p> 
<p>6. It is easier to use the decimal degrees in a GIS analysis. Touch the settings icon  to update from degrees, minutes and seconds to decimal degrees. A new window loads.</p>	<p>7. Touch “Coordinates format” in the new window</p>  <p>8. A new context menu appears from which you select “Decimal Degrees (DD)”</p>  <p>9. The settings window is reloaded with the coordinates changed to decimal degrees.</p>

<p>4. Return to the GPS window to note that the coordinate format has changed.</p>	

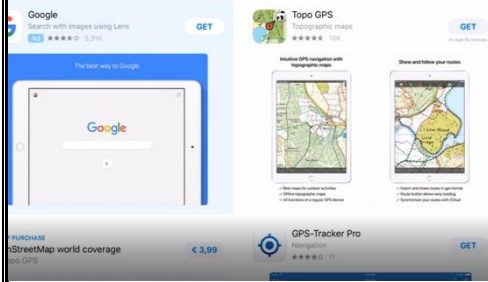
Self-Assessment Exercise

Show evidence of first GPS reading (if you used an Android device).

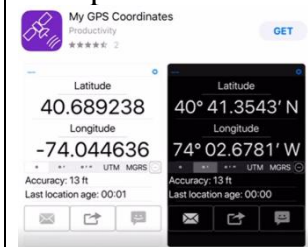
3.3.2 Download and Installation of GNSS Applications For IPAD and Iphone Devices

<p>1. Load the App Store application in your Ipad device -</p>	
<p>2. The App Store opens, displaying an array of applications.</p>	<p>3. At the bottom righthand of the screen, you can see the “search” button.</p>
	<p>Click in the search window and type in “GPS”</p>
<p>Press the “Search” icon on the keypad</p>	

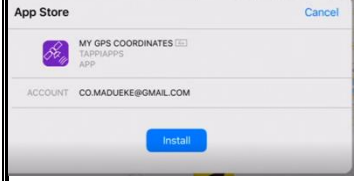
A new window with a long list of GPS-related application is loaded



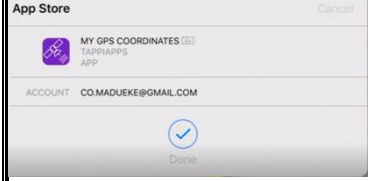
5. Scroll up and down to find an appropriate application. In this tutorial, we will select “My GPS Coordinate” by pressing “GET” on top of it.



6. Press the “Install” button in the pop-up window.

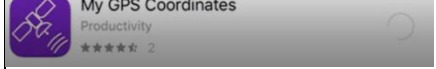


Which changes to

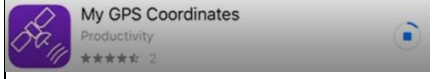


Then disappears.

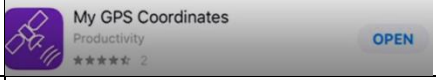
7. You will notice that “GET” has been replaced by a whitish revolving icon



Which soon turns into a blue ever-increasing circle with a blue square in the middle.

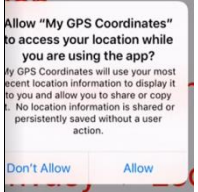


When the blue circle completes, the installation is complete and the icon is replaced by “OPEN”

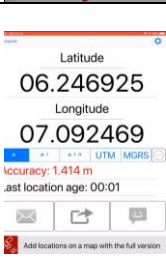


Touch “OPEN” to load the application. If location setting is not activated in your device, you will get an error message (probably with a lot of red letters).

A new pops-up window appears on the error message. Press “Allow” on the window.



8. The geographic coordinates are loaded in the GPS window.



9. You can format the coordinates to meet your needs using the menu below the coordinates.



10. The decimal coordinates = Decimal Degrees, = Degrees and Minutes, = Degrees, Minutes and Seconds,

	while UTM = Universal Transverse Mercator
3. Close application. When the need arises, open from the icon on the tablet menu (desktop)	



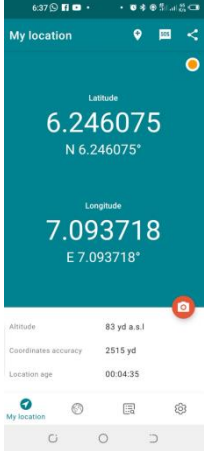

Self-Assessment Exercise

Show evidence of first reading (if you used an Apple device).

3.3.3 Record Geographic Coordinates

The geographic coordinates (longitude, latitude and altitude) can be recorded on a field book during the fieldwork or recorded on the devices (android or tablet), or both. In the subsequent sections we will go through the measurement and recording steps.

3.3.3.1 Record Geographic Coordinates With Android Devices


1. Open the GPS coordinate application from your phone desktop - 		
2. It begins to load with the following screen 		
The coordinate eventually load. (Note that if the location setting is not activated, you may have to go through the appropriate steps outlined in the download and installation tutorial). 		
4. Stand for a short while on the site of interest to allow the reading to stabilize. Record the reading on a piece of paper, along with the site name and other features.	5. Alternatively, if you want to record the reading on the device, press the camera-like icon within the red background. 	
A new window opens in which the readings are outlined. Press the circular icon at the bottom center.	A new window appears, showing an image of the site. Press the larger white circular icon at the bottom of the screen.	Minor adjustment is made to the window. Touch the tick mark at the bottom right.

<p>2. In the new window, press “SAVE”.</p>	<p>3. Type in an appropriate name and press “OK”.</p>	
	<p>2. Press “OK”</p>	
<p>13. You do not need to close the application (if you choose). Walk (or drive or run, etc.) to the next site and repeat steps 4 to 12. Repeat as many times as necessary.</p>		

Self-Assessment Exercise

Show evidence (image) of one reading (if android device was used).

3.3.3.2 Record Geographic Coordinates with Ipad or Iphone Devices

<p>1. Open the GPS coordinate application from your tablet desktop - </p>		
<p>2. The site coordinates are automatically loaded.</p>	<p>3. Wait for the reading to stabilize (and if the accuracy is red and high, wait for it to turn black and good down to</p>	<p>5. Type in your email address(es) and change the subject to capture the variations in site name, since you may repeat the process for several sites. Send the mail.</p>

less than or equal to 5. Record coordinate.

4. Alternatively, if no paper is available or you want to play safe and have a back-up record, touch the envelope icon to email it to yourself.

You do not need to close the application (if you choose). Walk (or drive or run, etc.) to the next site and repeat steps 2 to 5. Repeat as many times as necessary.

Self-Assessment Exercise

Show evidence (image of the email) of one reading (if Apple device was used).


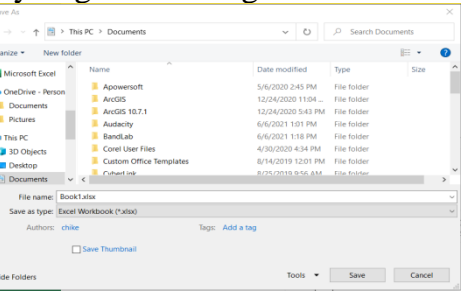
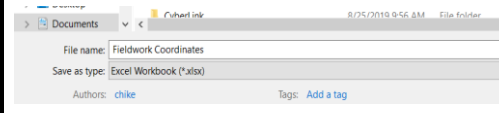
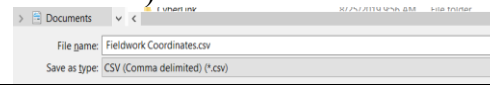
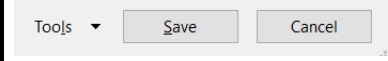
3.3.4 Save Geographic Coordinates in Excel

For the Ipad open you email and for the android device open the images. Type the coordinates (Longitude [X], Latitude [Y] and Altitude [Z]) into a Microsoft Excel document. The document would subsequently not be saved as an Excel workbook, but as a CSV (comma-separated values).

For the tablet you get an email, while for the phone, you get an image, as shown below. Note that in the email, you will not see the altitude, but you can see the altitude in the android image.

Type the site coordinates generated in the course of the fieldwork into a Microsoft Excel workbook.

	A	B	C	D
	Site	Longitude (X)	Latitude (Y)	Altitude_yd (Z)
1	Site 1	7.091557	6.248142	89
2	Site 2	7.091321	6.248043	91
3	Site 3	7.091664	6.248106	83
4	Site 4	7.09183	6.246456	83
5	Site 5	7.091971	6.246252	83
6	Site 6	7.092207	6.246211	83
7	Site 7	7.092569	6.245537	83
8	Site 8	7.090281	6.244516	91
9	Site 9	7.090624	6.247006	103
10	Site 10	7.090773	6.247849	91
11	Site 11	7.091274	6.24777	91

	<p>3. Go through the process of saving the excel workbook until you get to the sage below.</p> 
<p>4. Type in an appropriate file name.</p> 	<p>5. Click on the arrow in front of the “Save as type: Excel Workbook...” to show other formats. Select “CSV (Comma delimited)” from the list.</p> 
<p>6. Press the “Save” button</p> 	<p>7. The document is saved as a CSV file. Make sure you know where you saved it in the system because you will use it in subsequent units.</p>

Self-Assessment Exercise

Show evidence of satellite data in MS Excel.

3.4 Conclusion

The GNSS receive can be used as a tool to aid in the determination of the geographic coordinates of a site. Armed with this coordinate, someone who has not been to the site can locate it with some degree of accuracy. Nevertheless, the GNSS receiver can also be used to capture the boundaries of a particular area of land. For instance, if a farmer acquires a piece of land of about 5 hectares, the GNSS receiver can be used to delineate the boundary. To do this, the geographic coordinates of the sharp edges of the land can be captured, such that when these edge coordinates are linked, the boundaries would have automatically been delineated. If the land is square or rectangular, the job is easier as all you need to do is to capture the coordinates of the four corners. If it is irregular, the task becomes more cumbersome, but still very achievable. We have captured a couple of these in this unit. These have been outlined

in the Microsoft Excel document. We will use those to generate maps in subsequent units.

3.5 Summary

From this unit, you have learnt about the download and installation of GNSS applications. Some of the key things learnt include the following;

- Download and installation of GNSS applications
- Record geographic coordinates
- Save geographic coordinates in excel

3.6 Tutor-Marked Assignment

1. Provide a screenshot of the navigation system you downloaded.
2. Provide a screenshot of one of your position measurements.
3. Provide an excel sheet with the list of your recorded geographic coordinates.
4. Prior to using this tutorial, have you used your phone GPS as outlined in this tutorial? If so, explain the circumstance.

3.7 References/Further Reading/Web Resources

For audiovisual tutorials on the download, installation and utilization of GPS or GNSS applications and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Installing a GPS Application on an Android Device

<https://www.youtube.com/watch?v=FwmWyomfN7E&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=6>

Recording Site Coordinates On-the-Go with an Android Device

<https://www.youtube.com/watch?v=yV7TNsO7uJM&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=7>

Installing a GPS Application in a Tablet Device

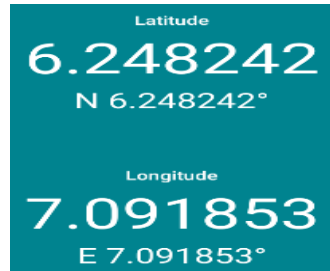
<https://www.youtube.com/watch?v=cKTHOm2DZ9Y&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=8>

Recording Site Coordinates On-the-Go with a Tablet Ipad Device

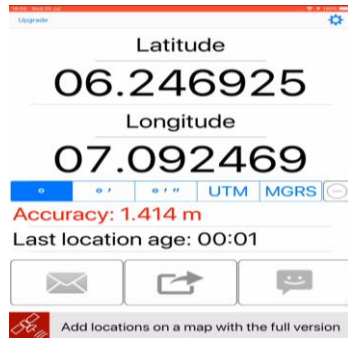
<https://www.youtube.com/watch?v=XVCuGniMmqc&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=9>

3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

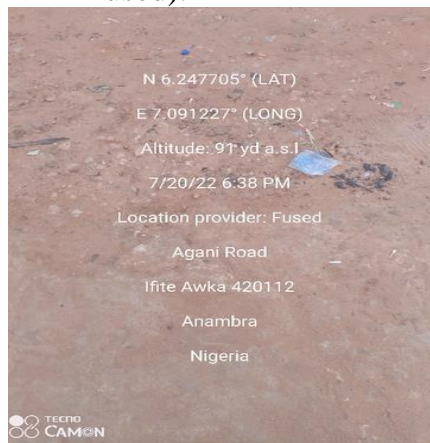
1. Show evidence of first GPS reading (if android device was used).



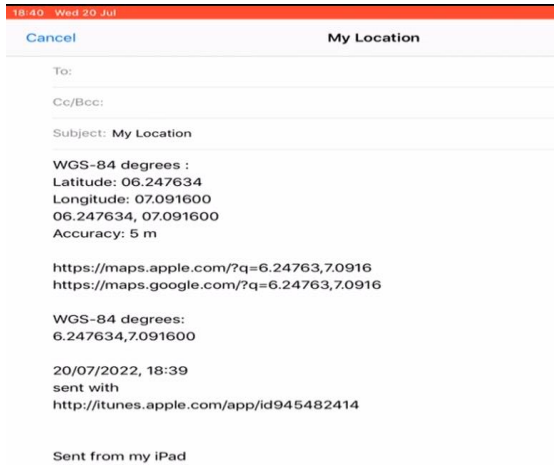
2. Show evidence of first reading (if Apple device was used).



4. Show evidence (image) of one reading (if android device was used).



4. Show evidence (image of the email) of one reading (if Apple device was used).



5. Show evidence of satellite data in MS Excel.

	A	B	C	D
1	Site	Longitude (X)	Latitude (Y)	Altitude_yd (Z)
2	Site 1	7.091557	6.248142	89
3	Site 2	7.091321	6.248043	91
4	Site 3	7.091664	6.248106	83
5	Site 4	7.09183	6.246456	83
6	Site 5	7.091971	6.246252	83
7	Site 6	7.092207	6.246211	83
8	Site 7	7.092569	6.245537	83
9	Site 8	7.090281	6.244516	91
10	Site 9	7.090624	6.247006	103
11	Site 10	7.090773	6.247849	91
12	Site 11	7.091274	6.24777	91
13				

MODULE 6 COMPUTER CARTOGRAPHY

Unit 1	Administrative Maps
Unit 2	Satellite and Elevation (Dem) Data
Unit 3	Manipulation of Vector Data
Unit 4	Manipulation of Raster Data (Dems)
Unit 5	Generation of Slope Map
Unit 6	Generation of Landform Maps Reflecting The Soil-Landscape
Unit 7	Generation of Maps of The Rivers And Streams of An Area
Unit 8	Map Layout

UNIT 1 ADMINISTRATIVE MAPS

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Download of Administrative Maps
 - 1.3.2 Display of Administrative Map in QGIS
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

Administrative maps (vector) can be downloaded from various online sources. Some of these include World Bank Online Directory, DIVA GIS, GADM and Natural Earth online directories. In this tutorial, we will learn how to download administrative maps from the World Bank Online Directory. Hopefully, I will also include a YouTube video link in the reference outlining the steps for spatial data download from different online data repositories.

1.2 Objectives

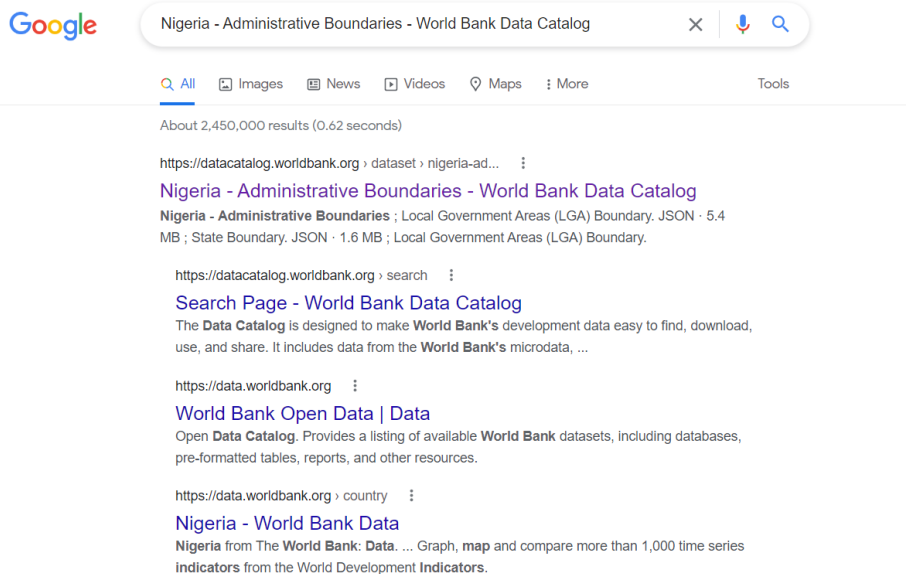
By the end of this unit, you will be able to:

- Be able to download administrative maps of an area of interest
- Be able to display vector maps in GIS application

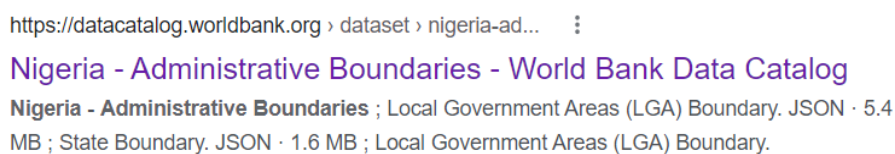
1.3 Main Content

1.3.1 Download of Administrative Maps

1. To download the administrative map of Nigeria from the **World Bank Data Catalog**, log into the internet.
2. Copy and paste the following website on your browser and hit the “Enter” key on your keyboard (<https://datacatalog.worldbank.org/dataset/nigeria-administrative-boundaries-2017>)
3. Alternatively (especially if this does not work due to updates), search for “Nigeria - Administrative Boundaries - World Bank Data Catalog” using your preferred web search tool, e.g., google search, yahoo search, etc. You will get a list of options:



4. Click on the first link (or any of the links that is closely related to the search)



5. The following window is loaded from step 2 (if it works) or step 4.

THE WORLD BANK | Data Catalog

HOME DATA COLLECTIONS GETTING STARTED FAQs LOGIN

Home / Search Results / Details

Nigeria - Administrative Boundaries

Metadata last updated on - Oct 21, 2021

The datasets are curated from the The Humanitarian Data Exchange (HDX). The Humanitarian Data Exchange (HDX) is an open platform for sharing data, launched in July 2014. The goal of HDX is to make humanitarian data easy to find and use for analysis. Our growing collection of datasets has been accessed by users in over 200 countries and territories. A team...

View More

Overview

Local Government Areas (LGA) Boundary [↓](#)
JSON • Last Updated: Nov 14, 2018 • Size: 5.4 MB

State Boundary [↓](#)
JSON • Last Updated: Nov 14, 2018 • Size: 1.8 MB

Local Government Areas (LGA) Boundary [↓](#)
ZIP • Last Updated: Nov 14, 2018 • Size: 1.9 MB
 METADATA [↓](#)

State Boundary [↓](#)
ZIP • Last Updated: Nov 14, 2018 • Size: 0.6 MB
 METADATA [↓](#)

Metadata

Coverage & Extent

Geographical Coverage [Nigeria](#)

Additional Metadata

View More

Data Access and Licensing

Classification: [Public](#)

This dataset is classified as **Public** under the Access to Information Classification Policy. Users inside and outside the Bank can access this dataset.

License: [Creative Commons Attribution 4.0](#)

This dataset is licensed under [Creative Commons Attribution 4.0](#)

Topics

- Energy and Extractives

Collections

Energy Data Info, World Bank Energy Datasets

Tags

energydata.info

Data Extent

6. Ignore the JSON files. Below them you will see two options (ZIP files)

Local Government Areas (LGA) Boundary [↓](#)
ZIP • Last Updated: Nov 14, 2018 • Size: 1.9 MB
 METADATA [↓](#)

State Boundary [↓](#)
ZIP • Last Updated: Nov 14, 2018 • Size: 0.6 MB
 METADATA [↓](#)

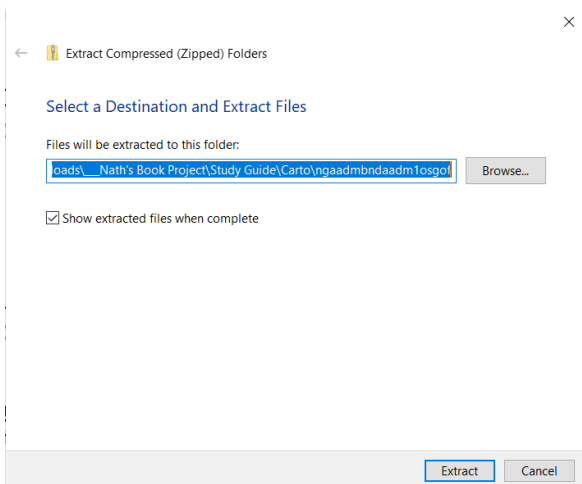
7. Since you require detailed data (including local government areas) click on the first

Local Government Areas (LGA) Boundary [↓](#)
ZIP • Last Updated: Nov 14, 2018 • Size: 1.9 MB
 METADATA [↓](#)

8. The zip file begins to download. When download is complete, copy the file into an appropriate directory.

Name	Date modified	Type	Size
ngaadmbndaadm1osgof.zip	7/22/2022 11:01 PM	Compressed (zipp...	

9. To unzip, right-click on the file and select “extract all” from the context menu. Click “Extract” on the pop-up window.



10. An unzipped folder appears in the directory (in addition to the zip file). This is the folder you will work with.

Name	Date modified	Type	Size
ngaadmbndaadm1osgoof	7/22/2022 11:12 PM	File folder	
ngaadmbndaadm1osgoof.zip	7/22/2022 11:01 PM	Compressed (zipp...	656 KB

11. If you open the folder, you may find another folder. Open it, and you will see several files. When working with the GIS, you will open the one that ends with “.shp”.

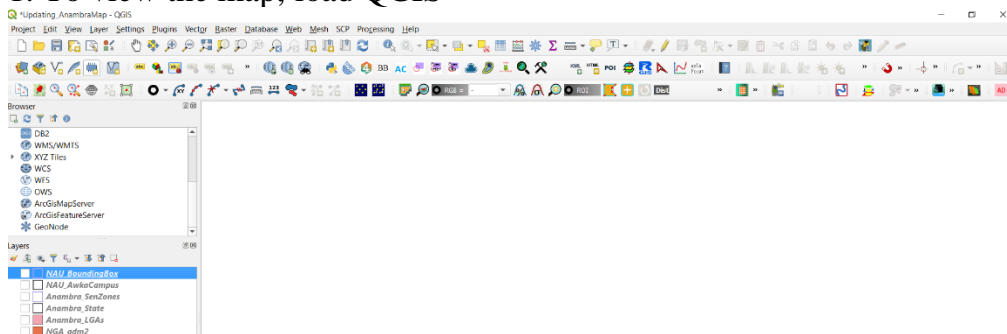
Name	Date modified	Type	Size
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.CP...	7/22/2022 11:12 PM	CPG File	1 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.dbf	7/22/2022 11:12 PM	DBF File	16 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.prj	7/22/2022 11:12 PM	PRJ File	1 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.sbn	7/22/2022 11:12 PM	SBN File	1 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.sbx	7/22/2022 11:12 PM	SBX File	1 KB
<input checked="" type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.shp	7/22/2022 11:12 PM	SHP File	614 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.sh...	7/22/2022 11:12 PM	XML Document	262 KB
<input type="checkbox"/> nga_admbnda_adm1_osgoof_20161215.shx	7/22/2022 11:12 PM	SHX File	1 KB
<input type="checkbox"/> Read me.txt	7/22/2022 11:12 PM	Text Document	1 KB


Self-Assessment Exercise

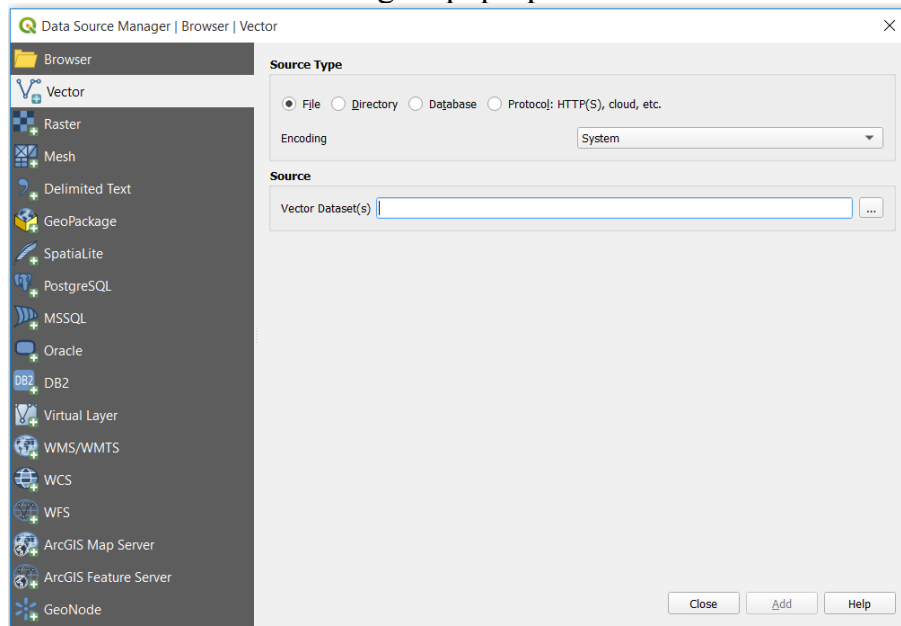
Show evidence of the downloaded administrative map.

1.3.2 Display of Administrative Map in QGIS

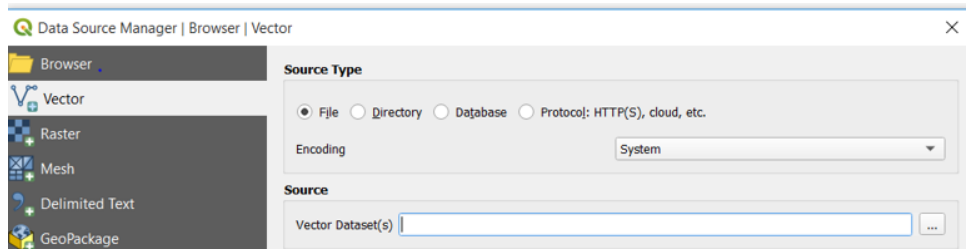
1. To view the map, load QGIS



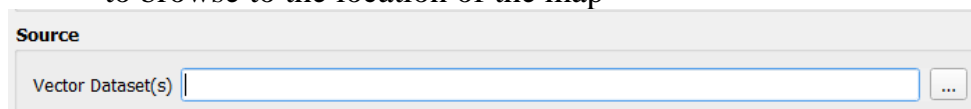
2. Click the “Open Data Source Manager” icon [] to load the “Data Source Manager” pop-up window



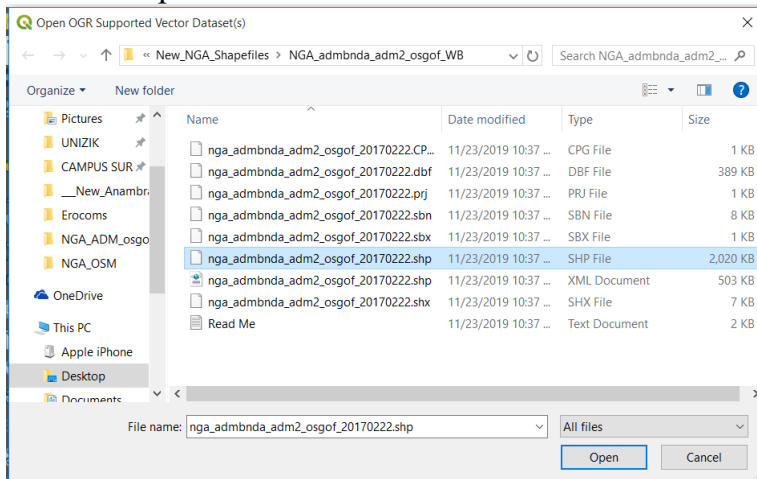
3. Click the “Vector” tab



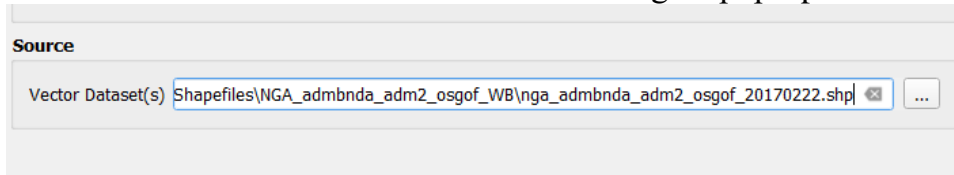
4. Click the three dots (...) in front of the “Vector Dataset(s) option to browse to the location of the map



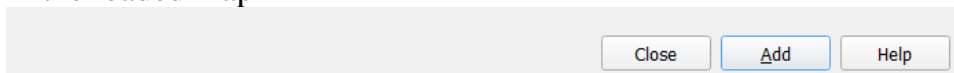
5. Select the shapefile (nga_admbnda_adm2_osgof_20170222.shp) and click “Open”



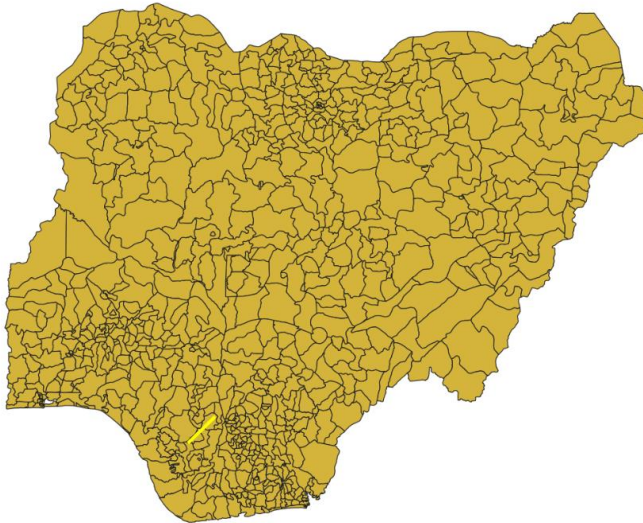
6. The file is loaded in the “Data Source Manager” pop-up window



7. Click “Add” to load it onto the map window, then click “Close” to view the loaded map



8. The map can subsequently be manipulated as required



Self-Assessment Exercise

Show evidence of displayed administrative map.

1.4 Conclusion

Administrative maps of any country in the world are already available. One does not need to go through the trouble of recreating what is already available. They can be downloaded freely from specific online directories. In this unit, we have explored some of those. It is however noteworthy that some of these maps may not be very accurate in their depiction of the boundaries. You may need to get data from several sources, open all of them as layers in a GIS and switch from one to the other to ascertain whether they are aligned to each other. The one that is not in line, if any, would probably be inaccurate.

1.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- How to download the administrative map Nigeria from an online directory.
- How to open an administrative (vector) map in QGIS.

1.6 Tutor-Marked Assignment

1. Show evidence of download of the administrative map of Nigeria.
- 2a. View the YouTube Video on how to download the administrative map from other sources.
- b. Download the maps as instructed in the YouTube video
- 3a. Open all downloaded maps.
 - b. Do they all align?

1.7 References/Further Reading/Web Resources

For audiovisual tutorials on the download of administrative maps from different sources and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Download of Administrative Maps from the World Bank Data Catalogue

https://www.youtube.com/watch?v=7oct0_zJK3M&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=10

Download of Administrative Maps from DIVA GIS

https://www.youtube.com/watch?v=hDza4s_CHKk&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=11

Download of Administrative Maps from GADM

<https://www.youtube.com/watch?v=PTSLzjajOqY&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=12>

Download of Administrative Maps from the Natural Earth Online Directory

<https://www.youtube.com/watch?v=oU7gCIYKZW8&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=13>

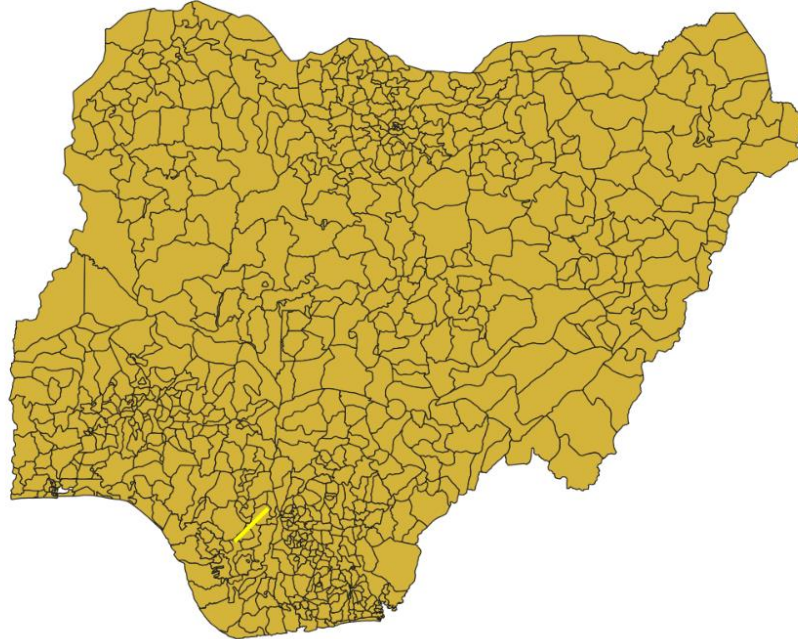
1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Show evidence of the downloaded administrative map.

Name	Date modified	Type	Size
ngaadmbndaadm1osgof	7/22/2022 11:12 PM	File folder	
ngaadmbndaadm1osgof.zip	7/22/2022 11:01 PM	Compressed (zipp...	656 KB

Name	Date modified	Type	Size
nga_admbnda_adm1_osgof_20161215.CP...	7/22/2022 11:12 PM	CPG File	1 KB
nga_admbnda_adm1_osgof_20161215.dbf	7/22/2022 11:12 PM	DBF File	16 KB
nga_admbnda_adm1_osgof_20161215.prj	7/22/2022 11:12 PM	PRJ File	1 KB
nga_admbnda_adm1_osgof_20161215.sbn	7/22/2022 11:12 PM	SBN File	1 KB
nga_admbnda_adm1_osgof_20161215.sbx	7/22/2022 11:12 PM	SBX File	1 KB
nga_admbnda_adm1_osgof_20161215.shp	7/22/2022 11:12 PM	SHP File	614 KB
nga_admbnda_adm1_osgof_20161215.sh...	7/22/2022 11:12 PM	XML Document	262 KB
nga_admbnda_adm1_osgof_20161215.shx	7/22/2022 11:12 PM	SHX File	1 KB
Read me.txt	7/22/2022 11:12 PM	Text Document	1 KB

2. Show evidence of displayed administrative map.



UNIT 2 SATELLITE AND ELEVATION (DEM) DATA

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Downloading Remote-Sensed Data
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

Remote-sensed satellite imageries and other products are currently available for free download. The USGS Earth Explorer data portal is your one stop shop for obtaining geo-spatial datasets from an extensive collection of remote-sensed data. Users can navigate via interactive map or text search to obtain Landsat satellite imagery, elevation model data, Sentinel satellite data, land cover data, and many other datasets. Users can search by exact location via the interactive map or input specific coordinates to view what data types are available.

2.2 Objectives

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

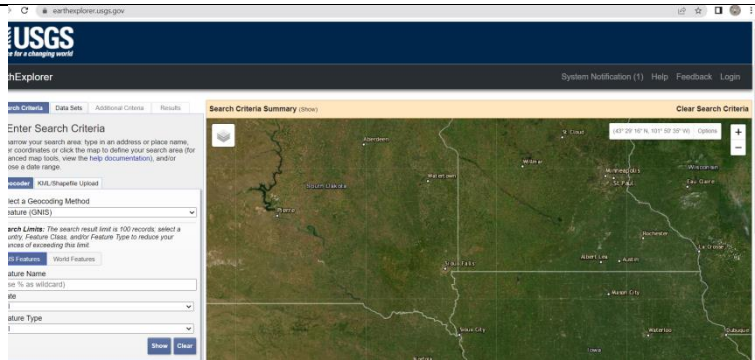
- Download remote-sensed data

2.3 Main Content

2.3.1 Downloading Remote-Sensed Data

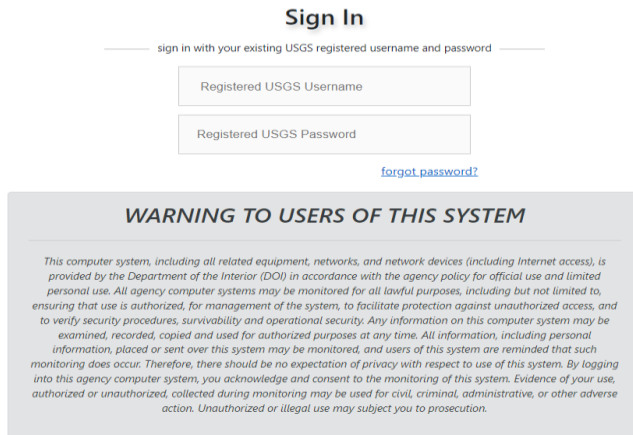
Log onto the United States Geological Survey (USGS) website: <https://earthexplorer.usgs.gov/>. Or search for EarthExplorer on Google search or any other search engine. Click of the EarthExplorer link to access the USGS EarthExplorer web page.

The image below will be displayed on the screen

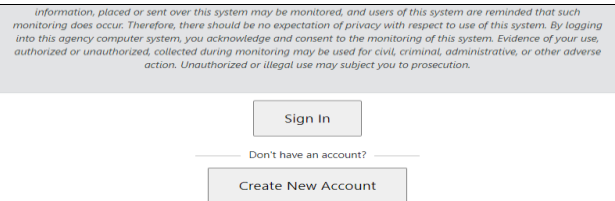


If you have not downloaded any data from the directory before, press the "Login" button at the top righthand corner of the window displayed on the screen to be taken to the login page.

ERS consolidates user profile and authentication for all EROS web services into a single independent application.



Scroll down and press the "Create New Account" button.

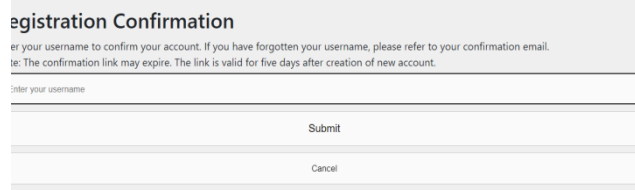


Registration does not cost money. It only takes your through several windows, requiring you to provide information on your biodata, affiliation, work status, the value of the data to you, etc.

At the end of the registration process, you would have selected a username and password, with which you can access the USGS directory whenever the need arises.

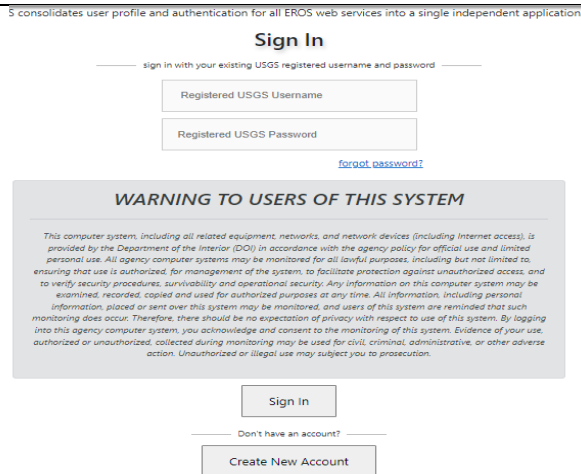
After concluding the registration, check your email. You will get an email requesting that you confirm your registration. Press the provided link to confirm.

You will be taken to a page where you will be required to fill in your username before pressing the "Submit" button.



Go back to the EarthExplorer homepage and click "Login" at the top right side of the screen

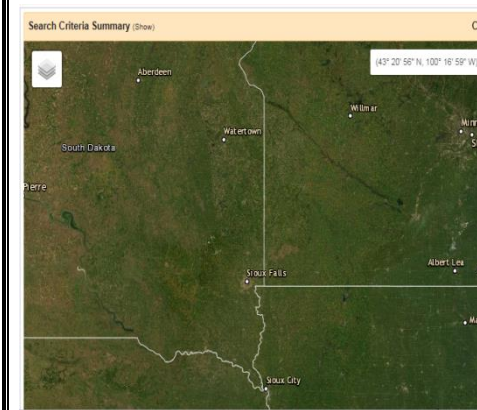
0. Fill in your username and password in the "Sign in" window. Click "sign in"



1. It takes you back to the homepage, but this time, your username is displayed on the top right of the screen



2. The map view window automatically shows a part of the USA



• Click the + or - symbol in the " " icon at the top right corner of the map window to zoom in or zoom out

• If you zoom out till the whole North American continent is displayed on the screen



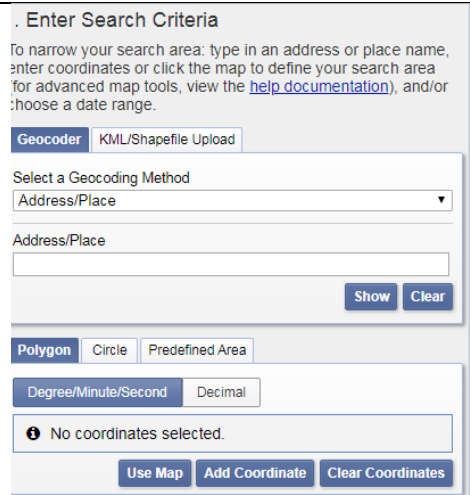
• Click, hold and drag the screen to show the part of the globe that is of interest to you



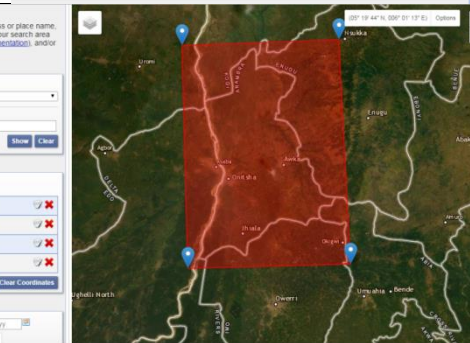
• Zoom into your region of interest, dragging and repositioning the map accordingly



Next, you have to show the area of the map for which you require data. You can either upload a kml or shapefile, input the coordinates manually or click on the map view window to indicate the region of interest

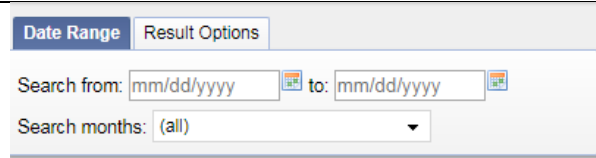


In this case, I select the easy option since I can already see my study area on the map screen. I click four times on the map, such that I now have a box surrounding my region of interest

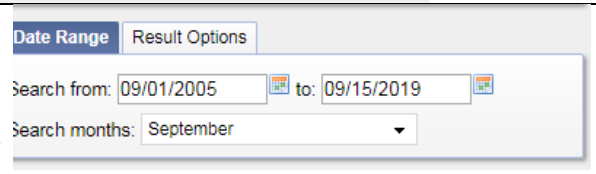


You can also see the coordinates of the four corners of the box shown on the left side of the screen

Fill in the data range required



You might decide to select a specific month. In this case, leave it at "all" so that data for the 12 months of the year can be made available



Click "Data Sets" at the bottom left of the screen


The menu for selecting your data of interest is displayed

Click "Digital Elevation" to select DEM data



Click "SRTM" to display the datasets stored under SRTM



<p>2. Select Your Data Set(s)</p> <p>Check the boxes for the data set(s) you want to search. When done selecting data set(s), click the <i>Additional Criteria</i> or <i>Results</i> buttons below. Click the plus sign next to the category name to show a list of data sets.</p> <p><input type="checkbox"/> Use Data Set Prefilter (What's This?)</p> <p>Data Set Search: <input type="text"/></p> <ul style="list-style-type: none"> <input type="checkbox"/> Aerial Imagery <input type="checkbox"/> AVHRR <input type="checkbox"/> CEOS Legacy <input type="checkbox"/> Commercial Satellites <input type="checkbox"/> Declassified Data <input type="checkbox"/> Digital Elevation <input type="checkbox"/> Digital Line Graphs <input type="checkbox"/> Digital Maps <input type="checkbox"/> EO-1 <input type="checkbox"/> Global Fiducials <input type="checkbox"/> HCMM <input type="checkbox"/> ISERV <input type="checkbox"/> Land Cover <input checked="" type="checkbox"/> Landsat <input type="checkbox"/> NASA LPDAAC Collections <input type="checkbox"/> Radar <input type="checkbox"/> Sentinel 	<p>Click the "<input type="checkbox"/></p> <p>SRTM 1 Arc-Second Global " to mark it as such " <input checked="" type="checkbox"/> SRTM 1 Arc-Second Global "</p> <p>Scroll down and click " Landsat " "</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Landsat <input type="checkbox"/> Landsat Collection 1 Level-3 <input type="checkbox"/> Landsat Analysis Ready Data (ARD) <input type="checkbox"/> Landsat Collection 1 Level-2 (On-Demand) <input type="checkbox"/> Landsat Collection 1 Level-1 <input type="checkbox"/> Landsat Legacy
<p>Click " Landsat Collection 1 Level-1 "</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Landsat Collection 1 Level-1 <input type="checkbox"/> Landsat 8 OLI/TIRS C1 Level-1 <input type="checkbox"/> Landsat 7 ETM+ C1 Level-1 <input type="checkbox"/> Landsat 4-5 TM C1 Level-1 <input type="checkbox"/> Landsat 1-5 MSS C1 Level-1 	<p>Select " <input checked="" type="checkbox"/> Landsat 8 OLI/TIRS C1 Level-1 "</p> <p>[You may also select any or all of them]</p> <p>Click " <input type="button" value="Additional Criteria >"/> "</p>
<p>A new menu is displayed, giving you the option to define more criteria for data selection</p> <p>3. Additional Criteria (Optional)</p> <p>If you have more than one data sets selected, use the dropdown to select the additional criteria for each data set.</p> <p>Data Sets: SRTM 1 Arc-Second Global</p> <p>Entity ID: <input type="text"/> <input type="text"/> <input type="text"/> <input type="text"/></p> <p><input type="button" value="Clear Criteria"/></p>	<p>Being that SRTM was first selected before the Landsat data, it is automatically first available for download</p> <p>Data Sets: SRTM 1 Arc-Second Global</p> <p>Do not define further criteria, simply click " <input type="button" value="Results >"/> " at the bottom left side of the screen</p>
<p>The available data for the selected area are shown on the left side of the screen</p>	<p>Clicking the "  " icon displays on the map window how the images cover the area of interest</p>



Similarly clicking the "🗺️" icons displays the DEMs as they appear over the study area

Clicking the "📥" icon will open the image download interface



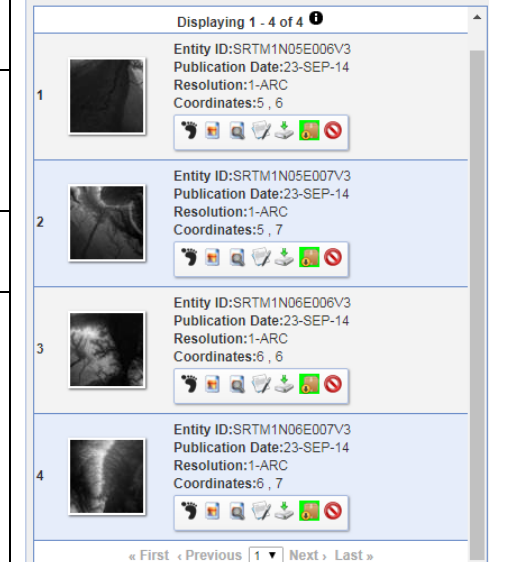
Click the "Download" in front of "GeoTIFF 1 Arc-second (24.8 MB)" to download DEM

Simply click "🗑️" under each of the DEMs to place them in the same basket

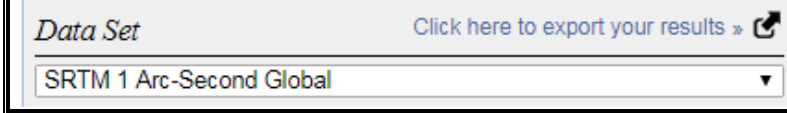
Close the download interface by clicking the "✖️" icon at the top right corner of the interface

Repeat the download process for all four DEMs

If you do not want to download immediately, click the "🗑️" icon to add data to bulk download basket



At the top left of the screen, the dataset selected is still

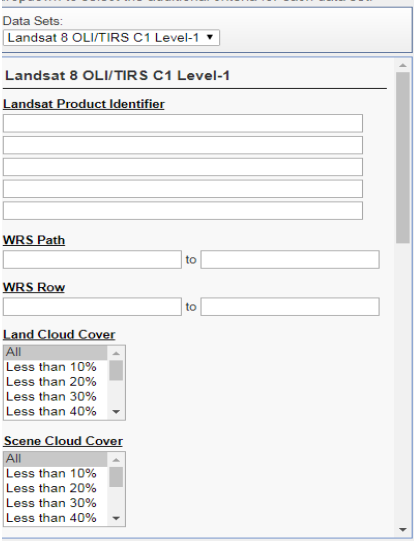


Click the "▼" at the end of "SRTM 1 Arc-Second Global" and select "Landsat 8 OLI/TIRS C1 Level-1" from the displayed options

5. Landsat datasets are loaded in place of the DEMs



6. Go to the top left corner of the screen and click "Additional Criteria" to load a set of options for choosing the most appropriate images



Leaving the prior settings untouched, change "Land Cloud Cover" and "Scene Cloud Cover" to "Less than 10%"

Under "Collection Category" select "Tier 1"



Click "Results" to load available satellite imageries

There are up to 40 imageries that meet the set criteria



The "👤", "📄", "📥" and "🛒" can all be used in the same way that they were used to display and download the DEMs

Use the "👤" key to navigate and determine the images that cover the study area

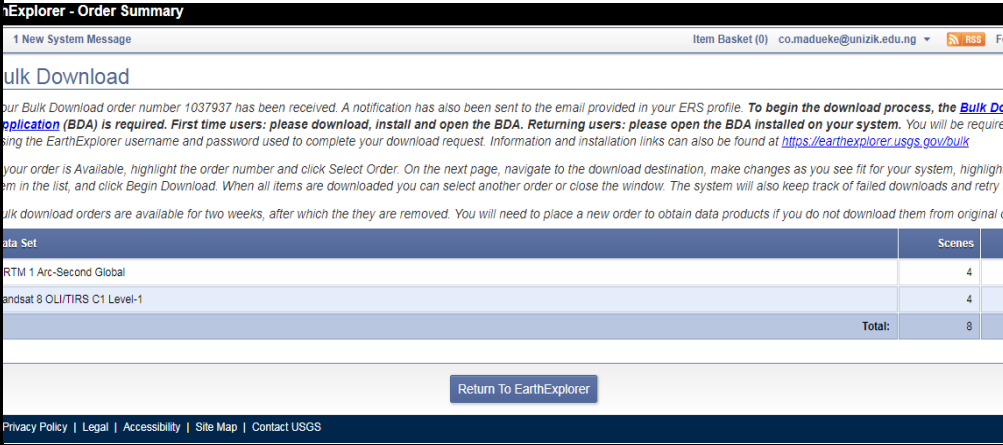
Add all the appropriate images to the bulk download basket using the "🛒" icon

Item Basket (8) shows that there are now 8 items in the bulk download basket

Click "View Item Basket »", then click "Save Changes"

Click "Proceed To Checkout »" then click "Submit Order"

A new page is displayed, showing the types, number and size of datasets in bulk download



You will receive an email, with a link that will enable you to access the data in your bulk download

Self-Assessment Exercise

Show evidence of downloaded raster (DEM) data.

2.4 Conclusion

In this unit, we succeeded in downloading satellite imageries and digital elevation model (DEM). In subsequent sections, we will focus on the manipulation and analysis of elevation data. It is also noteworthy that, even though the spatial extent of interest in this tutorial is Anambra state, you may choose to download data for other parts of Nigeria or the earth. Either way, the same methodology still applies.

2.5 Summary

From this unit, you have learnt about the downloading remote-sensed data. Some of the key things learnt include the following;

- EarthExplorer as an online repository of remote-sensed data
- Downloading remote-sensed data

2.6 Tutor-Marked Assignment

1. Show evidence of download of satellite imagery
2. Show evidence of download of elevation data

2.7 References/Further Reading/Web Resources

For audiovisual tutorials on the download satellite imageries and elevation (DEM) data from the USGS EarthExplorer online directory and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

EarthExplorer: Registering with the USGS EarthExplorer

<https://www.youtube.com/watch?v=6SqO6fBrxJ0&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=14>

EarthExplorer: Confirmation of Registration and Signing in










<https://www.youtube.com/watch?v=EOPkznIs99E&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=15>

EarthExplorer: Downloading Remote sensed Data

<https://www.youtube.com/watch?v=iHptjmvVUGY&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=16>

2.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Show evidence of downloaded raster (DEM) data.

AP_02755_FBS_F0100_RT1		5/29/2022 5:44 PM	File folder
Name	Date	Type	Size
 AP_02755_FBS_F010...		TIF File	80,549 KB
 AP_02755_FBS_F010...		JPG File	802 KB
 AP_02755_FBS_F010...		XML Document	1 KB
 AP_02755_FBS_F010...		WLD File	1 KB
 AP_02755_FBS_F010...		TIF File	150,910 KB
 AP_02755_FBS_F010...		XML Document	148 KB
 AP_02755_FBS_F010...		KMZ	7,494 KB
 AP_02755_FBS_F010...		TIF File	750 KB
 AP_02755_FBS_F010...		TIF File	116,624 KB

UNIT 3 MANIPULATION OF VECTOR DATA

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3 Main Content
 - 3.3.1 Import CSV Files
 - 3.3.1.1 Convert CSV File to Shapefile
 - 3.3.1.2 Create Polygon from Point Data
 - 3.3.1.3 Convert Shapefile to KML File
 - 3.3.1.4 Open KML File in Google Earth Pro
 - 3.3.2 Import Shapefiles
 - 3.3.2.1 Compare the Spatial Extent of Administrative Maps from different Datasets
 - 3.3.3 Relevant Vector Operations
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

In this unit, we are going to work with some of the vector data that were downloaded in previous sections. These include the GPS data that was saved as a CSV file and the administrative maps downloaded from different online repositories. We are going to perform several vector operations on them.


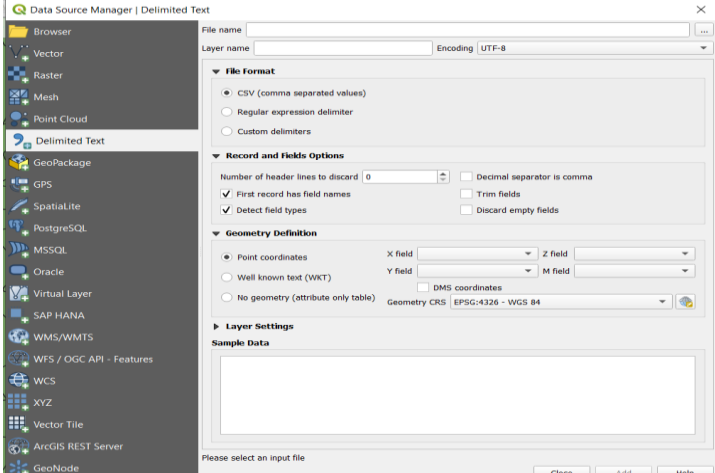

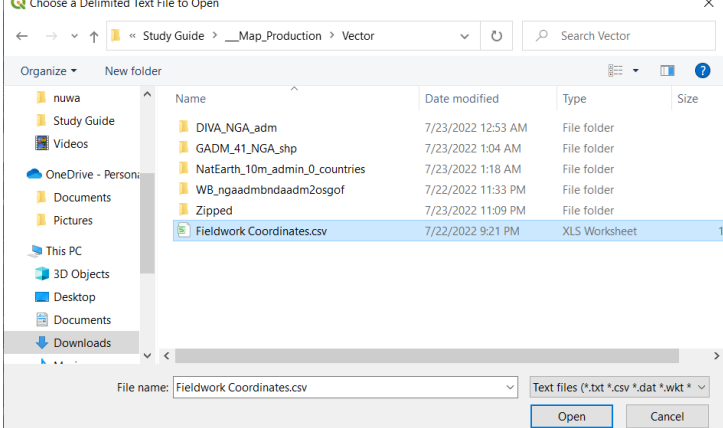
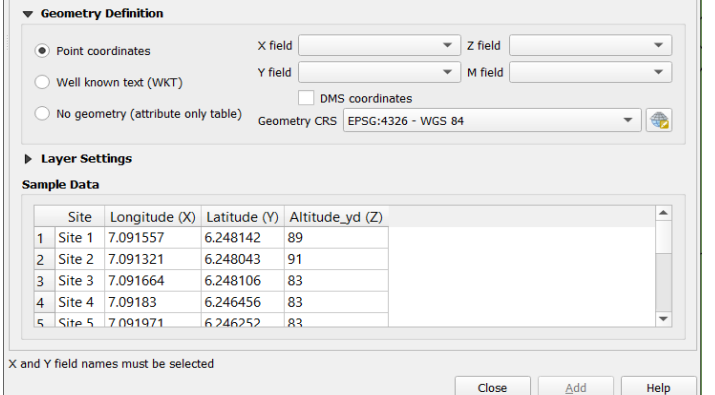
3.2 Objectives

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

- Be able to display vector data in a GIS application
- Be able to analyze vector data in a GIS application

3.3 Main Content

3.3.1 Import Csv Files

<p>1. Open QGIS (from the start menu or the desktop)</p>	<p>2. Click the “Open Data Source Manager” button on the top lefthand edge of the QGIS window</p> 																														
<p>3. Select “Delimited Text” in the pop-up window</p>																															
<p>4. Click the browse button (3 dots on the end of the “File name” row)</p>																															
<p>5. Browse to the location of the CSV file we saved in previous units. Press “Open” after selection.</p>																															
<p>6. An overview of CSV file contents is displayed at the bottom of the pop-up window as shown here.</p>	 <table border="1"> <thead> <tr> <th></th> <th>Site</th> <th>Longitude (X)</th> <th>Latitude (Y)</th> <th>Altitude_yd (Z)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Site 1</td> <td>7.091557</td> <td>6.248142</td> <td>89</td> </tr> <tr> <td>2</td> <td>Site 2</td> <td>7.091321</td> <td>6.248043</td> <td>91</td> </tr> <tr> <td>3</td> <td>Site 3</td> <td>7.091664</td> <td>6.248106</td> <td>83</td> </tr> <tr> <td>4</td> <td>Site 4</td> <td>7.09183</td> <td>6.246456</td> <td>83</td> </tr> <tr> <td>5</td> <td>Site 5</td> <td>7.091971</td> <td>6.246252</td> <td>83</td> </tr> </tbody> </table>		Site	Longitude (X)	Latitude (Y)	Altitude_yd (Z)	1	Site 1	7.091557	6.248142	89	2	Site 2	7.091321	6.248043	91	3	Site 3	7.091664	6.248106	83	4	Site 4	7.09183	6.246456	83	5	Site 5	7.091971	6.246252	83
	Site	Longitude (X)	Latitude (Y)	Altitude_yd (Z)																											
1	Site 1	7.091557	6.248142	89																											
2	Site 2	7.091321	6.248043	91																											
3	Site 3	7.091664	6.248106	83																											
4	Site 4	7.09183	6.246456	83																											
5	Site 5	7.091971	6.246252	83																											

7. Define the X and Y fields

Point coordinates X field Longitude (X) Z field

Well known text (WKT) Y field Latitude (Y) M field

No geometry (attribute only table) DMS coordinates

Geometry CRS EPSG:4326 - WGS 84

8. Press the “Add” button, then “Close”.

9. The map is loaded in the map window and the you can see the name in the layer panel.

3.3.1.1 Convert CSV File to Shapefile

1. To convert the CSV files to shapefile, right-click on the layer name in the layer panel and select “Export” in the context menu, then “Save feature as” from the subsequent menu.

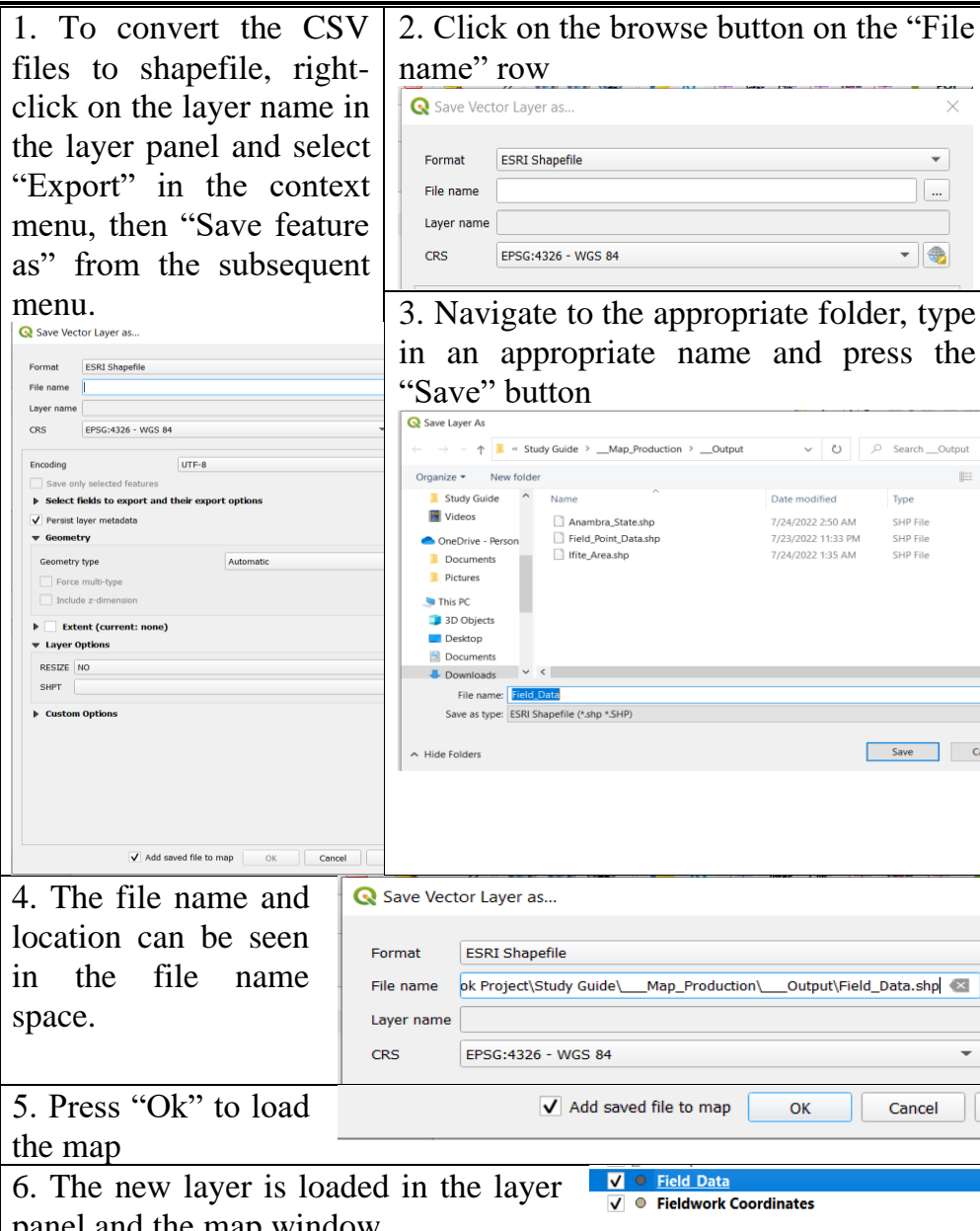
2. Click on the browse button on the “File name” row


3. Navigate to the appropriate folder, type in an appropriate name and press the “Save” button

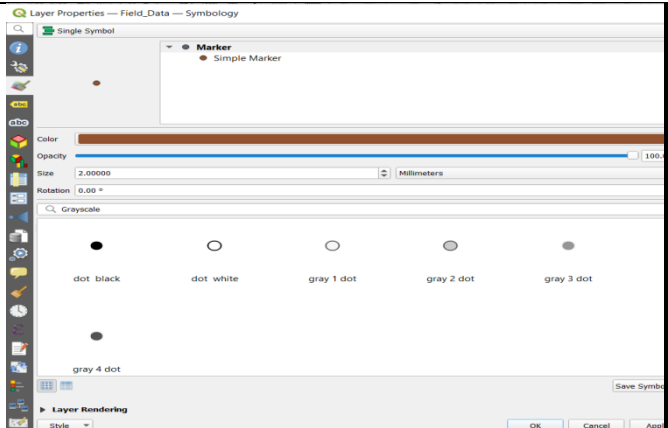
4. The file name and location can be seen in the file name space.

5. Press “Ok” to load the map

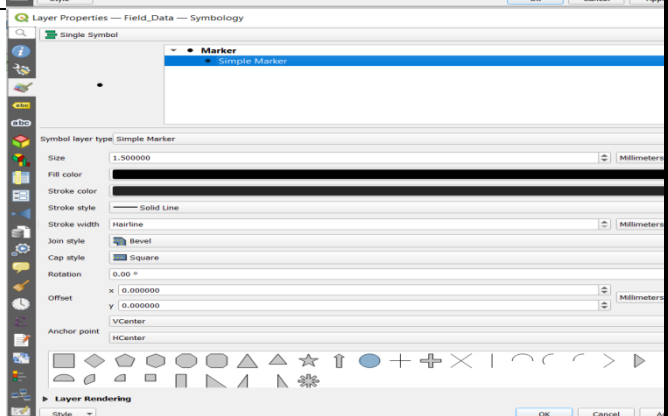
6. The new layer is loaded in the layer panel and the map window




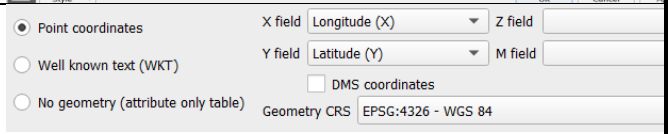
7. Right-click on the file in the layer panel and select “Properties” from the context menu. Select the “Symbology” tab ().



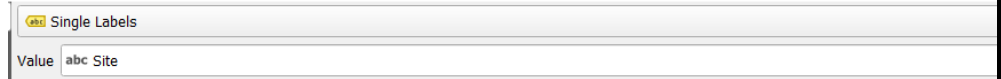
8. Select “Simple Marker” under the “Marker” pane. Reduce “Size” to 1.5, select black from the Fill and Stroke color options. Press “Apply”.



7. Press the label pane [] Define the X and Y fields



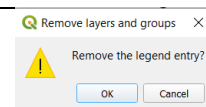
8. At the top of the pop-up window, you see a pane with “No label”
Click on the arrow at the end of that row and select “Single label” and select the title reflecting the site names (in my own case, “Site”) under the “Value” pane.



9. Press “Apply”, then “Ok”. You will note that the format of the point vectors has been changed and that its names are now reflected.



10. You can remove the CSV file now, having created the ESRI Shapefile. To do so, right-click on “Remove layer”, then “Ok” in the pop-up menu.



Self-Assessment Exercise

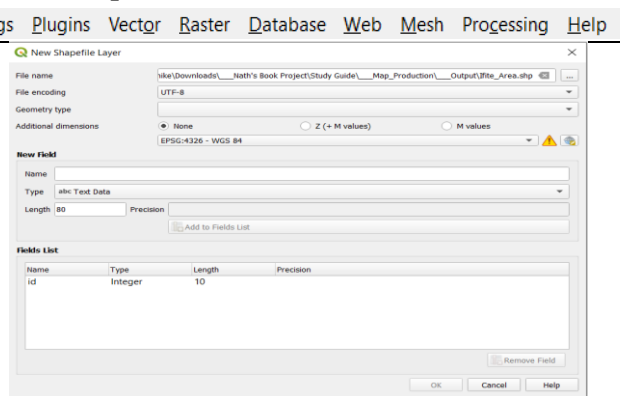
Show evidence of point data display in the map window.

3.3.1.2 Create Polygon from Point Data

1. Having loaded the point data collected during the fieldwork and converted it to shapefile, in this tutorial, I want to link the points to create a polygon.

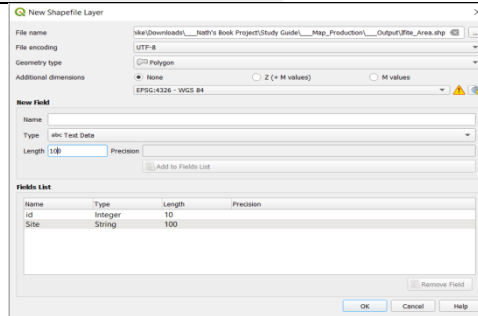
2. The first step is to create a new layer. To do so, click on the Layer menu and select “Create Layer” in the context menu, then click “New Shapefile Layer” in the subsequent menu.

4. Browse to you selected folder in the pop-up window and name the new layer accordingly and save to return to the pop-up window.

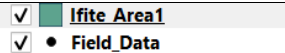




5. For the “Geometry type” option in the pop-up window, click on the arrow and select polygon.


6. Under “New Field”, Type in “Site” or the relevant term in the space provided for “Name”, for “Type” Text Data is already selected (if not, click on the option and select accordingly), define the length as 100, then click “Add to Field List” to add it to the Field List. Then press the “Ok” button.






7. The map is added to the layer panel, but the map window is still empty because the polygon is yet to be drawn.

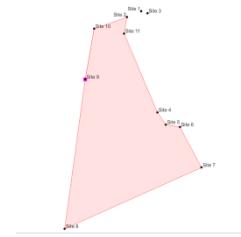


8. Right-click on the new layer [ Ifite Area1] and select “Toggle Editing”. Note the difference -  Ifite Area1 . The pencil icon within indicates that it is now editable.

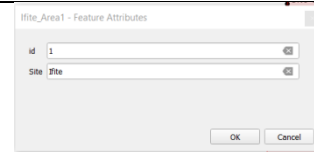
9. Note that the edit tools on the tools bar are activated []

10. To start adding polygons, click on the “Add Polygon Feature” tool []. Also click on the “Enable Snapping” tool [] to activate it.

11. Make sure that the layer is selected []. Move your cursor into the map window. When you come close to a point of interest, a purplish box would enclose the point (the snapping tool at work). Click on the point and move to the next point (in the appropriate sequence). Repeat the process until all the points are linked, with the space between them highlighted.





12. Right-click on the point from which you started to end the process. Type in a number, (e.g., 1) in the “id” option and name of the location (e.g., Ifite) in the “Name” option in the pop-up window. Press the “Ok” button.




13. The polygon is added. You can add several polygons in this way. But in this tutorial, we will add on one.



14. Press the save icon [] within the edit tools. Press the toggle edit tool icon [] to end conclude the editing process



15. Click on the “Pan” tool [] in the tool bar to change the cursor option. You have basically created a polygon from point data.

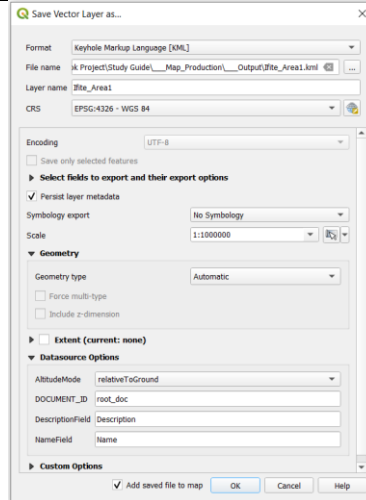
Self-Assessment Exercise

Show evidence of new polygon.

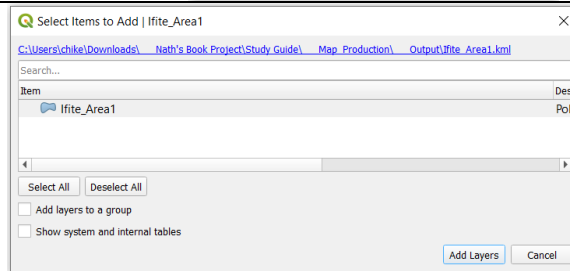
3.3.1.3 Convert Shapefile to Kml File

1. To convert the created shapefile to keyhole markup language (KML) format, right-click on the polygon name in the layer panel and select “Export” from the context menu, then “Save Feature As”.

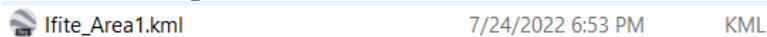
2. In the pop-up window, select “Keyhole Markup Language (KML)” under format, browse to the appropriate folder and type in an appropriate file name, the layer name appears automatically (it is still the file name that you typed in). Leave other options as is and press the “Ok” button.



3. If the following window pops up, click “Cancel” because you do not need to load the new KML file in the map window. You will use it to view the study site on Google Earth Pro.




4. Open the folder where you saved the file. You will find the KML file and can open it from there.



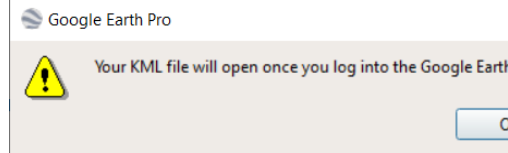
3.3.1.4 Open KML File in Google Earth PRO

<p>1. If Google Earth Pro is installed on your system, you can open the KML file by double-clicking on it or right-click and select “Open” from the context menu.</p>	
<p>2. If you have not installed Google Earth Pro, I will take you through the process of its download and installation. Log onto the internet. Using your preferred search engine, search for “Google Earth Pro Download”.</p>	
<p>3. You will get several hits. Click on the option that takes directly to the google.com web page.</p>	
<p>4. The page loads.</p>	
<p>5. Press “Google Earth Pro for desktop”.</p>	<p>6. Press “Download Earth Pro on desktop”.</p>
<p>7. Press “Accept and Download”.</p>	
<p>8. A thank you message is displayed and the download begins. It would not take long as it is a small file.</p>	

9. Browse to the location of the software [ GoogleEarthProSetup.exe] and go through the installation process as we did in prior units. Note that you should be connected to the internet before you commence because the application will automatically go online to get more information.

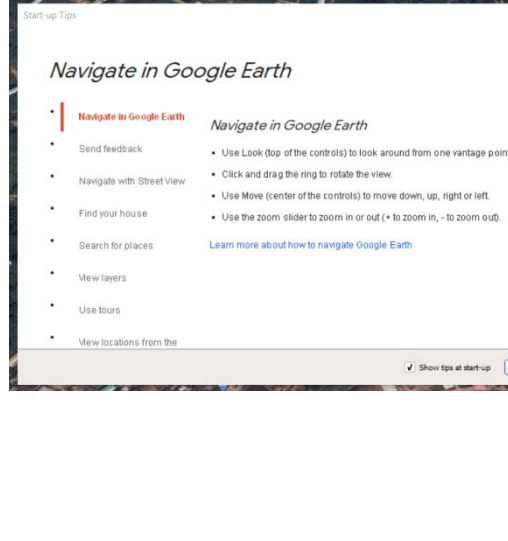
10. After installation, open the KML file as stated in step 1

11. You may get a pop-up message stating that your KML file will open once you log into the Google Earth Server. Press “Ok”.

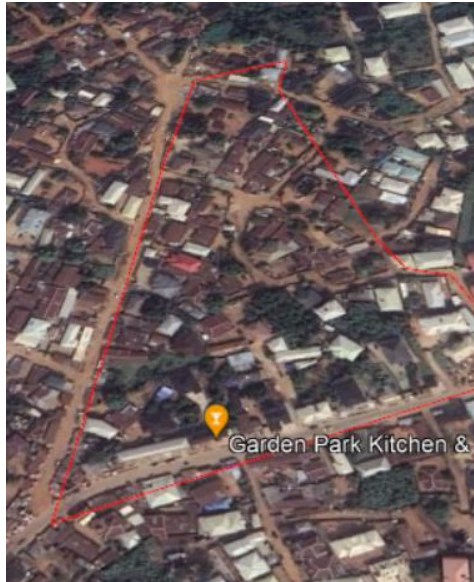


Google Earth begins to load.

12. It navigates to your study area. Press “Close” on the pop-up message to view site.




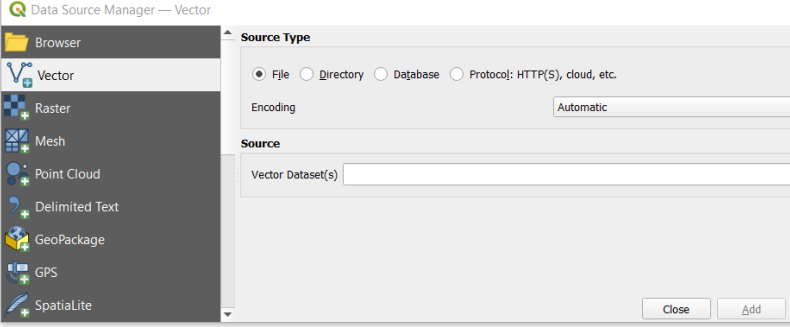
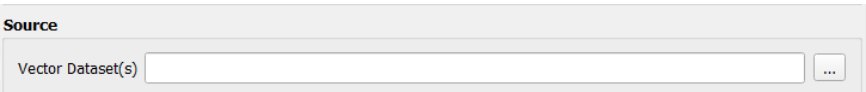
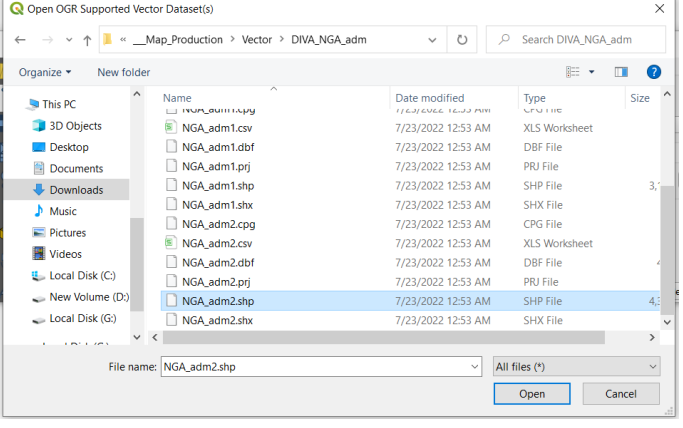
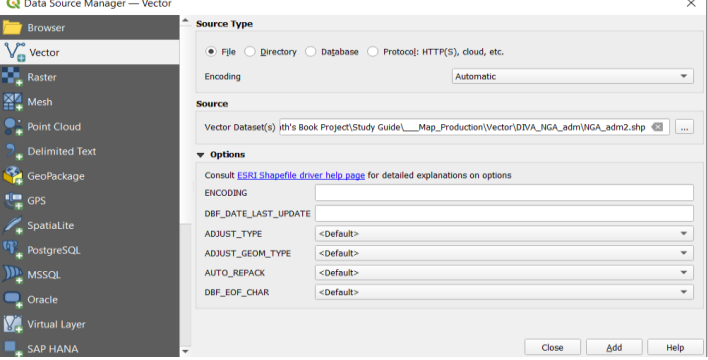
13. The site is indicated by the red line.



Self-Assessment Exercise

Show evidence of KML file display on Google Earth.


3.3.2 Import Shapefiles

<p>1. Open QGIS (from the start menu or the desktop)</p>	<p>2. Click the “Open Data Source Manager” button on the top lefthand edge of the QGIS window</p>	
<p>3. Select “Delimited Text” in the pop-up window</p>		
<p>4. Click the browse button (3 dots on the end of the “Vector Dataset(s)” row</p>		
<p>5. Browse to the location of the downloaded administrative maps. Open one of the folders (e.g., containing the DIVA GIS dataset), select “NGA_adm2.shp”, then Press “Open”.</p>		
<p>6. Press the “Add” button to load map. Press the browse button to return to the folder. Navigate to a new dataset (e.g., the GADM dataset).</p>		


7. Select “gadm41_NGA_2.shp”, press “Open”, then press “Add” to load.
8. Repeat for the other administrative maps. When all the maps are loaded, press the “Close” button. (Note that some of the maps do not have the adm0, adm1, adm2 separations in the parent folders).
9. You have successfully imported shapefiles as you can see in the layer panel and the map window.

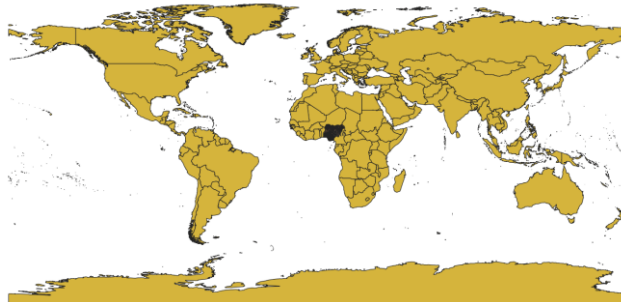
3.3.2.1 Compare the Spatial Extent of Administrative Maps from Different Datasets

1. You have now loaded different maps onto QGIS.

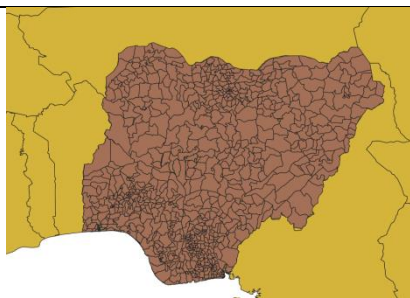
2. To zoom in press the “+” button in the tool bar and to zoom out press the “-” button. To view the full extent of the map, press the  button.

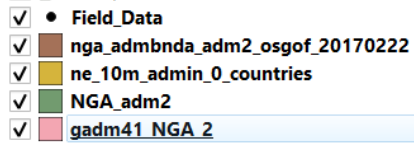
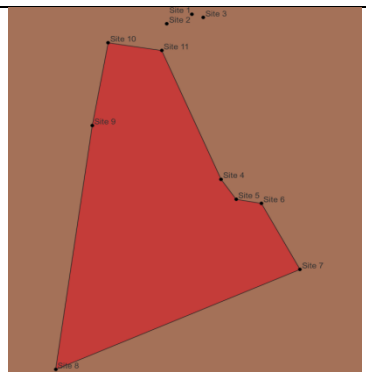
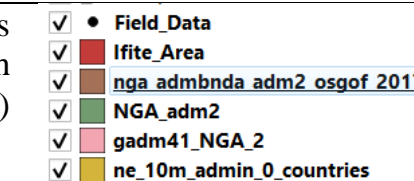


3. Press the “Zoom Full” button  to view the entire extent of the administrative map of the world (as downloaded from the Natural Earth online directory).



4. You can see that Nigeria is darker on that map. This is because there are other maps specific to Nigeria that are loaded on top of the world map. To see Nigeria in greater details, press the zoom in tool. Press inside the map window, just above the northwestern edge, hold and drag down until you get to the



<p>southeastern edge, release.</p>	
<p>5. You note that even though you had a point vector in the map window, you cannot see it. This is because it is at the bottom of the list of open maps in the layer panel. The point data should usually be on top, then the line data, before you get the polygon data. Press and hold the point data on the panel and drag to the top of the list. It should now be visible in the map window. (It may not be very clear due to the size of Nigeria, relative to a single point in Nigeria, but if the know the location – in my case, Anambra state – look at the rejoin of interest and repeat movement several times, and you will definitely see the change)</p>	
<p>6. To see that region clearly, zoom into the region as explained above. Alternatively, right-click on the point data in the panel and press “Zoom to Layer(s)” in the context menu. You may not see the polygon map you created. Drag it in the layer to just below the point data and it will also become visible.</p>	
<p>7. To zoom out such that you can see the LGAs again, press the “-” button, press, hold and drag within the map window (or just keep pressing over and over again in the map window until you get the view of interest).</p>	
<p>8. Look at the sequence of the maps in the Layers panel. The map with the largest spatial extent (global) should be at the bottom.</p>	

You will notice a white box with a tick sign in front of each map []. Press the tick sign in front of the topmost map of Nigeria, the sign disappears. Repeat again and again and observe what happens in the map window.

9. Switch the map on and off, watch the LGA boundaries, do they align. Note your observation. Leaving the topmost switched off, switch the second on and off to compare with the map below it. Repeat for the other maps. You will notice that they are not the same. Some or all of the maps have inaccurately depicted boundaries.

Self-Assessment Exercise

Show evidence of display of all administrative maps.

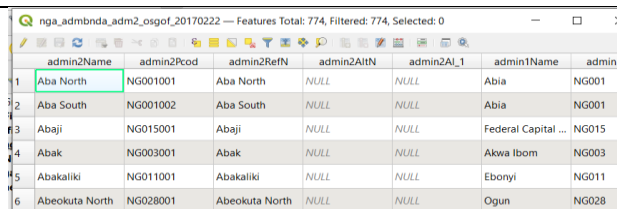
3.3.3 Relevant Vector Operations

3.3.3.1 Format Maps (Symbology and Label)


In this section, we will focus on the World Bank dataset. You can replicate the same operations for the other datasets.

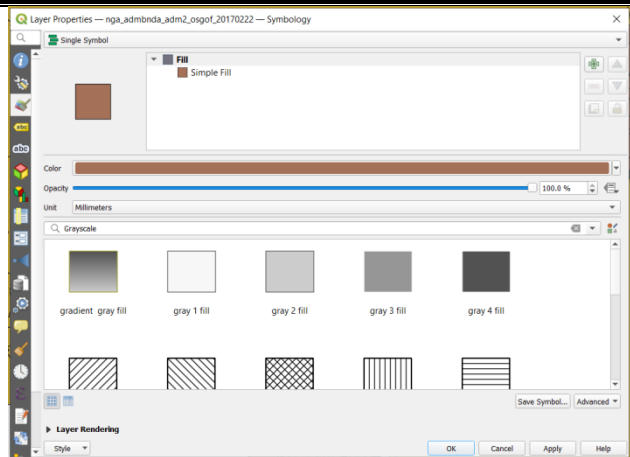
1. Perform the zoom to layer operation for the World Bank dataset. You can see many polygons representing LGAs, but you do not know which is which; or the ones in each state.

2. There are a lot of information stored within the map. These are called attributes. To view this information, right-click on the layer and select “Attribute Table” from the context menu. A table will be opened containing lots of information.

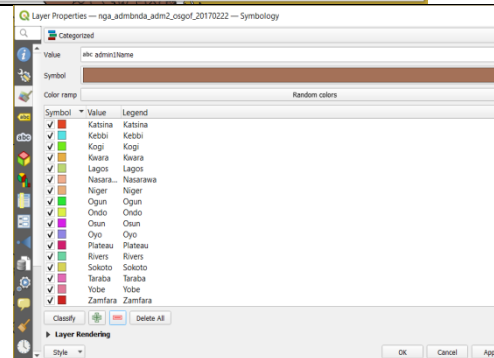



	admin2Name	admin2Pcod	admin2RefN	admin2AltN	admin2AI_1	admin1Name	admin1Pcod
1	Aba North	NG001001	Aba North	NULL	NULL	Abia	NG001
2	Aba South	NG001002	Aba South	NULL	NULL	Abia	NG001
3	Abaji	NG015001	Abaji	NULL	NULL	Federal Capital ...	NG015
4	Abak	NG003001	Abak	NULL	NULL	Akwa Ibom	NG003
5	Abakaliki	NG011001	Abakaliki	NULL	NULL	Ebonyi	NG011
6	Abeokuta North	NG028001	Abeokuta North	NULL	NULL	Ogun	NG028

3. Close the attribute table (we will come back to it later). Right click on the layer again, and select “Properties”. Select the “Symbology” pane [] in the pop-up window.

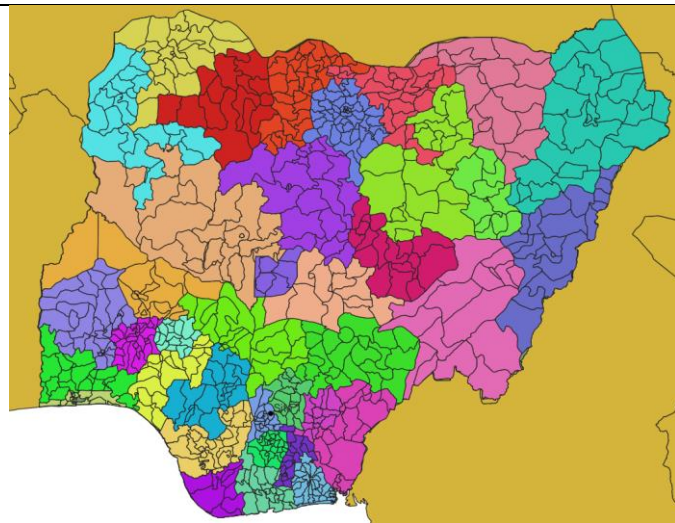


4. Note that at the top of the window, you have “Single Symbol”. That is why the entire map has the same colour. Press the drop-down arrow and select “Categorized”. The window changes. In the “Value” line, select “admin1Name” because I want to define the state boundaries. (NOTE: admin1Name = Nigeria, admin1Name = States, admin2Name = LGAs).



Then, press the classify button to see the names listed out with different colour depictions. Scroll down to the bottom, select “All Other...” and press the delete button [].

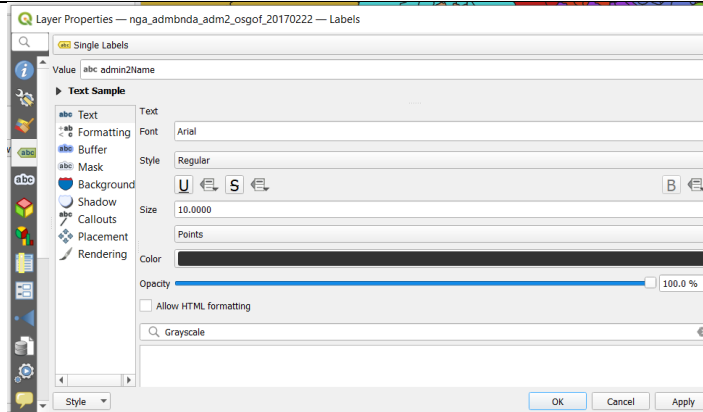
5. Press the “Apply” button and watch what happens in the map window. Now you can see that the states are depicted with different colours.



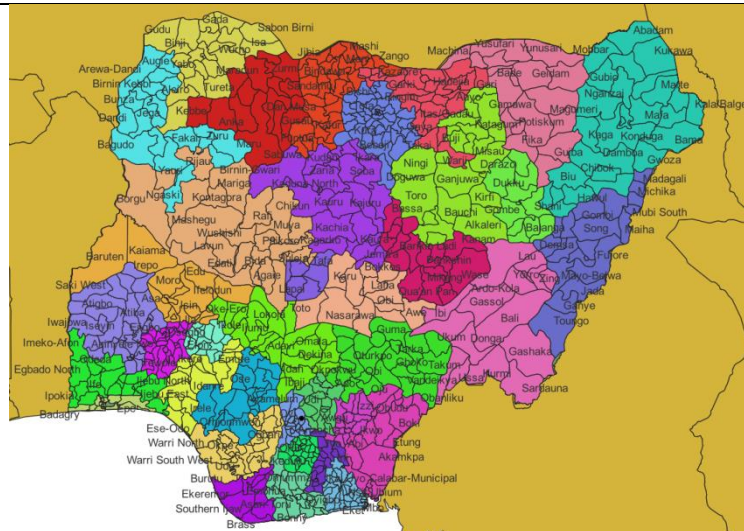
6. If you want to label the LGAs in the map, you can also do that. Select the “Label” pane [abc].



7. Click on the drop-down arrow next to “No Labels” and select “Single Label”. The window is reloaded and “admin2Name” may appear in the “Value” row; if not, click on the drop-down arrow and select it. You can reformat the fonts to suit your needs, then press the “Apply” button.



8. The LGA names appear in the map.



9. It looks too crowded so I will once again eliminate the names. Go to the top of the window, press the drop-down arrow in the “Single Label”

row and select “No Label”. Press the “Apply” button to eliminate the labels. Press the “OK” button.

10. You will notice that the layer panel is somewhat different. How is it different?

11. Press on the arrow in front of the World Bank map and the states will be listed out with their respective colours. You can scroll down to view.

- Field_Data
- Ifite_Area
- nga admbnda adm2 osgof 20170222
- NGA_adm2
- gadm41_NGA_2
- ne_10m_admin_0_countries

- Abia
- Adamawa
- Akwa Ibom
- Anambra
- Bauchi
- Bayelsa
- Benue
- Borno
- Cross River
- Delta
- Ebonyi
- Edo
- Enugu
- Gombe
- Imo
- Jigawa
- Kaduna
- Kano
- Katsina
- Kebbi
- Kwara
- Lagos
- Nasarawa
- Niger
- Ogun
- Ondo
- Osun
- Plateau
- Rivers
- Sokoto
- Taraba
- Togo
- Yobe
- Zamfara

Self-Assessment Exercise

Display map as shown in the map window.

3.3.3.2 Extract and Save a Part of the Map

(e.g., a state) as a New Map

In this section, we will create a new map from the administrative map of Nigeria. We will extract Anambra state or any other state and save it as a new map layer. To do this, the selection of the target polygons is essential.

1. Open the attribute table like we did in section 3.3.1.

2. The sorting of admin1Name looks haphazard.

	admin2Name	admin2Pcod	admin2RefN	admin2AItn	admin2AI_1	admin1Name	admin1P
1	Aba North	NG001001	Aba North	NULL	NULL	Abia	NG001
2	Aba South	NG001002	Aba South	NULL	NULL	Abia	NG001
3	Abaji	NG015001	Abaji	NULL	NULL	Federal Capital ...	NG015
4	Abak	NG003001	Abak	NULL	NULL	Akwa Ibom	NG003
5	Abakaliki	NG011001	Abakaliki	NULL	NULL	Ebonyi	NG011
6	Abeokuta North	NG028001	Abeokuta North	NULL	NULL	Ogun	NG028

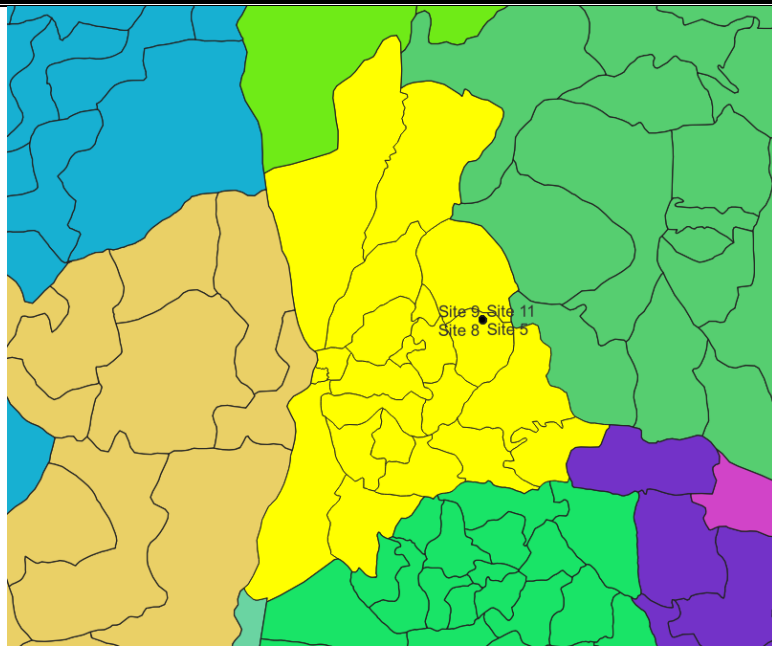
3. To arrange it in alphabetical order, click on the title. If you click again, you rearrange in reverse (alphabetical) order. Click again to return to the appropriate order.

	admin2Name	admin2Pcod	admin2RefN	admin2AltN	admin2AL_1	admin1Name	admin1Pcod
1	Aba North	NG001001	Aba North	NULL	NULL	Abia	NG001
2	Aba South	NG001002	Aba South	NULL	NULL	Abia	NG001
3	Arochukwu	NG001003	Arochukwu	NULL	NULL	Abia	NG001
4	Bende	NG001004	Bende	NULL	NULL	Abia	NG001
5	Ikwoano	NG001005	Ikwoano	NULL	NULL	Abia	NG001
6	Isiala-Ngwa No...	NG001006	Isiala-Ngwa No...	NULL	NULL	Abia	NG001
7	Isiala-Ngwa So...	NG001007	Isiala-Ngwa So...	NULL	NULL	Abia	NG001
8	Isiukuwato	NG001008	Isiukuwato	NULL	NULL	Abia	NG001
9	Obi Ngwa	NG001009	Obi Ngwa	NULL	NULL	Abia	NG001
10	Ohafia	NG001010	Ohafia	NULL	NULL	Abia	NG001
11	Osisioma Ngwa	NG001011	Osisioma Ngwa	NULL	NULL	Abia	NG001
12	Ugwunagbo	NG001012	Ugwunagbo	NULL	NULL	Abia	NG001
13	Ukwa East	NG001013	Ukwa East	NULL	NULL	Abia	NG001
14	Ukwa West	NG001014	Ukwa West	NULL	NULL	Abia	NG001
15	Umu-Nneochi	NG001017	Umu-Nneochi	NULL	NULL	Abia	NG001
16	Umuahia North	NG001015	Umuahia North	NULL	NULL	Abia	NG001
17	Umuahia South	NG001016	Umuahia South	NULL	NULL	Abia	NG001
18	Demsa	NG002001	Demsa	NULL	NULL	Adamawa	NG002
19	Fufure	NG002002	Fufure	NULL	NULL	Adamawa	NG002

4. Scroll down until you get to Anambra state or any other state of interest. (Note that you have several rows of each state because each row represents an LGA. Look at admin2Name to see the respective LGAs). Click on number 70 in the first column, the entire row containing data on the first LGA in Anambra state (Aguata) is highlighted. Hold down the “Shift” key on your keyboard and click on number 90 representing the last LGA in Anambra state (Oyi). All the LGAs in Anambra state are highlighted.

	admin2Name	admin2Pcod	admin2RefN	admin2AltN	admin2AL_1	admin1Name	admin1Pcod
69	Uyo	NG003031	Uyo	NULL	NULL	Akwa Ibom	NG003
70	Aguata	NG004001	Aguata	NULL	NULL	Anambra	NG004
71	Anambra East	NG004002	Anambra East	NULL	NULL	Anambra	NG004
72	Anambra West	NG004003	Anambra West	NULL	NULL	Anambra	NG004
73	Anaocha	NG004004	Anaocha	NULL	NULL	Anambra	NG004
74	Awka North	NG004005	Awka North	NULL	NULL	Anambra	NG004
75	Awka South	NG004006	Awka South	NULL	NULL	Anambra	NG004
76	Ayamelum	NG004007	Ayamelum	NULL	NULL	Anambra	NG004
77	Njikoka	NG004013	Njikoka	NULL	NULL	Anambra	NG004
78	Ekwusigo	NG004009	Ekwusigo	NULL	NULL	Anambra	NG004
79	Idemili North	NG004010	Idemili North	NULL	NULL	Anambra	NG004
80	Idemili South	NG004011	Idemili South	NULL	NULL	Anambra	NG004
81	Ihiala	NG004012	Ihiala	NULL	NULL	Anambra	NG004
82	Dunukofia	NG004008	Dunukofia	NULL	NULL	Anambra	NG004
83	Nnewi North	NG004014	Nnewi North	NULL	NULL	Anambra	NG004
84	Nnewi South	NG004015	Nnewi South	NULL	NULL	Anambra	NG004
85	Ogbaru	NG004016	Ogbaru	NULL	NULL	Anambra	NG004
86	Onitsha North	NG004017	Onitsha North	NULL	NULL	Anambra	NG004
87	Onitsha South	NG004018	Onitsha South	NULL	NULL	Anambra	NG004
88	Orumba North	NG004019	Orumba North	NULL	NULL	Anambra	NG004
89	Orumba South	NG004020	Orumba South	NULL	NULL	Anambra	NG004
90	Oyi	NG004021	Oyi	NULL	NULL	Anambra	NG004
91	Alkaleri	NG005001	Alkaleri	NULL	NULL	Bauchi	NG005

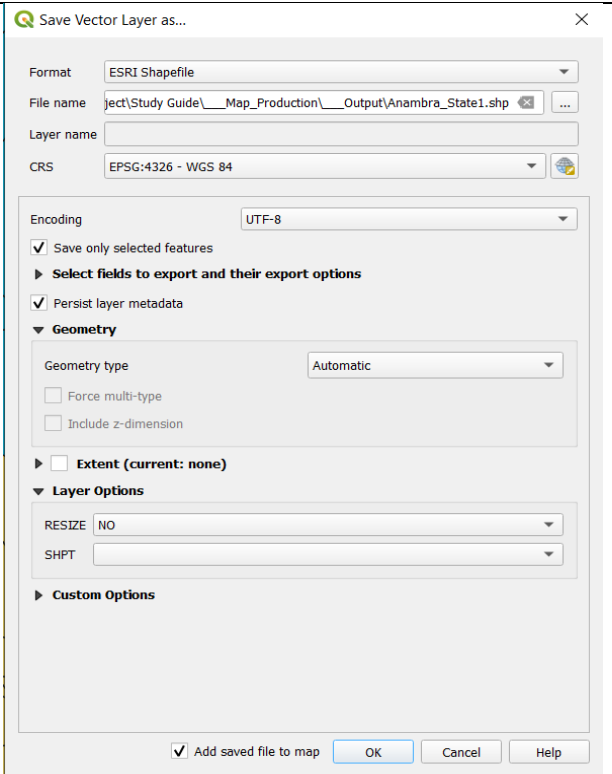
5. Look at the map window, and you will notice that Anambra state is highlighted in yellow. Zoom in to get a clearer view.



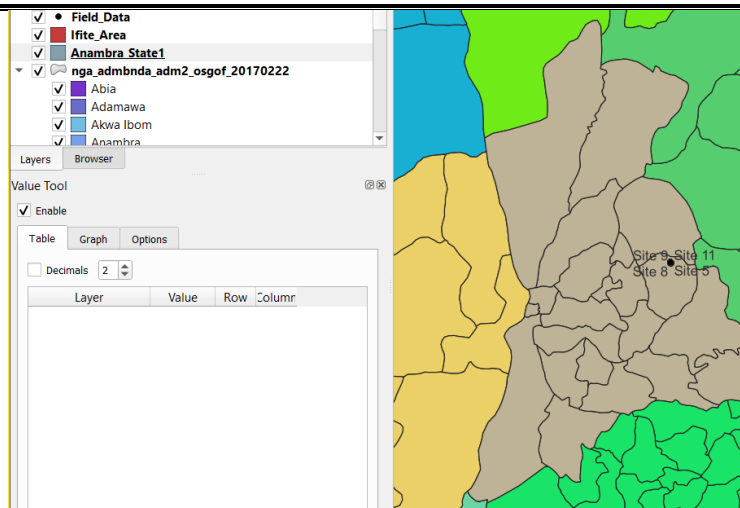
6. To save Anambra state as a new map layer, right-click on the target administrative map, select “Export” from the context menu, then “Save Feature As”.



7. In the pop-up window, make sure that the format is “ESRI Shapefile”, browse to the appropriate folder and type in “Anambra State”, press “Save”, make sure that “Save only selected features” is marked.


Save only selected features



8. Press “OK” to load a new map (Anambra State) in the map window and the layer panel.



9. Switch off the Anambra State map in the layer panel and you will see that Anambra state is still highlighted in the map of Nigeria. To remove selection, click on the “Deselect Features” tool []. A similar tool is also available in the attribute table window []

10. Note that you can perform the selection manually in the map window. To do so, press the “Select Features by Area or Single Click” tool []. Then click on a LGA in the map window. It is highlighted, but when you click on a new location, the old highlight disappears to be replaced by the new one. To highlight more than one location at the same time, hold down the “Shift” and click again and again on several locations. They are all highlighted. You can save the same way that we did above.

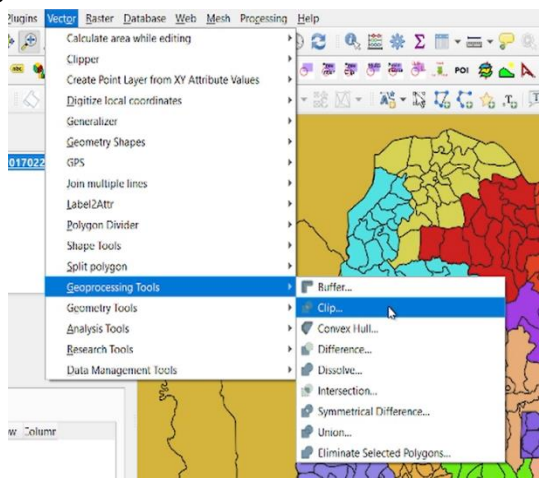
NOTE: Make sure that the appropriate map is selected in the “Layer” panel, otherwise, the selection will not work.

Self-Assessment Exercise

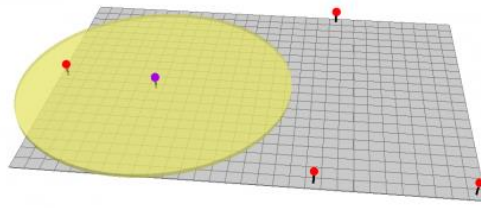
Show the extracted map as displayed in the map window.

3.3.3.3 Other Operations

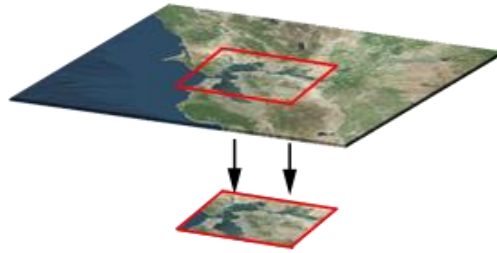
In QGIS, the following tools can be found under geoprocessing tools. Click on the vector tool in the tool bar. Select “Geoprocessing Tools” from the context menu. The tools will be listed in an extending context menu.



Buffer Tool: Buffers are proximity functions. When you use this geoprocessing tool, it creates a polygon at a set distance surrounding the features.

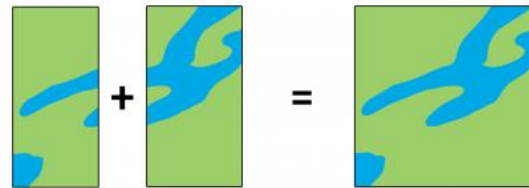


Clip Tool: The clip tool is an overlay function that cuts out an input layer to the extent of a defined feature boundary. The result of this tool is a new clipped output layer.



To clip data, you need points, lines, or polygons as input and a polygon as the clipping extent. The preserved data is the result of a clip.

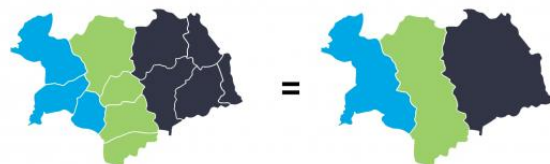
Merge Tool: The merge tool combines data sets that are the same data type (points, lines, or polygons). When you run the merge tool, the resulting data will be merged into one.



Similar to the clip tool, we use the merge tool regularly. For merging, data sets have to be the same type. For example, you cannot merge points and polygons into one data set.

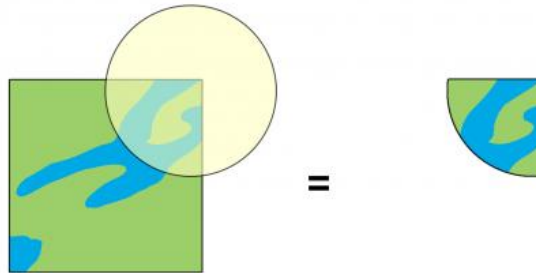
Dissolve Tool:

The dissolve tool unifies boundaries based on common attribute values. In other words, dissolve merges neighboring boundaries if the neighbors have the same attributes.



For example, if you want to remove the borders of countries to form a continent, the dissolve tool is the tool to use. But you would need an attribute for each country and the continent it belongs to.

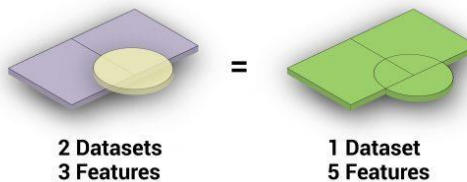
Intersect Tool: The intersect tool is very similar to the clip tool because the extents of input features define the output. The only exception is that it preserves attributes from all the data sets that overlap each other in the output.



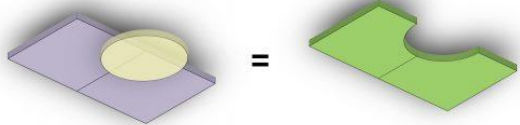
The intersect tool performs a geometric overlap. All features that overlap in all layers will be part of the output feature class – attributes preserved.

The tool accepts different data types (points, lines, and polygons). When features overlap each other, they will be in the output.

Union Tool: The Union tool spatially combines two data layers. It preserves features from both layers to the same extent. It gets a bad reputation because it creates a lot of features. The union tool maintains all input feature boundaries and attributes in the output feature class.



Erase (Difference) Tool:
 The Erase Tool removes features that overlap the erase features. This geoprocessing tool maintains portions of input features falling outside the erase features extent. The result is a new feature with the erase feature extent removed. (NOTE: The input layer is what will be erased. The erase feature determines what to erase).



Self-Assessment Exercise

List four vector operations that you have not yet used.

3.4 Conclusion

Given the fact that some of the maps may not be very accurate, there arises a dilemma as to which one to use. For the purpose of this course the choice may not matter since is only meant for instructional purpose. On the other hand, if you are contracted to generate a map by a government or company of even for your final year project, you need to be sure that you map is (largely) accurate. You may consequently need to source maps from different datasets and compare to determine where you have greater agreement. In this unit, the GADM and DIVA GIS boundaries align. Under normal circumstances, this may be considered as a sign of accuracy. This is not necessarily so; maybe both maps were gotten from the same source or one from the other. I trust the World Bank dataset more. It is an institution that requires the use of accurate boundary data in its operations. To double-check further, get the geographic coordinates of several boundary towns (e.g., boundary towns in Enugu and Anambra states). Save as CSV file and import into QGIS. Observe whether some towns you know are in Anambra state ended up in Enugu state, and vice versa. Repeat for all the datasets. That would be a good litmus test as to the accuracy of the boundaries. Note that you do not need to go to the boundary towns to get the coordinates. Search for the coordinates online (e.g., search for coordinates of Ugwuoba, etc.).

3.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

3.6 Tutor-Marked Assignment

1. Show evidence of each operation performed
- 2a. Which is most accurate?
- b. Explain why you think so,

3.7 References/Further Reading/Web Resources

For audiovisual tutorials on QGIS vector operations and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

QGIS Vector Operations: Manipulation and Conversion of CSV Files

<https://www.youtube.com/watch?v=-VouqSHq8nE&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=17>

QGIS Vector Operations: Creation and Manipulation of Polygons

https://www.youtube.com/watch?v=8DN_bn3NO9c&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=18

QGIS Vector Operations: Working with Polygons, Creating and Opening KML Files, Google Earth Pro

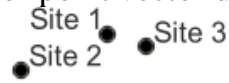
<https://www.youtube.com/watch?v=GhA-yONzdkU&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=19>

QGIS Vector Operations: Format, Highlight, Extract and Save Parts of a Map Layer

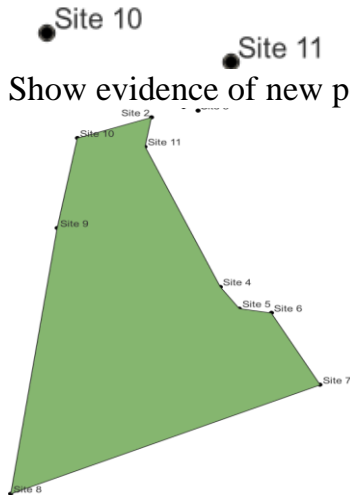
https://www.youtube.com/watch?v=CVN62dDYs_I&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=20

3.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

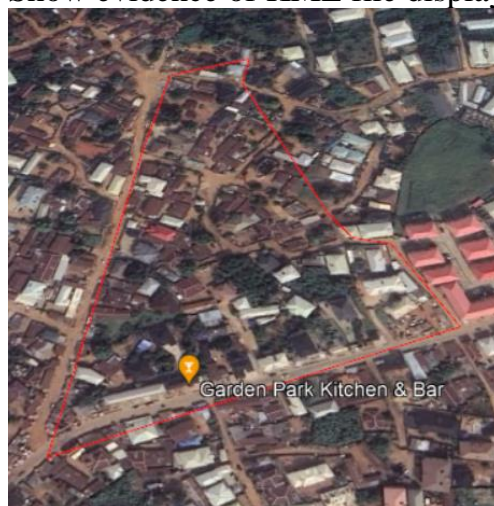
1. Show evidence of point vector display in the map window.



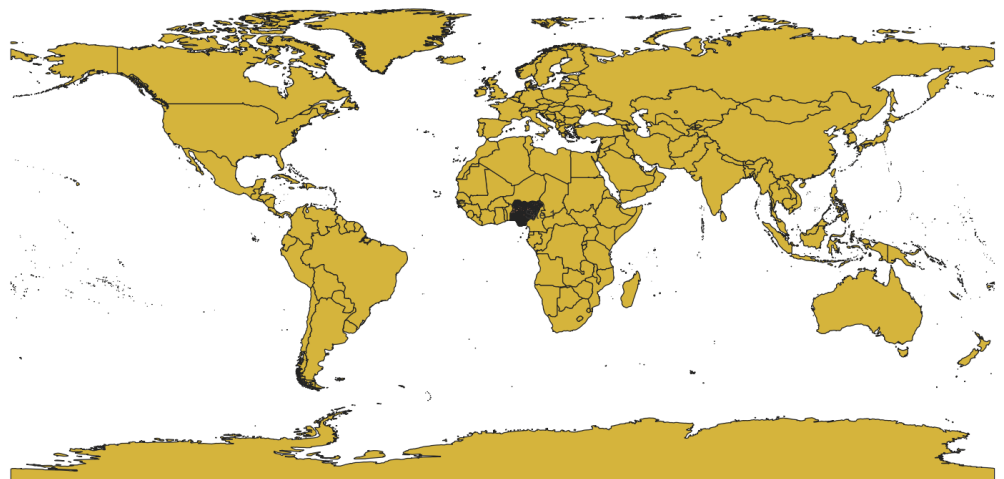
2. Show evidence of new polygon.



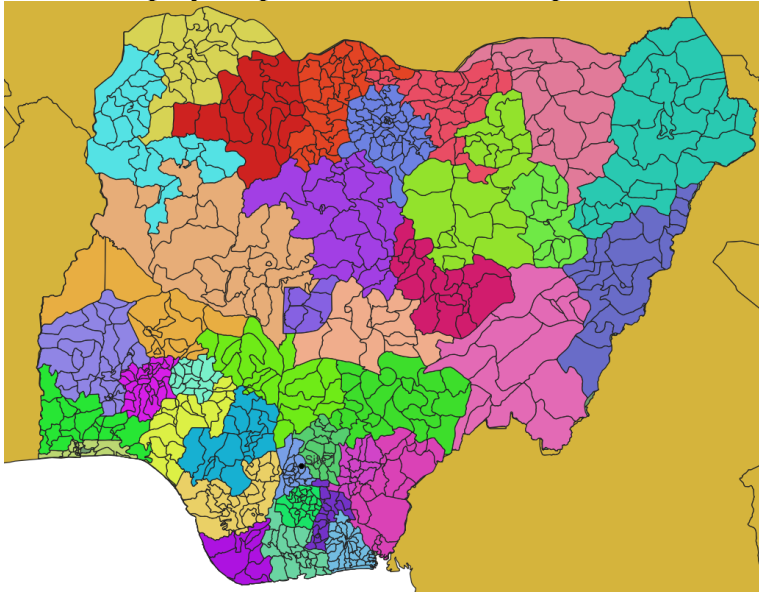
3. Show evidence of KML file display on Google Earth.



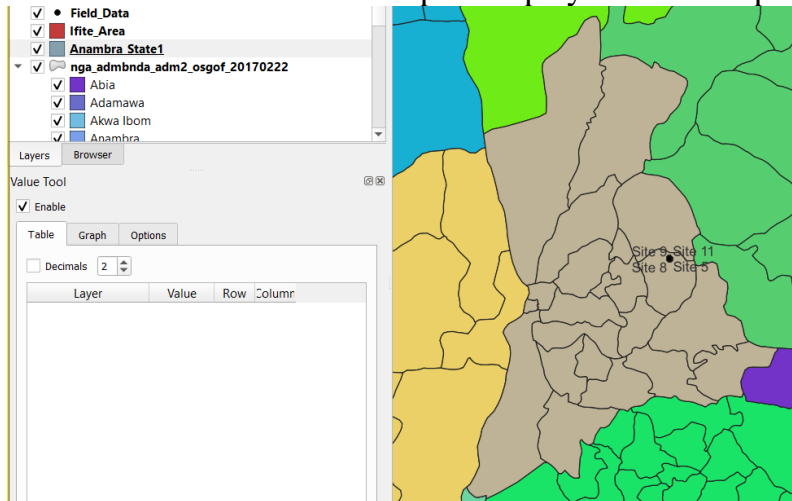
4. Show evidence of display of all administrative maps.



5. Display map as shown in the map window.



6. Show the extracted map as displayed in the map window.



7. List four vector operations that you have not yet used.
 i) Buffer ii) Clip iii) Intersect iv) Erase

UNIT 4 MANIPULATION OF RASTER DATA (DEMS)

Unit Structure

- 4.1 Introduction
- 4.2 Objectives
- 4.3 Main Content
 - 4.3.1 Import Raster Data (DEM) in QGIS
 - 4.3.2 Clip Raster Data
 - 4.3.3 Merge Raster Data
- 4.4 Conclusion
- 4.5 Summary
- 4.6 Tutor-Marked Assignment
- 4.7 References/Further Reading/Web Resources
- 4.8 Possible Answers to Self-Assessment Exercise(s) within the content

4.1 Introduction

In this unit we are going to focus on the manipulation of DEM data. We will perform several operations, including, loading raster data, clipping, merging, saving and identifying pixel values. The DEM will be trimmed down to roughly the spatial extent of Anambra state, in preparation for use in subsequent units for terrain analysis.


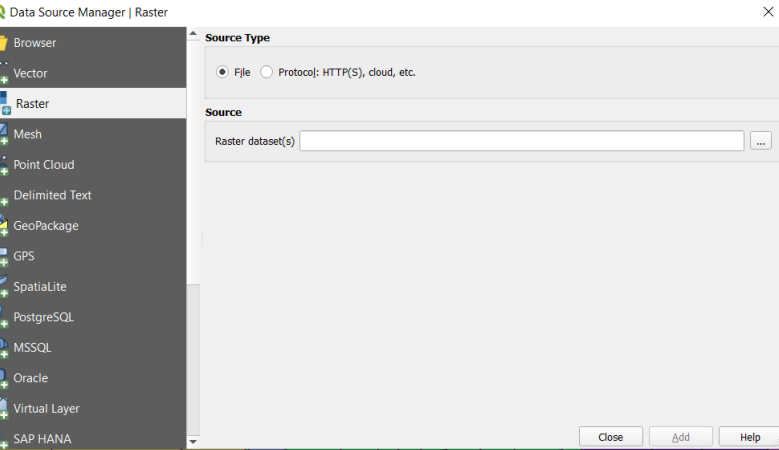
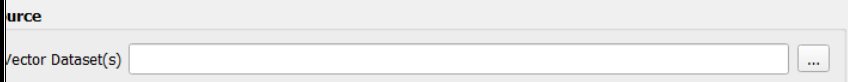
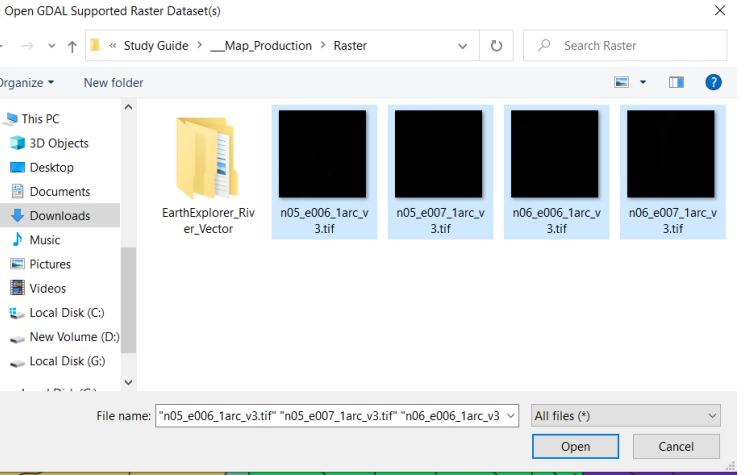
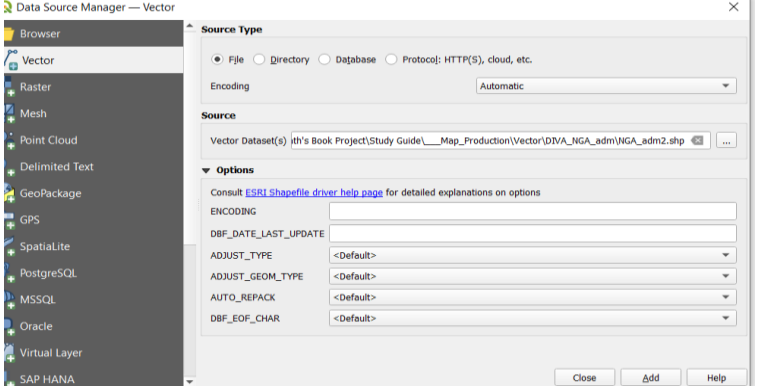
4.2 Objectives

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

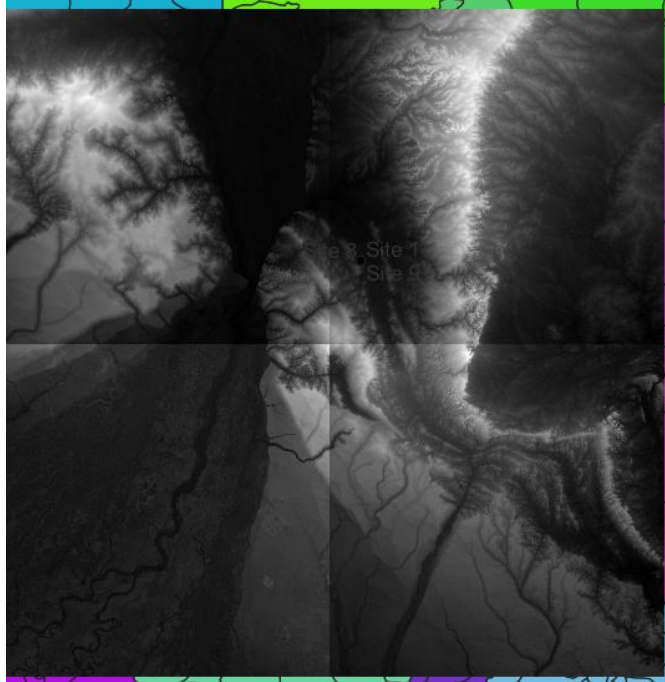
- Be able to manipulation of raster data (DEMs) in a GIS application

4.3 Main Content

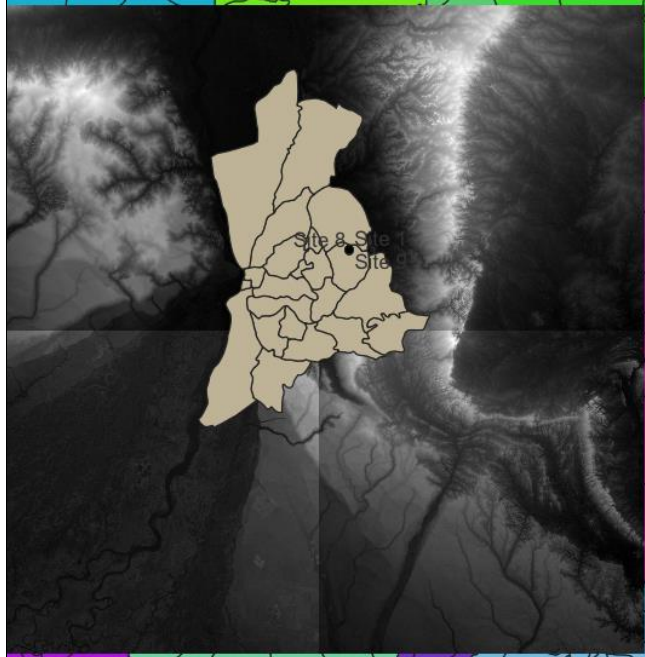
4.3.1 Import Raster Data (Dem) In QGIS

<p>Open QGIS (from the start menu or the desktop)</p>	<p>Click the “Open Data Source Manager” button on the top lefthand edge of the QGIS window</p> 
<p>Select “Raster” in the pop-up window</p>	
<p>Click the browse button (3 dots on the end of the “Raster Dataset(s)” row</p>	
	
<p>Browse to the location of the downloaded DEMs. Select one, hold shift and select the other three, one after the other. Press the “Open” button.</p>	
<p>Press the “Add” button to load the Raster (DEMs) and press the “Close” button.</p>	

The DEMs are loaded in both the map window and the layer panel. Note that all four DEMs are will aligned, but you can still tell the difference.



Drag the Anambra State map up in the layer panel, until it is above the DEMs.

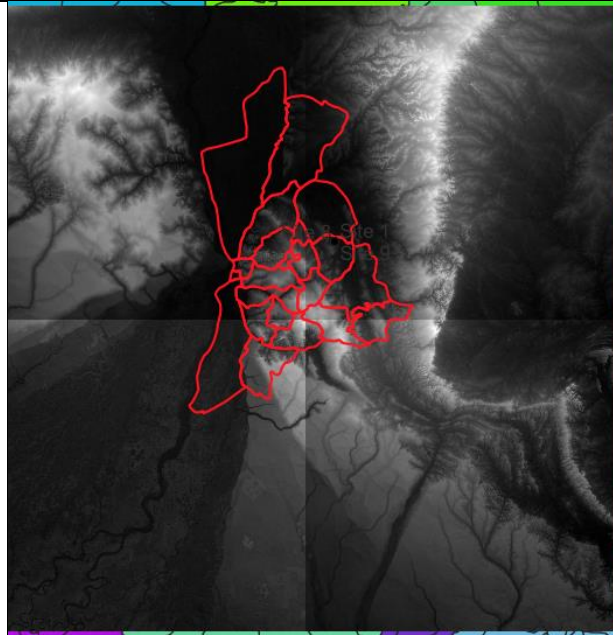


To view the DEM below the Anambra State map, right-click on it and select “Properties.”

Select “Symbology” tab; under “Fill”, select “Simple Fill”; in the “Fill Style” row with “Solid” currently displayed, press the drop-down arrow and select “No Brush”.



Press “Apply” and view what happens in the map window. (The Anambra Map virtually disappears)

Back in the “Layer Properties” pop-up window, press the drop-down arrow for “Stroke Color”, which is currently black and select red and increase the “Stroke thickness” to 0.45. Press “Apply” and then, “OK”. Observe the map window.

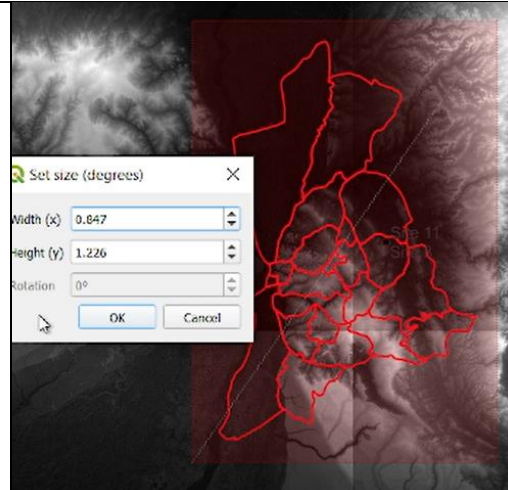


Note that the white areas are on higher elevation while the dark areas are on lower elevation. (The brighter the colour, the higher the elevation, the darker the colour, the lower the elevation).

0. Create a rectangular polygon covering the entire area of Anambra state.

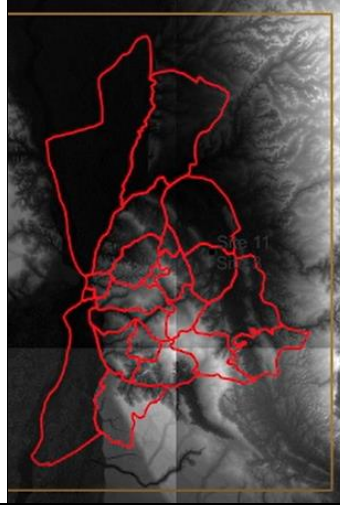
Create new shapefile layer; activate toggle editing; instead of using the “Add Polygon Feature” tool [], we will use the “Draw Rectangle Geometry” tool [].

1. Click just beyond the southwestern edge of Anambra state, hold and drag towards the northeastern edge. Let go beyond the edge to see a pop-up window. Click “OK”.



2. Type in “id” and “Name” in the next pop-up window.

3. Format the new vector layer and change fill type, stroke color and width. Apply and Okay.



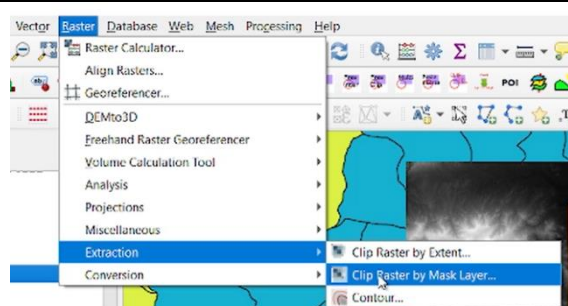
Self-Assessment Exercise

Show evidence of raster display.

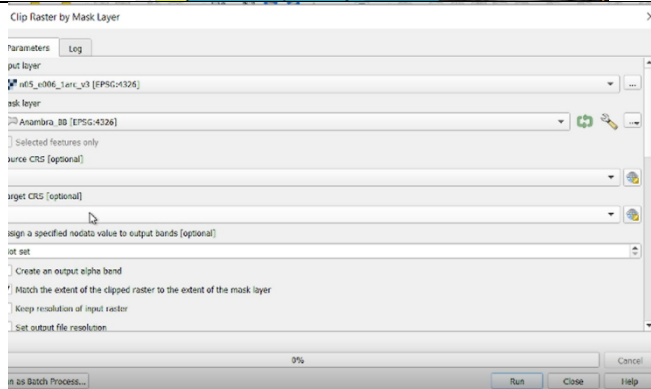
4.3.2 Clip Raster Data

In this section, we are going to use the Anambra bounding box to clip/cut out sections of the DEMs.

Click on “Raster” on the menu bar, select “Extraction” then, subsequently select “Clip Raster by Mask Layer” and click.



In the pop-up window, under “Input Layer”, click on the drop-down arrow to and select the first raster. Under “Mask Layer”, select Anambra_BB. Leave the other settings as defined.



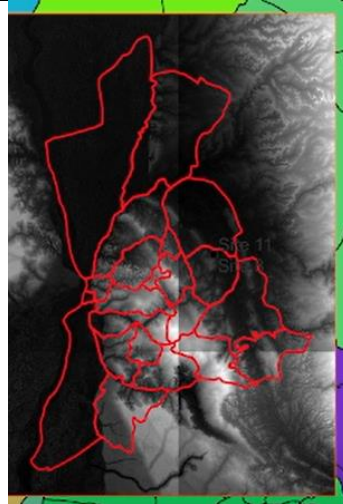
Click on the “Run” button to execute command

Go back to the “Parameters” pane. []

Go back to the “Input Layer” and select the second raster data. Press “Run” to execute command.

Repeat steps 5 and 6 to clip all target raster layers.

Deactivate the parent raster layers. You will notice that You have new layers within the spatial extent of the Anambra_BB layer. In the Layer Panel, you will notice that these are called “Clipped (mask)” Remove the parent layers, leaving behind the clips.



Self-Assessment Exercise

Show evidence of clipped raster.

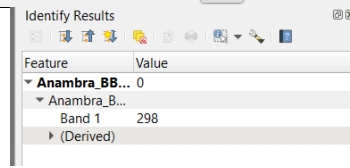
4.3.3 Merge Raster Data

In this section, we are going to merge the clipped layers.

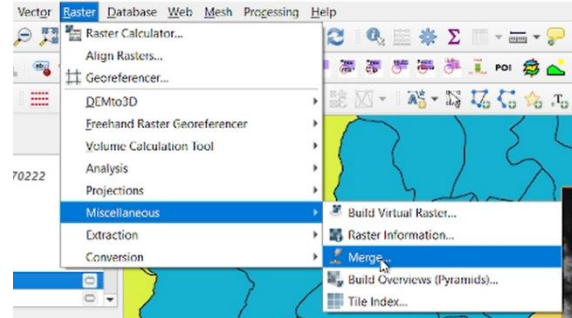
Before we commence, let us perform some basic operations. Raster data are made up of pixels/grids, which determine the resolution of the data. This DEM has a resolution of 30m. Zoom in until you see the grid cells or pixels.

2. Each pixel has a single, value. To identify the value, press the “Value” tool [].

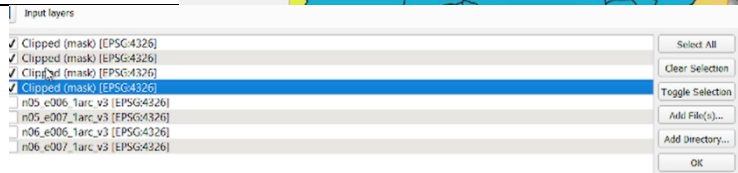
3. Make sure the raster is selected and click on a pixel in the raster. The value appears on a new pane. Click on several pixels and observe the pane. Close the pane by clicking on the “x” at the top-right hand corner.



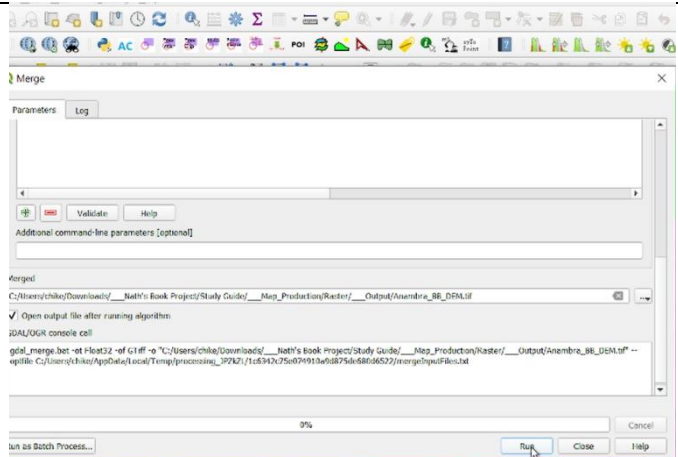
Now back to the actual raster operations of interest. To merge the raster clips, click on “Raster” on the menu bar, select “Miscellaneous” then, subsequently select “Merge” and click.



In the pop-up window, under “Input Layer”, browse to select the layers to be merged.




Press “OK”. Under “Merged”, browse to your target folder, input an appropriate name, press the “Save” button and press the “Run” button in the parent pop-up window.



Close the pop-up window. A new raster layer can be seen in the layers panel. Remove the raster clips.

The raster layer is now ready for terrain analysis in subsequent units. Save the changes/updates made in the QGIS document.

NOTE: Do not wait until you are done to save. You should click the “Save” button [] from time to time as you continue to work, so that if the system hangs, as sometimes happens, most of the work already done would have been saved.

Self-Assessment Exercise

What is the range of elevation values recorded in you merged raster data?

4.4 Conclusion

There are many raster operations that we have not performed. However, having acquitted this baseline knowledge, it is expected that it will be easier for you to practice further and learn more. Having concluded the relevant raster operations, make sure the new datasets are saved because you will utilize them for terrain analysis in subsequent units.

4.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- Importing raster data in QGIS
- Clipping raster data with polygon layer
- Merging raster data.

4.6 Tutor-Marked Assignment

1. Show evidence that you performed the
 - a) Raster import operations
 - b) Clipping operations
 - c) Merging operations

4.7 References/Further Reading/Web Resources

For audiovisual tutorials on importing, clipping, merging and performing several raster operations in QGIS and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel:

https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Import Raster Layers into QGIS

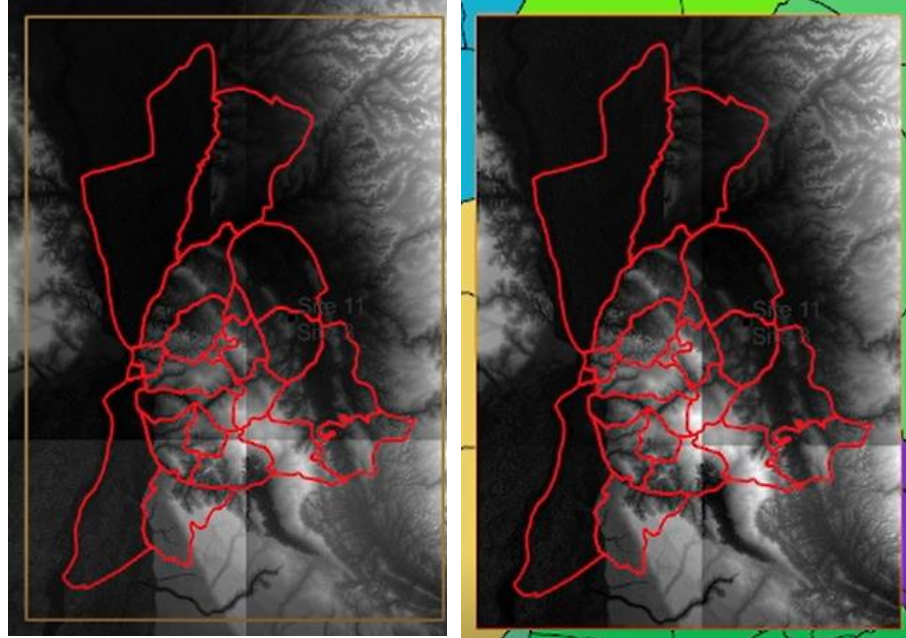
<https://www.youtube.com/watch?v=IYI8u2u1mqw&list=PLSLmCvtQVKMy7bhsK8kY1hXNwJXW2yJF&index=21>

Clip and Merger Raster Operations

<https://www.youtube.com/watch?v=AmoY42Jp8Bo&list=PLSLmCvtQVKMy7bhsK8kY1hXNwJXW2yJF&index=22>

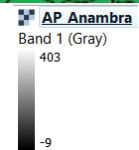
4.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Show evidence of raster display.
2. Show evidence of clipped raster.



3. What is the range of elevation values recorded in you merged raster data?

For my site, the elevation ranged from 9 m below sea level to 403 m above sea level.



UNIT 5 GENERATION OF SLOPE MAP

Unit Structure

- 5.1 Introduction
- 5.2 Objectives
- 5.3 Main Content
 - 5.3.1 Slope Analysis
 - 5.3.2 Slope Reclassification
- 5.4 Conclusion
- 5.5 Summary
- 5.6 Tutor-Marked Assignment
- 5.7 References/Further Reading/Web Resources
- 5.8 Possible Answers to Self-Assessment Exercise(s) within the content

5.1 Introduction

The steepness of a terrain plays a crucial role in land degradation/evolution, water flow (surface and underground) soil formation/variability, ecosystem diversity, etc. The advent compute technology, geographic information system and remote sensing enables the determination of the spatial variability of slope steepness across very large areas. This enables proactive land management and sustainable land use planning. In this unit, we are going to learn how this specific terrain analysis is performed in GRASS GIS.

5.2 Objectives

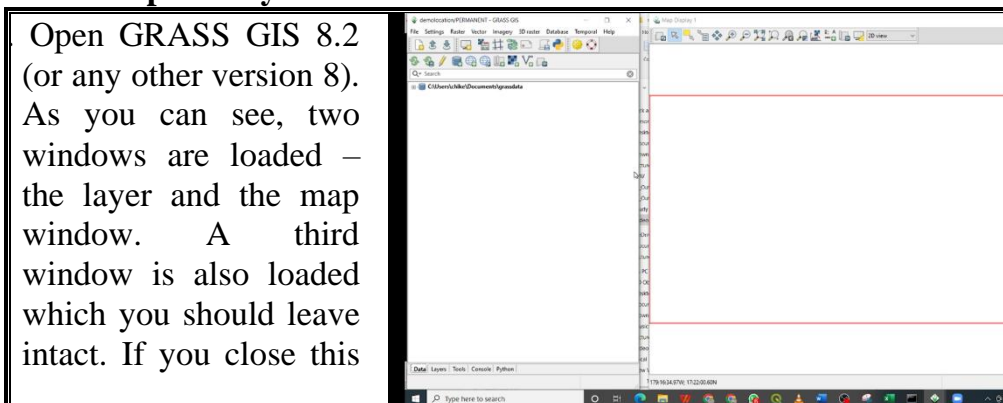
By the end of this unit, you will be able to:

- Be able to map the slope of an area using the digital elevation model (DEM)


5.3 Main Content

5.3.1 Slope Analysis

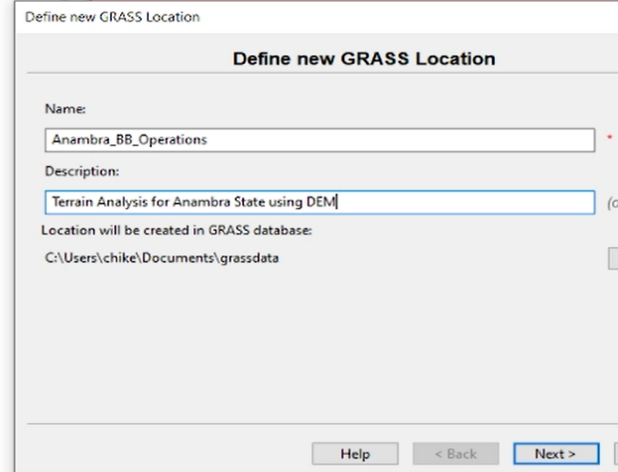
Open GRASS GIS 8.2 (or any other version 8). As you can see, two windows are loaded – the layer and the map window. A third window is also loaded which you should leave intact. If you close this



third window, the entire program closes.

2. Click on the “Create new location in current GRASS database” tool [] just above the “Layer” window.

In the pop-up window, type in an appropriate name and description. Press the “Next” button.



Define new GRASS Location

Define new GRASS Location

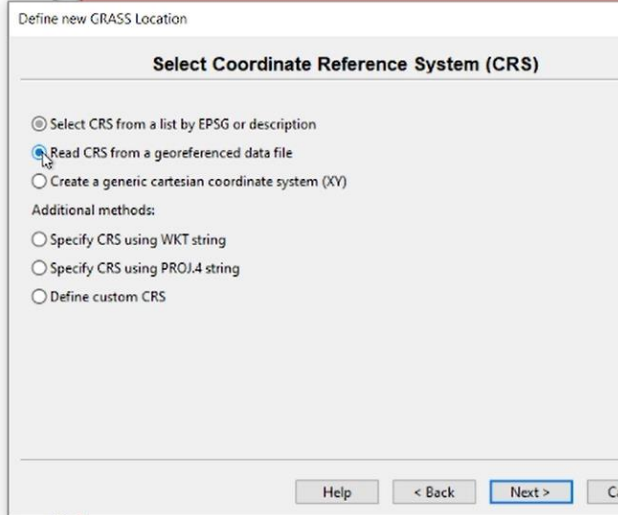
Name:
Anambra_BB_Operations

Description:
Terrain Analysis for Anambra State using DEM

Location will be created in GRASS database:
C:\Users\chike\Documents\grassdata

Help < Back Next >

In the next window, you are required to define GRASS location and select a coordinate reference system. Select “Read CRS from a georeferenced data file”. Press the “Next” button.



Define new GRASS Location

Select Coordinate Reference System (CRS)

Select CRS from a list by EPSG or description

Read CRS from a georeferenced data file

Create a generic cartesian coordinate system (XY)

Additional methods:

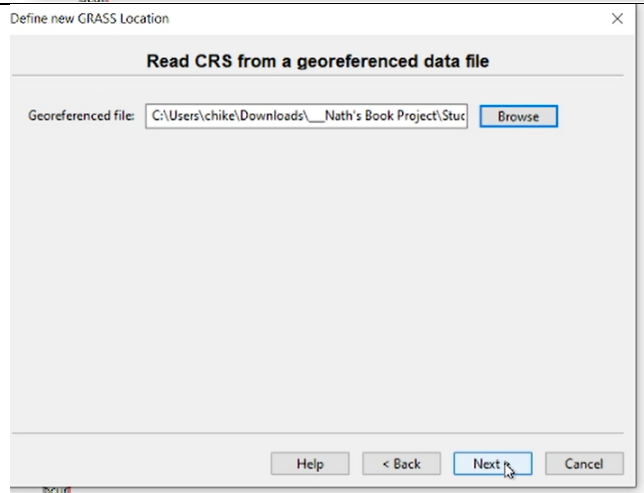
Specify CRS using WKT string

Specify CRS using PROJ.4 string

Define custom CRS

Help < Back Next >

In the next window, browse to the location of the raster data that you want to work on, select it and press the “Open” button. Press the “Next” button.



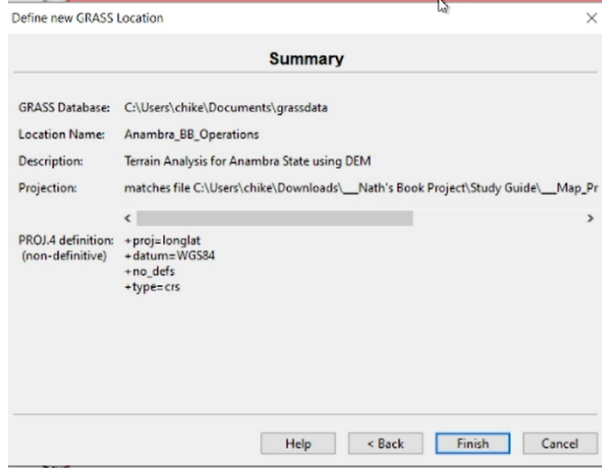
Define new GRASS Location

Read CRS from a georeferenced data file

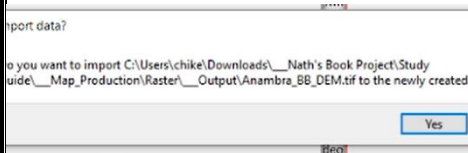
Georeferenced file: C:\Users\chike\Downloads__Nath's Book Project\Stuc Browse

Help < Back Next > Cancel

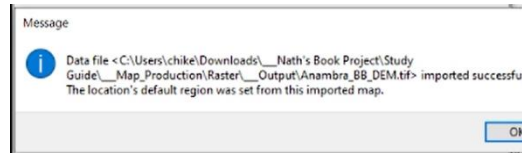
In the next window, an overview of the target CRS and allied information can be seen. Press the “Finish” button.



Click on “Yes” in the pop-up window.



8. Click on “OK” in the next pop-up window.

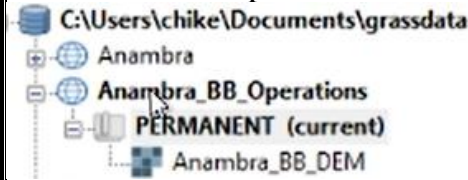


Again press “OK” in the next pop-up window.

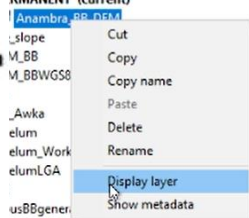


9. The map window reloaded to fit the configuration of the new definitions.

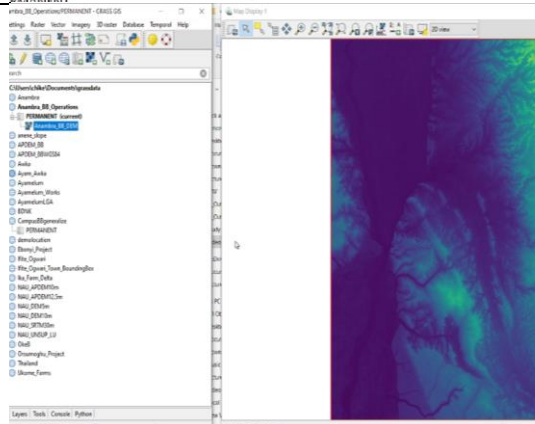
1. The loaded can be seen in the layers window, even if it is not loaded in the map window



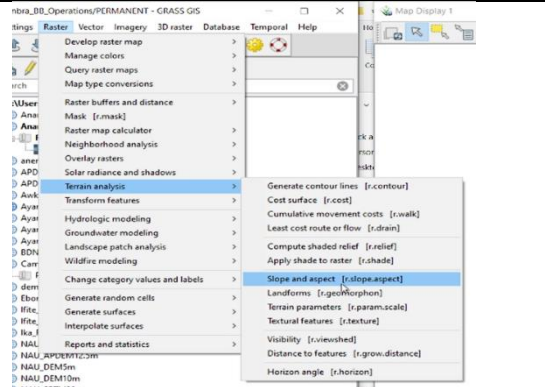
2. To load, right-click on it and select “Display Layer”.



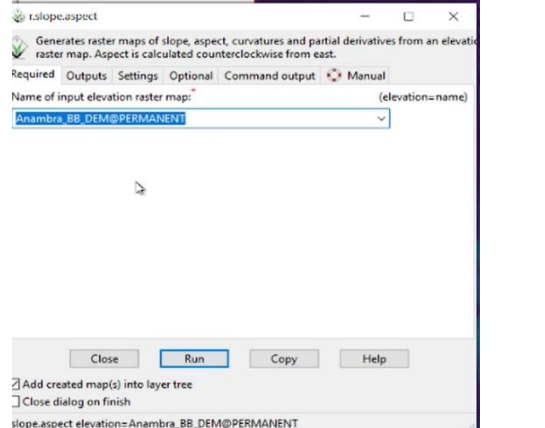
3. The raster data (DEM) appears, looking different for what it looks like in QGIS because of the peculiar symbology in GRASS GIS.



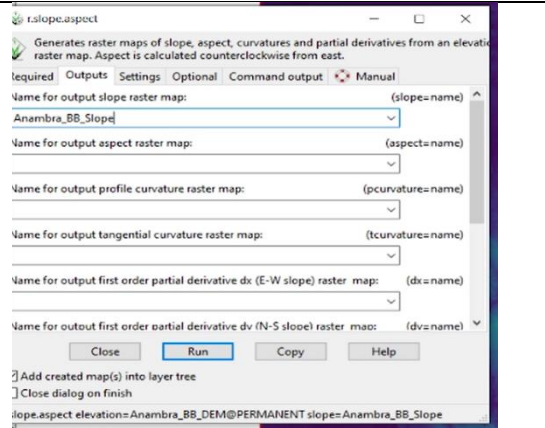
4. To generate the slope map, click on the “Raster” tool in the menu bar, select “Terrain Analysis” and then click on the “Slope and Aspect” tool.



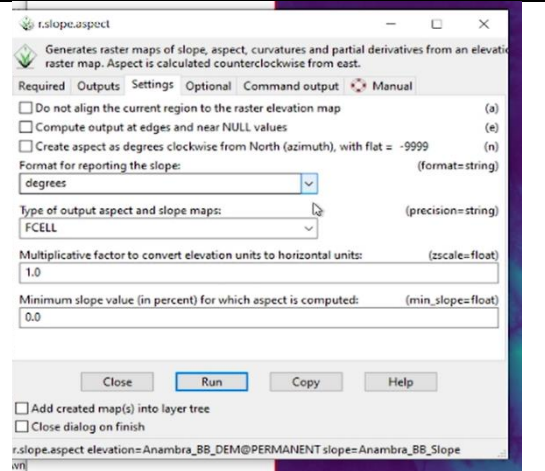
5. The “Required” tab is automatically selected. Under “Name of input elevation raster map” click on the drop-down arrow and select the DEM.



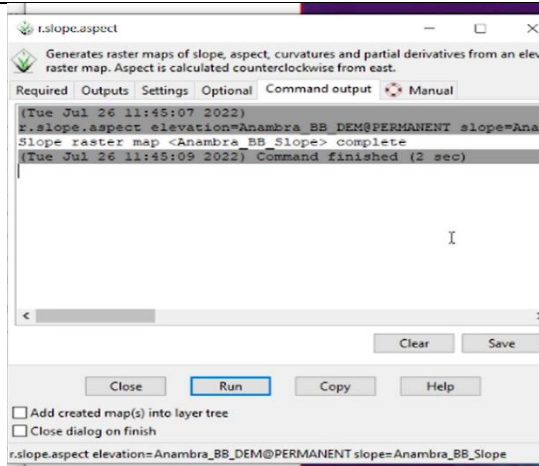
6. Select the “Output” tab. Under the “Name for output slope raster map”, type in an appropriate name. Leave the other options blank.



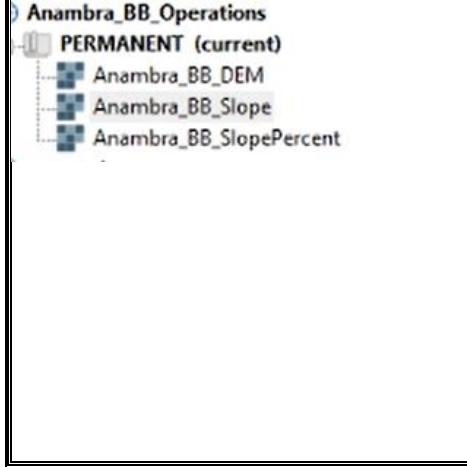
7. Select the “Settings” tab. Under “Format for reporting the slope” you can select degrees or percent. Leave the default settings (degrees) for now. Press the “Run” button.



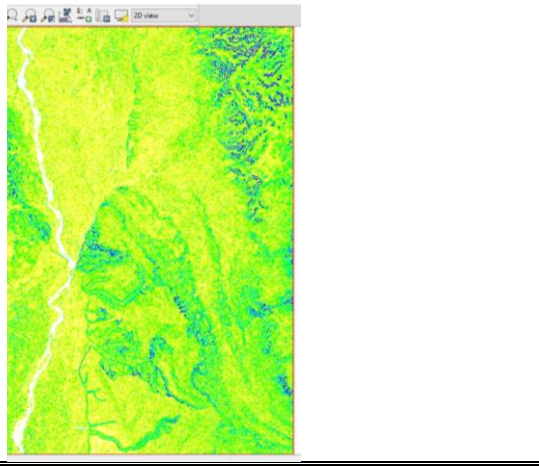
8. The map is loaded into the layer window. A message appears in the command output window acknowledging the successful generation of the slope map. Select the “Settings” tab. Under “Format for reporting the slope” you can select percent. Select the “Output” tab. Under the “Name for output slope raster map”, type in an appropriate name (probably adding PC to indicate percent). Again, leave the other options blank. Click on the “Run” button to execute the operation and generate percent slope. Close the pop-up window.



9. In the layer window you can see the new slope raster maps.



10. You can display specific layer in the map window as shown in step 12.



Self-Assessment Exercise

Show the slope raster.

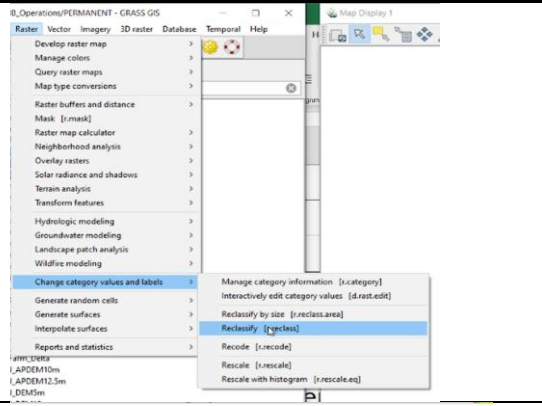
5.3.2 Slope Reclassification

The slope map that was generated is a continuous raster data; each grid cell has a unique data value. To generate slope classes, such as gentle, steep, moderate slope, etc., a range of values have to be defined. For this, we will use the FAO slope classification ranges.

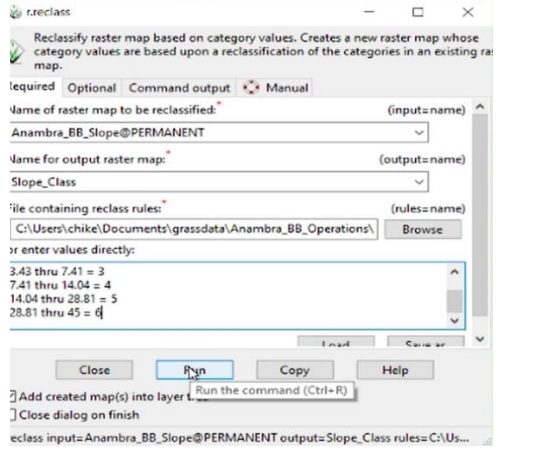
FAO Slope Classes

Class	Steepness	Slope Percent		Slope Degrees	
		From	To	From	To
Class 1	Flat or almost flat	0	2	0	1.15
Class 2	Gently sloping	2	6	1.15	3.43
Class 3	Sloping	6	13	3.43	7.41
Class 4	Moderately steep	13	25	7.41	14.04
Class 5	Steep	25	55	14.04	28.81
Class 6	Very steep	55	100	28.81	45.00

To reclassify the slope map, click on the “Raster” tool in the menu bar, select “Change category values and labels” and then click on the “Reclassify” tool.

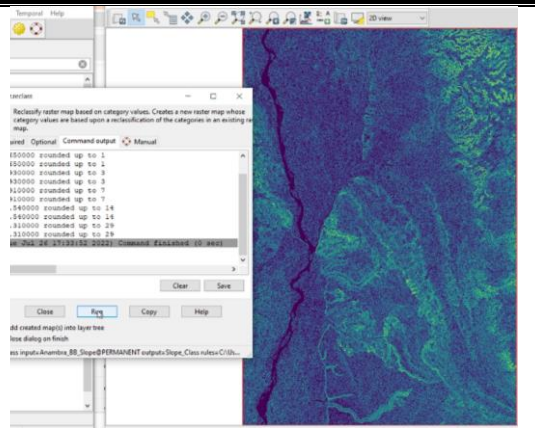


The “Required” tab is automatically selected. Under “Name of raster map to be reclassified” click on the drop-down arrow and select the slope (degrees) raster, under “Name of output raster map”, type in an appropriate name. Type in the rules:

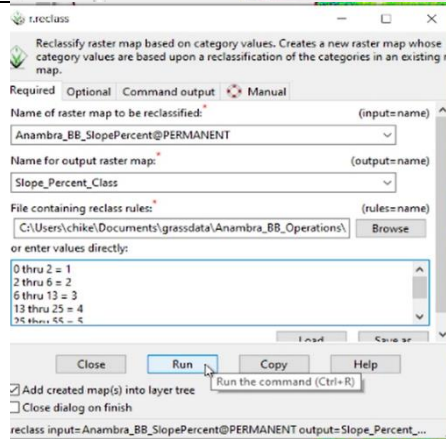


- 0 thru 1.15 = 1
 - 1.15 thru 3.43 = 2
 - 3.43 thru 7.41 = 3
 - 7.41 thru 14.04 = 4
 - 14.04 thru 28.81 = 5
 - 28.81 thru 45.00 = 6
- Click “Run” to execute.

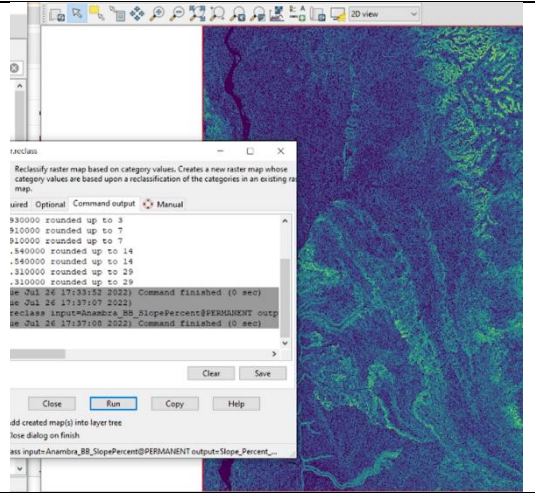
The operation is executed.



Go back to the “Required” tab. Under “Name of raster map to be reclassified” click on the drop-down arrow and select the slope (percent) raster, under “Name of output raster map”, type in an appropriate name (different from the name in step 2). Type in the rules:
 0 thru 2 = 1
 2 thru 6 = 2
 6 thru 13 = 3
 13 thru 25 = 4
 25 thru 55 = 5
 55 thru 100 = 6
 Click “Run” to execute.



The operation is executed.



Self-Assessment Exercise

Show evidence of reclassified slope.

5.4 Conclusion

In this unit, we generated the slope class map from the DEM. Furthermore, we delineated the slope classes of the study area in accordance with the specifications of the Food and Agriculture Organization of the United Nations. The map production process is however, still incomplete, as a novice observing the map may still not be able to make sense of it. In subsequent units, we will add more details. These details will make the maps more presentable and understandable.

5.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- Slope analysis with DEM data
- Slope classification

5.6 Tutor-Marked Assignment

1. Show evidence of generation of:
 - a. Slope maps (percent and degree)
 - b. Slope class maps
- 2a. Are the slope class maps generated from percent slope and degree slope maps different?
 - b. Why do you think they are similar or dissimilar? (depending on your answer)

5.7 References/Further Reading/Web Resources

For audiovisual tutorials on terrain analysis in GRASS GIS and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel: https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Major Difference Between GRASS GIS 7 and 8

<https://www.youtube.com/watch?v=ID9rJXnFMoA&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=23>

Slope Analysis in GRASS GIS

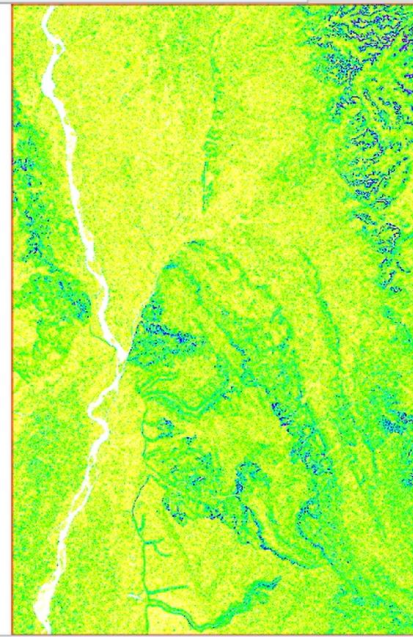
<https://www.youtube.com/watch?v=kECGQg3ANdU&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=24>

Slope Classification in GRASS GIS

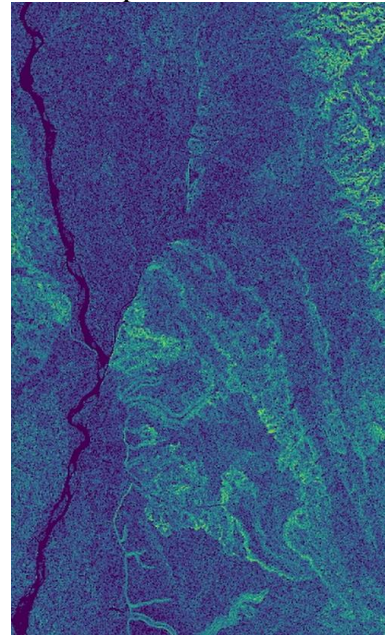
<https://www.youtube.com/watch?v=-28wtgd4jWc&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=25>

5.8 Possible Answers to Self-Assessment Exercise(S) within the Content

1. Show the slope raster.



2. Show evidence of reclassified slope.



UNIT 6 GENERATION OF LANDFORM MAPS REFLECTING THE SOIL-LANDSCAPE

Unit Structure

- 6.1 Introduction
- 6.2 Objectives
- 6.3 Main Content
 - 6.3.1 Geomorphons
 - 6.3.2 Generate Geomorphons in GRASS GIS
 - 6.3.3 Generate the Hillshade in GRASS GIS
 - 6.3.4 Drape the Geomorphons over the Hillshade to Depict Landform Variability
- 6.4 Conclusion
- 6.5 Summary
- 6.6 Tutor-Marked Assignment
- 6.7 References/Further Reading/Web Resources
- 6.8 Possible Answers to Self-Assessment Exercise(s) within the content

6.1 Introduction

The nature of the landscape/landforms, to a large extent, determines the nature of the soil, ecosystem, degree of land degradation, land use potentials and land allocation. In this unit, we are going to delineate the landform classes in a chosen area or state using the digital elevation model. The products of these operations are potentially fundamental to for sustainable resource use and management.

6.2 Objectives

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

- Be able to map the landform of an area

6.3 Main Content

6.3.1 Geomorphons

Geomorphon is a new concept of presentation and analysis of terrain forms. This concept utilizes 8-tuple pattern of the visibility neighborhood. The pattern arises from a comparison of a focus pixel with its eight neighbors starting from the one located to the east and continuing counterclockwise producing ternary operator. For example, a tuple {+, -, -, -, 0, +, +, +} describes one possible pattern of relative measures {higher, lower, lower, lower, equal, higher, higher, higher} for pixels surrounding

the focus pixel. The digital elevation model (DEM) is the main input required in the computation of Geomorphons. The Landform units of the geomorphon are shown in Figure 35.

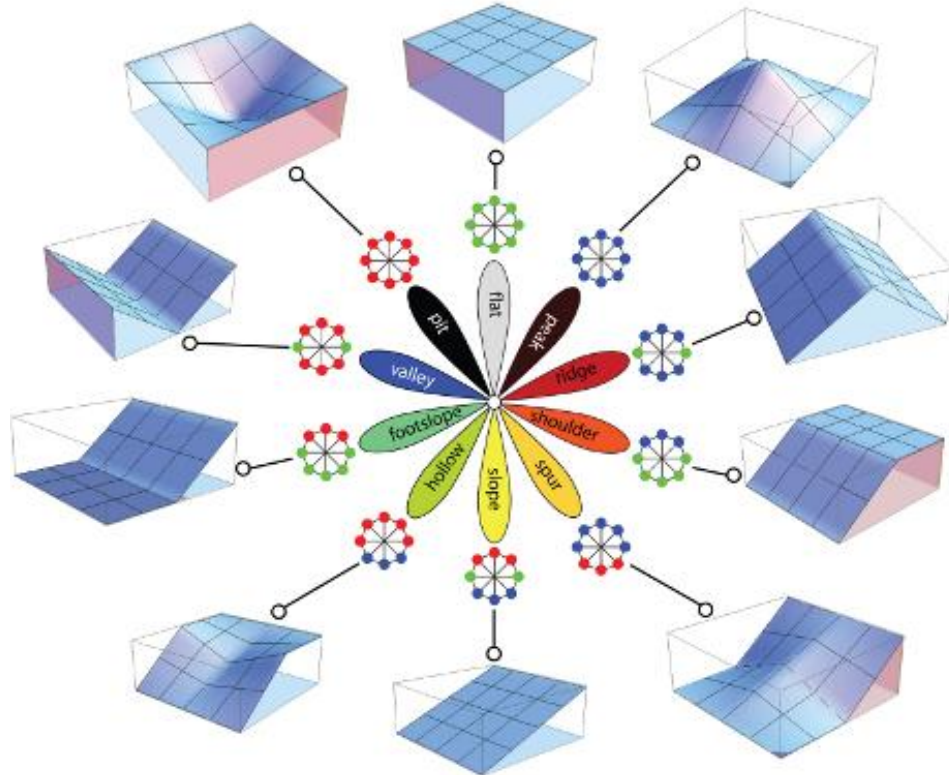
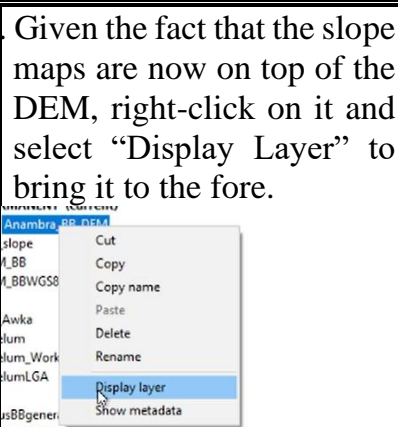
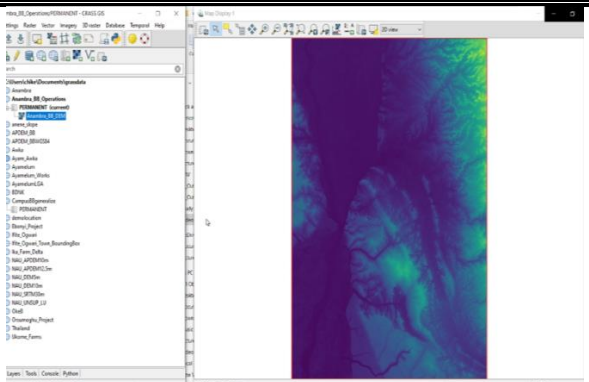


Figure 35: Landform Depictions in Geomorphons

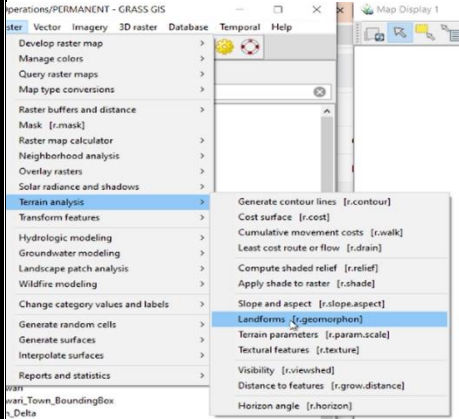
Self-Assessment Exercise

List the ten landform classes depicted by the geomorphons.

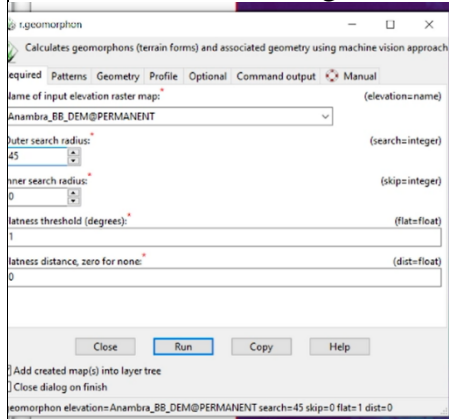
6.3.2 Generate Geomorphons in Grass GIS

<p>Given the fact that the slope maps are now on top of the DEM, right-click on it and select “Display Layer” to bring it to the fore.</p> 	
<p>To compute the geomorphons,</p>	<p>Select the “Required” tab. Under “Name of input elevation raster map”, click on the drop-down</p>

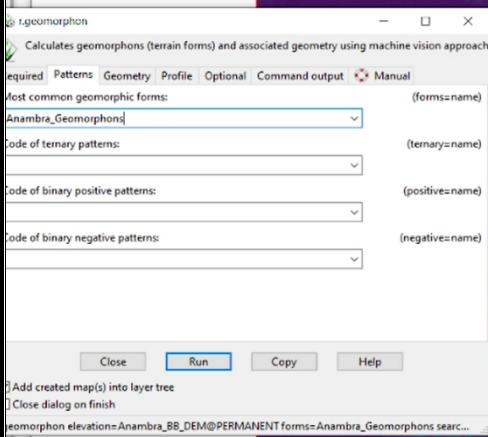
Analysis” and the click on the “Landforms [r.geomorphon]” tool.



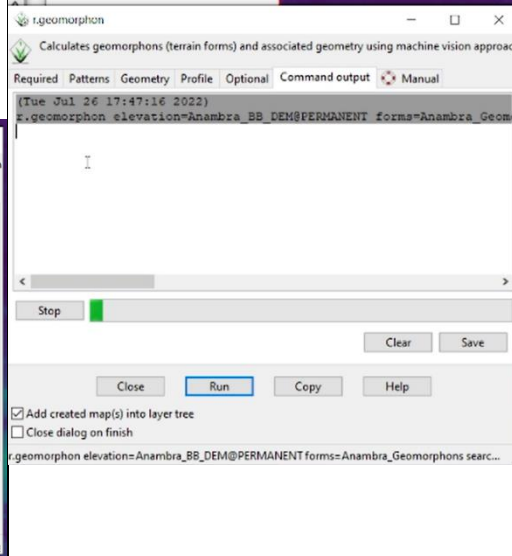
arrow and select the DEM. Under “Outer search radius” type in 45. Leave the other settings intact.



Select the “Patterns” tab. Under the “Most common geomorphic form”, type in an appropriate name. Retain the default settings for the others. Press the “Run” button to compute.

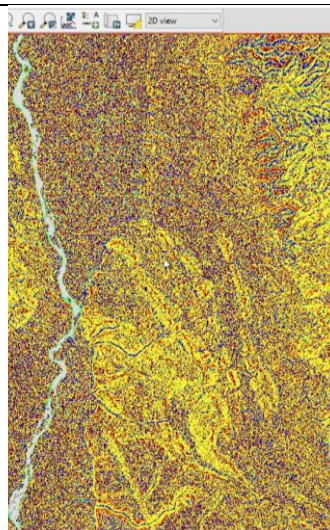


It may take a while to compute, depending on the spatial extent of the study area.



The geomorphon map is eventually loaded.

Use variations of the adjusted settings and compare the output generated.

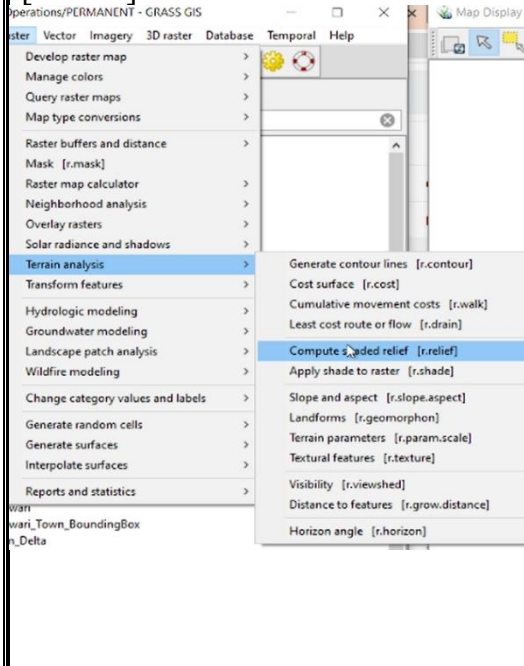


Self-Assessment Exercise

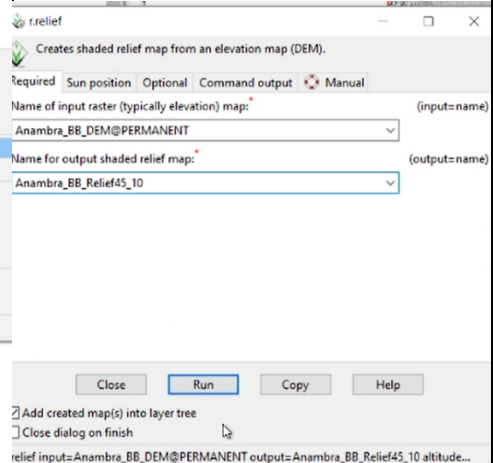
Show evidence of generated geomorphons.

6.3.3 Generate the Hillshade in Grass GIS

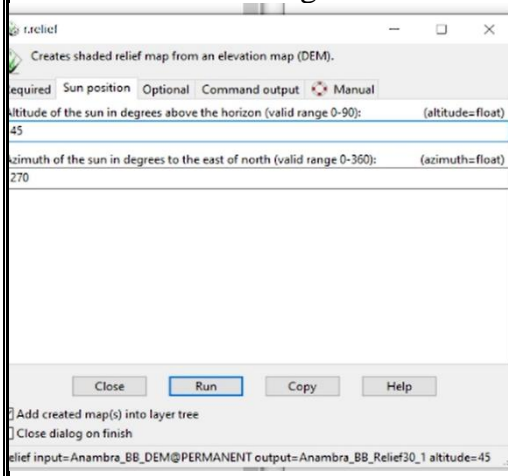
To compute the hillshade, click on the “Raster” tool in the menu bar, select “Terrain Analysis” and then click on the “Compute shaded relief [r.relief]” tool.



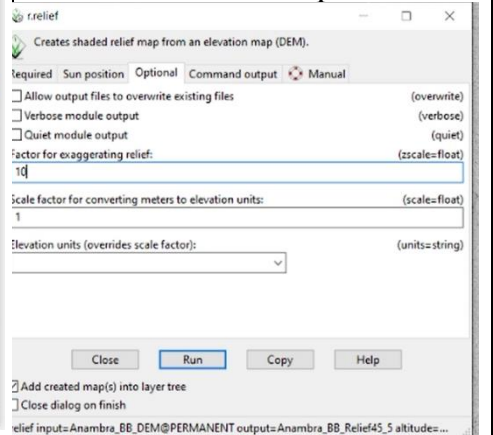
Select the “Required” tab. Under “Name of input raster map”, click on the drop-down arrow and select the DEM. Under “Name of output shaded relief map”, type in an appropriate name, probably adding the settings for solar altitude and exaggeration factor (e.g., Anambra_BB_Relief45_10).



Select the “Sun Position” tab. Under the “Altitude of the sun in degrees above the horizon”, type in 45. Retain default settings for others.

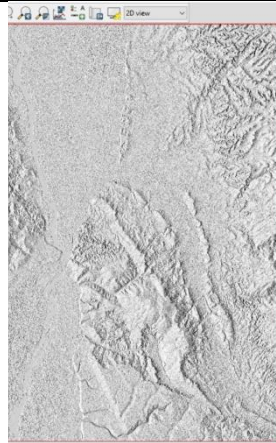


Select the “Optional” tab. Under the “Factor for exaggerating relief”, type in 10. Retain default settings for others. Press the “Run” button to compute.



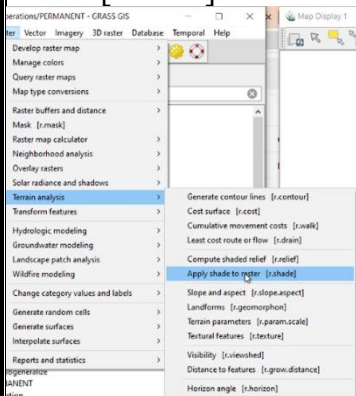
The output is eventually loaded on the map and layer window.

Use variations of these settings and compare the output generated.

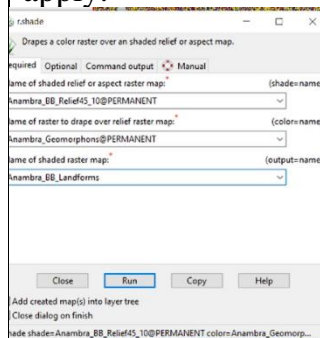


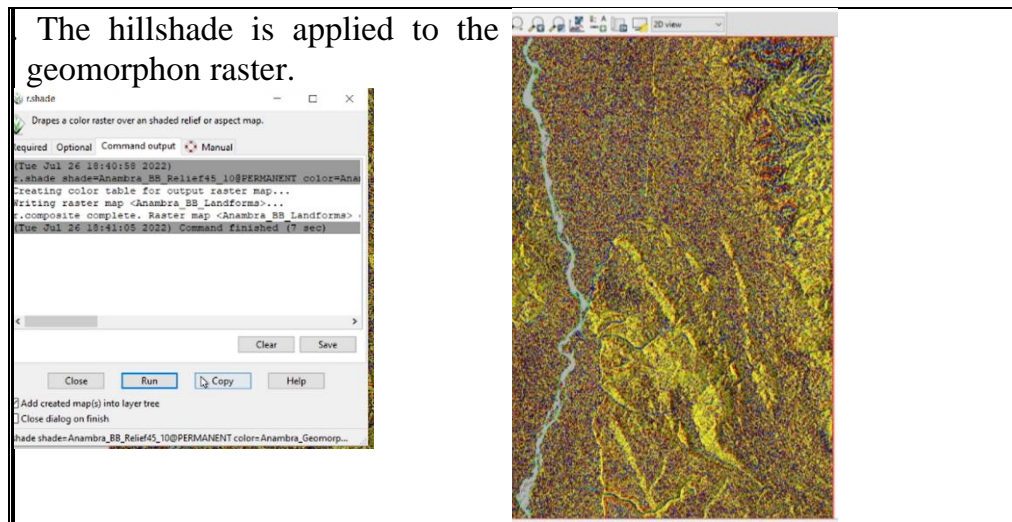
6.3.4 Drape the Geomorphons Over the Hillshade to Depict Landform Variability

To apply the hillshade, to the geomorphon raster, click on the “Raster” tool in the menu bar, select “Terrain Analysis” and the click on the “Compute shaded relief [r.relief]” tool.



Select the “Required” tab. Under “Name of shaded relief map or aspect raster map”, click on the drop-down arrow and select the Hillshade raster. Under “Name of raster to drape over relief raster map”, click on the drop-down arrow and select the geomorphon raster. Under “Name of shaded raster map”, type in an appropriate name. Press the “Run” button to apply.





Self-Assessment Exercise

Show evidence of geomorphon relief.

6.4 Conclusion

The geomorphon algorithm is a very valuable tool for delineating the spatial variability of soil-landscape using remote sensing data (digital elevation models). It enables effective and targeted resource use, management and land allocation. Furthermore, the combination of the hillshade with the geomorphon raster enables the visual depiction of the soil-landscape relations. The generation of the actual map layout would be discussed in subsequent units.

6.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- Basic overview of the geomorphons concept
- Generate geomorphons in GRASS GIS
- Generate the hillshade in GRASS GIS
- Combine the geomorphons with the hillshade to depict landform variability

6.6 Tutor-Marked Assignment

1. Correlate the geomorphon landform units to the toposequence/soil catena concept
2. Show evidence of
 - a) Geomorphons
 - b) Hillshade
 - c) Combination of the geomorphons and the hillshade

6.7 References/Further Reading/Web Resources

For audiovisual tutorials on terrain analysis in GRASS GIS and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel: https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Computation of Geomorphons and Hillshade in GRASS GIS

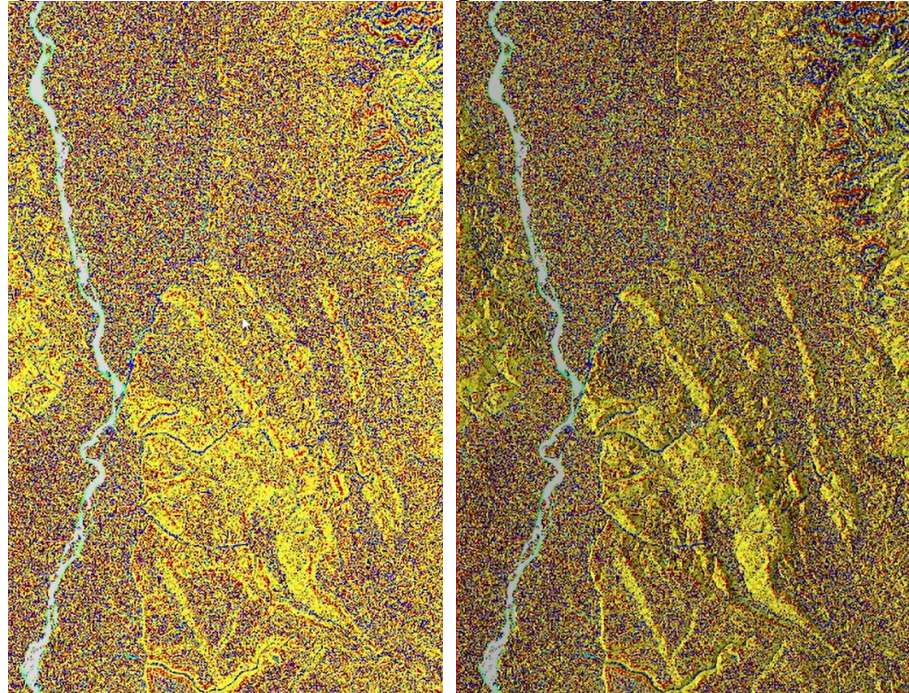
<https://www.youtube.com/watch?v=ipFNa-gcu1E&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=26>

Apply Shade to Geomorphon Raster Landform Generation in GRASS GIS

<https://www.youtube.com/watch?v=i19mdGnMAiU&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=27>

6.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List the ten landform classes depicted by the geomorphons.
*i) Flat ii) Peak iii) Ridge iv) Shoulder v) Spur
vi) Slope vii) Hollow viii) Footslope ix) Valley x) Pit*
2. Show evidence of generated geomorphons.
3. Show evidence of generated geomorphon relief.



UNIT 7 GENERATION OF MAPS OF THE RIVERS AND STREAMS OF AN AREA

Unit Structure

- 7.1 Introduction
- 7.2 Objectives
- 7.3 Main Content
 - 7.3.1 Surface Hydrology
 - 7.3.2 Exporting Raster and Vector Maps from GRASS GIS
- 7.4 Conclusion
- 7.5 Summary
- 7.6 Tutor-Marked Assignment
- 7.7 References/Further Reading/Web Resources
- 7.8 Possible Answers to Self-Assessment Exercise(s) within the content

7.1 Introduction

Mapping surface hydrology is an important project. It provides insight into location and state of surface water bodies like rivers, streams, lakes and even wetlands. It is consequently essential to the understanding of ecosystem dynamics. It also enables the understanding of hydrology from the perspectives of meeting human needs. For an irrigation project, water source is essential; conversely, from the urban planning perspective, it might provide insight into areas that should be avoided because it is bound to be waterlogged, or may require investment in drainage prior to actual development. All of these have to be taken into consideration by the urban, regional, rural or land use planner. This is because it is a critical requirement for every land use option. Furthermore, flow lines for water, if not effectively managed would potentially metamorphose into gully channels. Surface hydrology is not easy to assess through traditional surveys. Today, however, with the advent of remote sensing, digital elevation models (DEM) and geographic information systems, the task of assessing and delineating surface hydrology has become easier and more efficient. In this unit, we will run terrain analysis that would enable the delineation of the surface hydrology of an area of interest.

7.2 Objectives

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

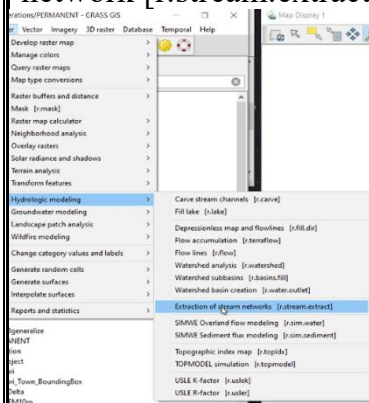
- Be able to map the drainage lines (rivers, streams, runoff flow channel) of an area

7.3 Main Content

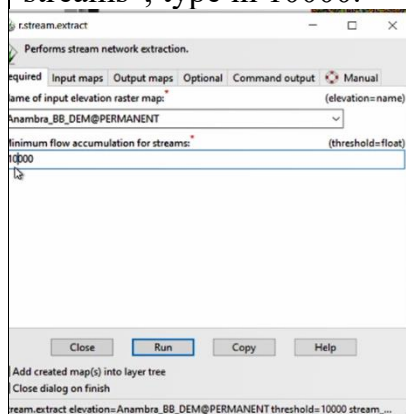
7.3.1 Surface Hydrology

In this unit, we are going to generate stream networks, as well as export raster and vector maps.

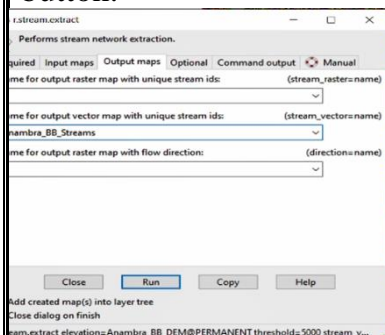
To generate the stream network of your site, click on the “Raster” tool in the menu bar, select “Hydrologic Modeling” and then click on the “Extraction of stream network [r.stream.extract]” tool.



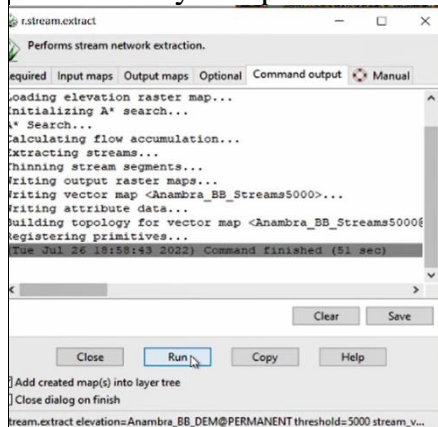
Select the “Required” tab. Under “Name of input elevation raster map”, click on the drop-down arrow and select the DEM. Under “Minimum flow accumulation for streams”, type in 10000.



Select the “Output maps” tab. Input a name under “Name of output vector map with unique stream id”. Leave the other options blank. Press the “Run” button.

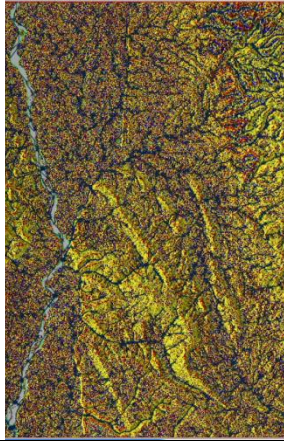


The stream network is successfully computed.



The dark network of lines are stream lines. I can format the symbology in GRASS GIS, but the cartographic output is better with QGIS, so we will do that later.

Rerun the analysis with different flow accumulation settings and compare the outputs generated.

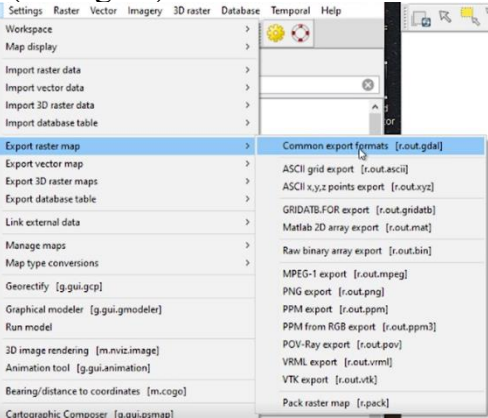


Self-Assessment Exercise

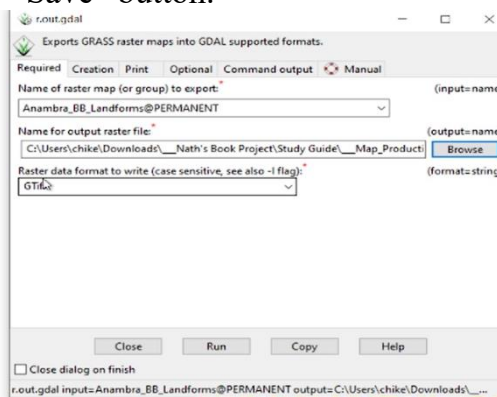
Show the evidence of the generated stream network.

7.3.2 Exporting Raster and Vector Maps from Grass GIS

To export a raster data, click on “File” in the menu bar, select “Export raster map” from the context menu, then click on “Common export formats (r.out.gdal)”.



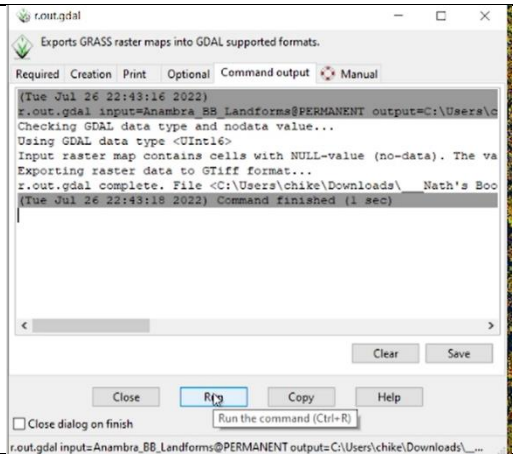
Select the “Required” tab in the pop-up window. Under “Name of raster map (or group) to export”, click on the drop-down arrow and select one of the generated raster maps (e.g., Anambra_BB_Landforms). Under “Name of output raster file”, browse to your work folder, type in an appropriate name and press the “Save” button.



Retain the default raster format (GTIFF). Press the “Run” button to export.

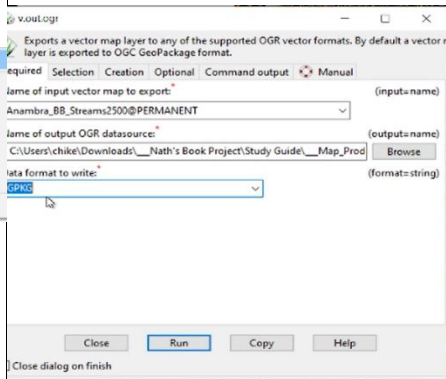
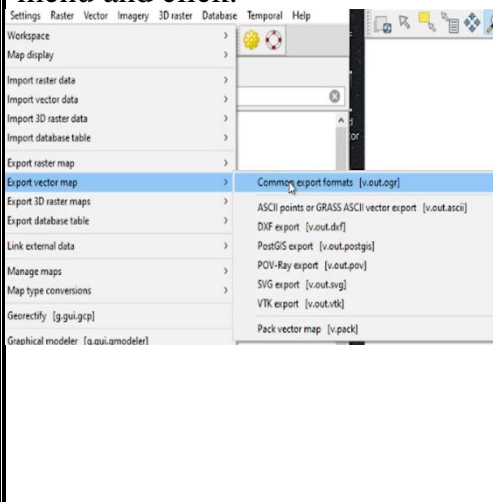
Repeat step 2 and 3 for each of the other raster maps.

When all the raster maps have been exported, press the “Close” button to exit.



To export a vector data, click on “File” in the menu bar, select “Export vector map” from the context menu, then click on “Common export formats (v.out.ogr)” from the context menu and click.

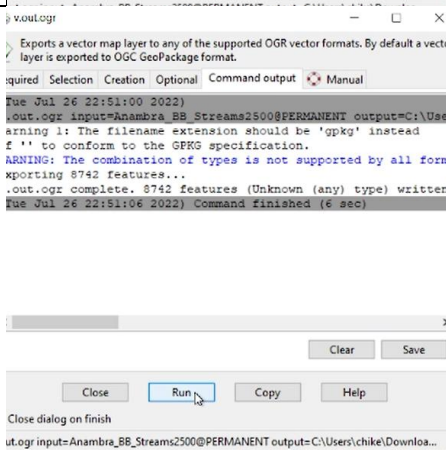
Select the “Required” tab. Under “Name of vector map (or group) to export”, click on the drop-down arrow and select one of the generated vector maps (e.g., Anambra_BB_Streams). Under “Name of output vector file”, browse to your work folder, type in an appropriate name and press the “Save” button.



Retain the default raster format (GPKG). Press the “Run” button to export.

Repeat step 7 and 8 for each of the other vector (streams) maps.

0. When all the raster maps have been exported, press the “Close” button to exit.



Self-Assessment Exercise

Show evidence of successful export of GRASS GIS vector data.

7.4 Conclusion

In this unit, we learned how to delineate surface hydrology. We also learned that developments computer technology, remote sensing, digital elevation models and geographic information systems has largely revolutionized the assessment and management of surface hydrology. It is however noteworthy that we cannot do without tradition field surveys because remote sensing is not always accurate. We to double-check analytical products from remote sensing through field operations called ground-truthing. As such, field studies will always be relevant. Remote sensing essentially improves field surveys by enabling target sampling, reducing fieldwork time, stress and financial cost.

7.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- Mapping of surface hydrology (e.g., runoff channels, streams, rivers, etc.)
- Exporting raster data (maps) generated in GRASS GIS into a format that can be viewed and used in other GIS applications
- Exporting vector maps generated in GRASS GIS into a format that can be viewed and used in other GIS applications

7.6 Tutor-Marked Assignment

1. Why is the mapping of surface hydrology important.
2. In mapping the surface hydrology of your study site (or state), what flow accumulation did you use. Justify your choice.
3. Show evidence of performing the following operations:
 - a) Mapping of surface hydrology of a state in Nigeria
 - b) Exporting raster files into common data formats
 - c) Exporting vector files into common data formats

7.7 References/Further Reading/Web Resources

For audiovisual tutorials on terrain analysis in GRASS GIS and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel: https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Generation of Stream Network from DEM in GRASS GIS

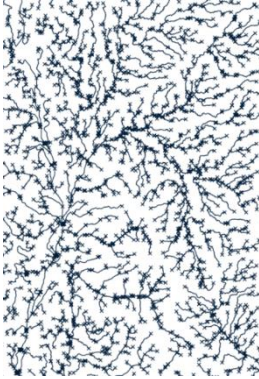
<https://www.youtube.com/watch?v=fr1fxYhUqic&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=28>

Export of GRASS Raster and Vector Data

<https://www.youtube.com/watch?v=uciOiPgQuXI&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=29>

7.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Show the evidence of the generated stream network.
2. Show evidence of successful export of GRASS GIS vector data.



```

v.out.ogr
Exports a vector map layer to any of the supported OGR vector formats. By default a vector
layer is exported to OGC GeoPackage format.
Required Selection Creation Optional Command output Manual
[Thu Jul 26 22:51:00 2022]
v.out.ogr input=Anambra_BB_Streams2500PERMANENT output=C:\Users\chike\Downlo...
Warning 1: The filename extension should be 'gpkg' instead
of '*' to conform to the GPKG specification.
WARNING: The combination of types is not supported by all forms
Exporting 8742 features...
v.out.ogr complete. 8742 features (Unknown (any) type) written
[Thu Jul 26 22:51:06 2022] Command finished (6 sec)
  
```

UNIT 8 MAP LAYOUT

Unit Structure

- 8.1 Introduction
- 8.2 Objectives
- 8.3 Main Content
 - 8.3.1 Principal Components of the Map Layout
 - 8.3.2 Preliminary Operations
 - 8.3.3 Single Map in the Print Layout
 - 8.3.4 Duplicating a Map Layout for the Generation of Other Maps with Similar Layouts
 - 8.3.5 Multiple Maps in the Print Layout
 - 8.3.6 Exporting Map as PDF or JPG
- 8.4 Conclusion
- 8.5 Summary
- 8.6 Tutor-Marked Assignment
- 8.7 References/Further Reading/Web Resources
- 8.8 Possible Answers to Self-Assessment Exercise(s) within the content

8.1 Introduction

It may feel good to run complex analysis and generate equally complicated outputs, but if you cannot effectively communicate your findings to someone else – who did not perform the operations with you – the whole endeavor is a meaningless waste of time. In essence, for your map products to be meaningful, it must be understandable to a novice. He or she needs to simply study your map and understand what it is meant to communicate, even in your absence. This is facilitated by a well-designed map layout. The major component of a map layout include: title fonts, logos, north arrow, legend, scale bar, supplementary text, credit text, borders. It is noteworthy that a map printout does not need to contain all of the above. In this unit, we will practically design a map layout in QGIS and export map products.

8.2 Objectives

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

- Outline the principal components of a map layout
- Generate a printable map

8.3 Main Content

8.3.1 Principal Components of The Map Layout

The principal components of the map layout include:

1. **Title Font:** An attractive, well-designed font is used here. The use of a serif font is visually livelier, but not all serif fonts look good.
2. **Logos:** The logos may be reduced to a much smaller size and grouped together in an out-of-the-way position at the side of the map. Logos are only there to keep sponsors and local authorities happy. They are of no significance for orienteering and simply do not need to dominate a map.
3. **North Arrowheads:** Small arrowheads are amply adequate to indicate north. They are visually less intrusive and take up far less space.
4. **Legend:** Aligning the legend symbols against the border with the text to the inner side allows much more white space around the map
5. **Scale Bar:** Scale bars do not necessarily have to be constructed from a series of rectangles. A graduated line may be adequate. Scale bar text, showing the distance interval and/or the units, need not be large.
6. **Supplementary Text:** 'Contour Interval', 'Magnetic North 1998' and 'Scale 1:5000' are neatly grouped together beneath the map title where they can all be easily read in one go. The colour is much easier on the eye than before.
7. **Credits Text:** The credits text is 6pt. It is there primarily for legal and administrative purposes and has no need to look prominent. Note that the text is right-aligned against the border.
8. **Border:** The border may be up to 2mm wide, and the colour should be unobtrusive.

Self-Assessment Exercise

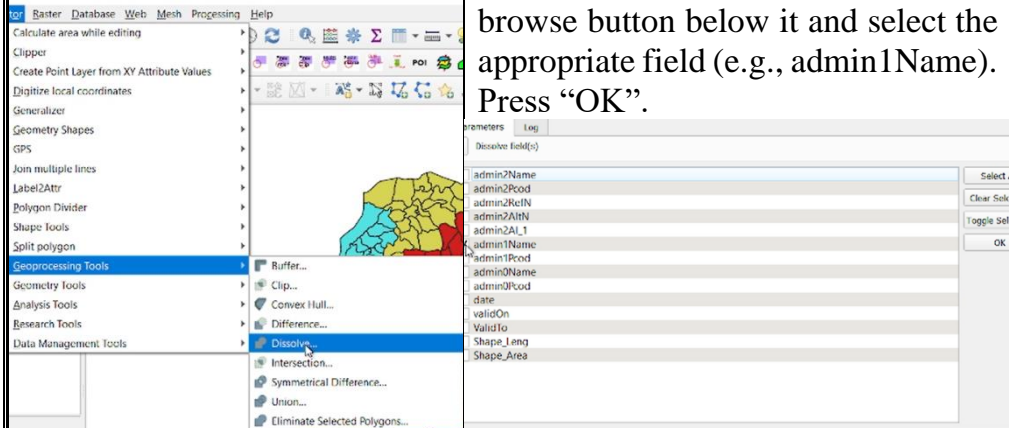
List five components of a map layout.

8.3.2 Preliminary Operations

Import the GRASS GIS-generated raster and vector data in the same way that we have done so far in preceding units.
 Remove all irrelevant raster or vector maps (e.g., all administrative maps, except for the map from the World Bank directory).

To generate a new map without the LGA boundaries, click on “Vector” on the menu bar, select “Geoprocessing Tools” then, click on “Dissolve”.

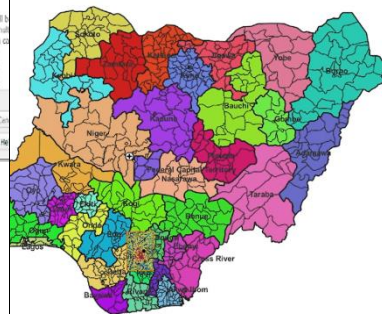
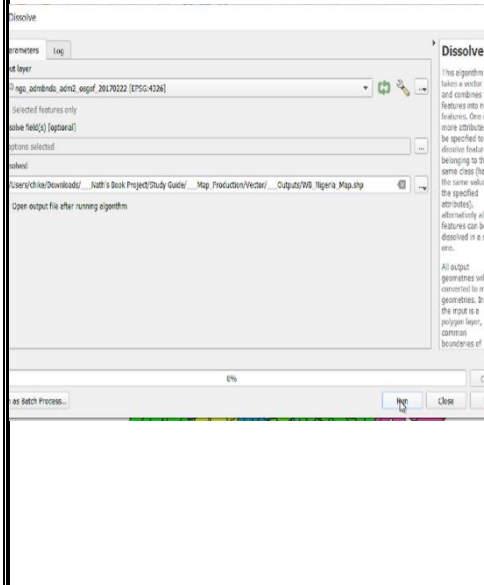
Click on the drop-down arrow under “Input layer” and select the appropriate map (e.g., administrative map of Nigeria). To select the “Dissolve field(s)” click on the browse button below it and select the appropriate field (e.g., admin1Name). Press “OK”.



Under “Dissolved”, browse to the work folder, type in an appropriate name and press the “Save” button.

Press the “Run” button to execute command

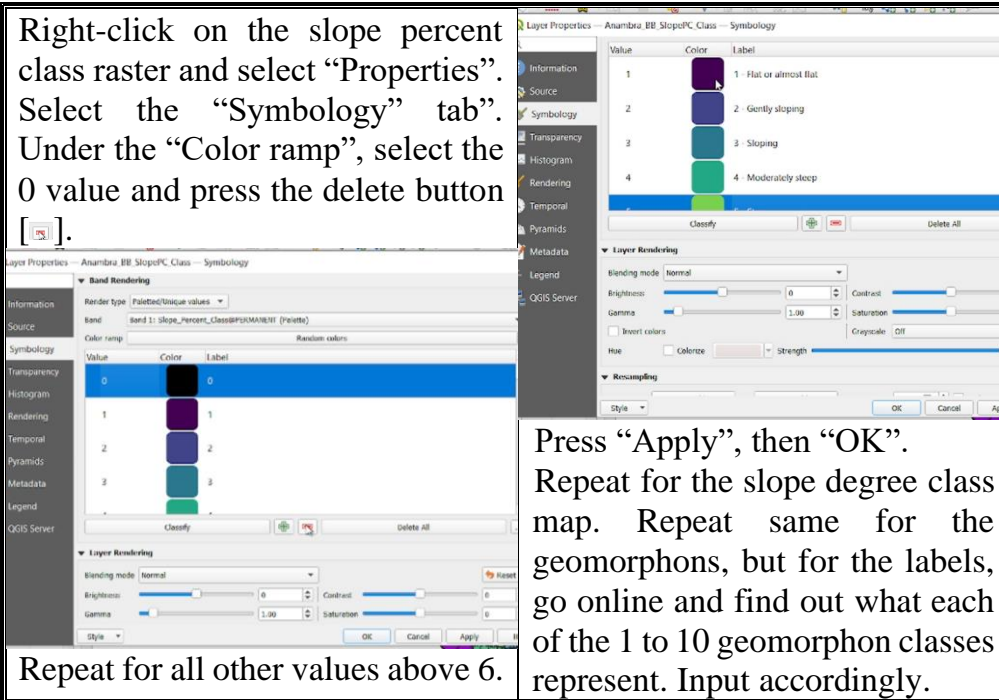
A new map is loaded. Make it transparent and label with state names using the “admin1Name” field. The original Nigerian map with the LGAs should be below the new map, and when both are active, the labels and the symbology would appear to exist on same map.



With regards to the raster maps, you need to edit the Geomorphon, Slope Percent Class and Slope Degree Maps.

Double-click on the numbers under the “Label” column and type in a name in line with the FAO slope classes.

Right-click on the slope percent class raster and select “Properties”. Select the “Symbology” tab”. Under the “Color ramp”, select the 0 value and press the delete button [X].

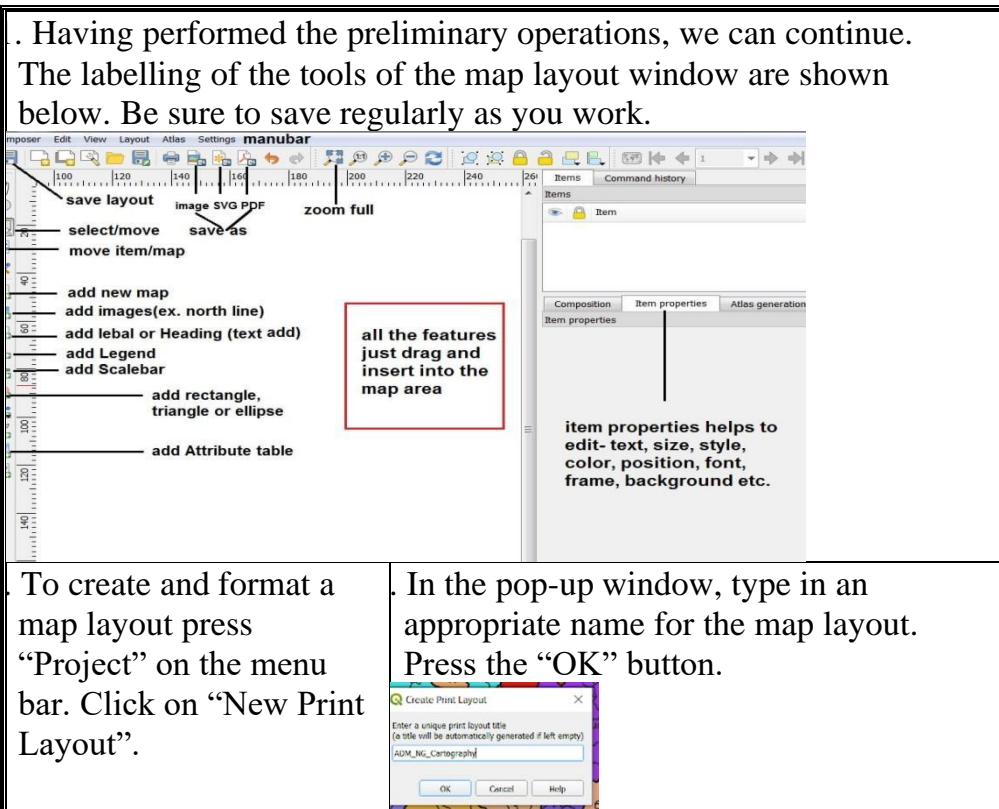


Press “Apply”, then “OK”. Repeat for the slope degree class map. Repeat same for the geomorphons, but for the labels, go online and find out what each of the 1 to 10 geomorphon classes represent. Input accordingly.

Repeat for all other values above 6.

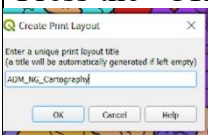
8.3.3 Single Maps in The Print Layout

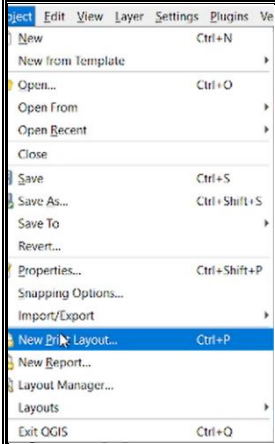
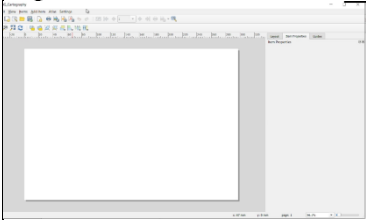

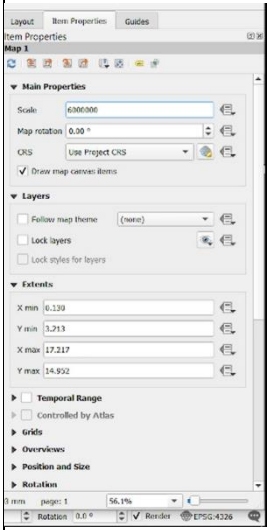
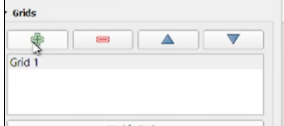
Having performed the preliminary operations, we can continue. The labelling of the tools of the map layout window are shown below. Be sure to save regularly as you work.

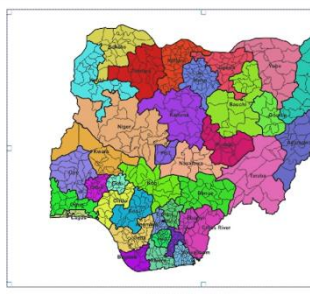
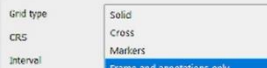
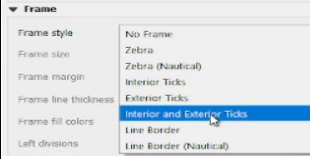
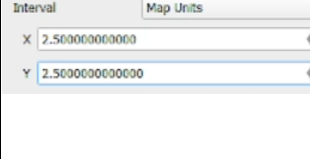
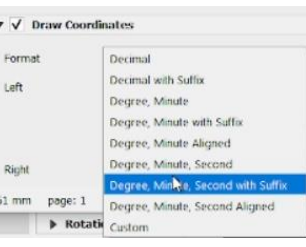
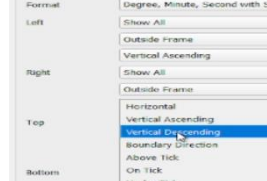
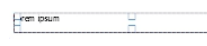







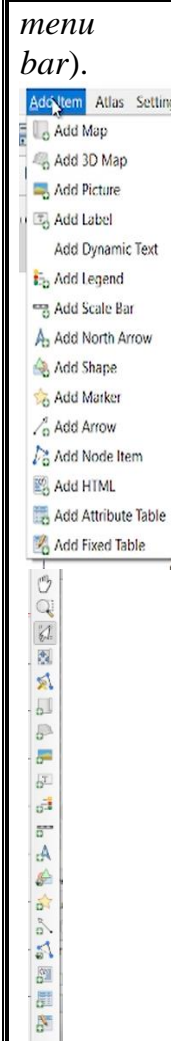
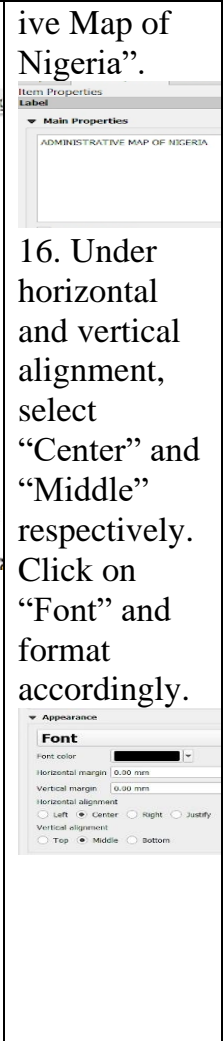
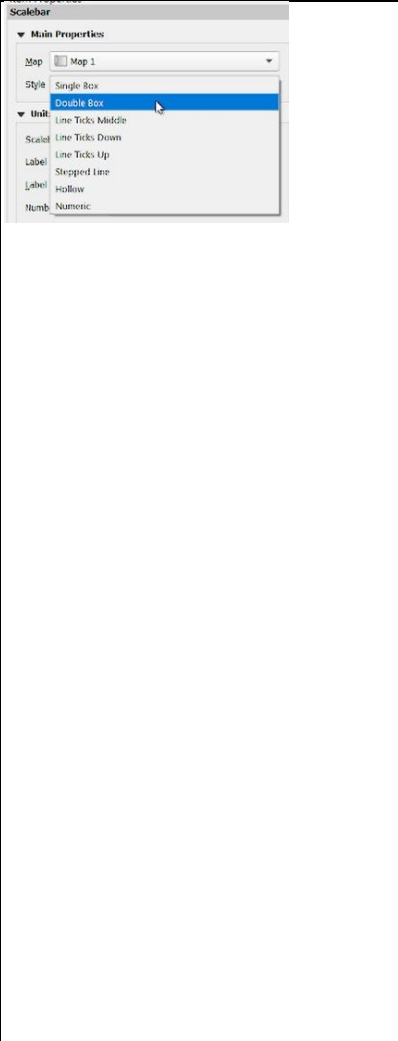




To create and format a map layout press “Project” on the menu bar. Click on “New Print Layout”.

In the pop-up window, type in an appropriate name for the map layout. Press the “OK” button.



	<p>3. The map (print) layout window opens.</p> 	<p>NOT E: Save from time to time because QGIS is susceptible to crashes. As such if it crashes you can reopen and continue.</p>
<p>4. Click on the “Add Map” button [] on the tool bar at the lefthand side of the layout window. Click in one corner of the map layout window, hold and drag to the other corner and let go. The active map(s) in the QGIS map window will be displayed.</p>	<p>5. While the map is selected, you can edit it using the “Item Properties” edit pane on the right side of the window.</p> 	<p>6. Adjust the scale (increase or decrease) until you have the proper configuration in the map window. 7. Scroll down to find “Grid”. Click the drop-down arrow to expose more details. Click on the “+” icon to load new grid. Click on “Modify Grid.”</p> 

		<p>8. The settings options specific to grid properties are loaded. Under Grid type, select “Frames and annotations only”.</p> 	
<p>9. For “Frame style” select “Interior and Exterior Ticks”.</p>  <p>10. Under “Interval”, fill in 2.5 for both X and Y. (You may try out different settings to find out the best for your map).</p> 	<p>11. Highlight [▼▼] draw coordinates and select “Degrees Minutes Seconds and Suffix” from the “Format” dropdown menu.</p> 	<p>12. Under “Draw coordinates”, for the “Left”, where you have “Horizontal” click and select (Vertical Ascending) and for the right, click and select “Vertical Descending”.</p> 	
<p>13. Add Item tools: If you click on “Add Item” on menu bar, you will see the components of the map layout that may need to be added. (Also accessible on the</p>	<p>14. Click on the “Add Label” tool. Click, hold and drag at the top of the map window.</p>  <p>15. In the “Item Properties” panel, under “Main Properties” of “Label”, delete the text and type “Administrat</p>	<p>17. Add label again, this time regular font at the bottom of the map window, with text, “Geographic Coordinate System: WGS 84”.</p>  <p>18. Add scale bar.</p>  <p>19. With the scale bar still selected, format using the “Item Properties” panel. Under “Style”, select “Double-bar” or any other of interest.</p>	<p>20. Under “Segment” increase “left” to 1 and “right” 4.</p>  <p>21. The scale bar is new.</p>  <p>22. Add “North Arrow” to the top right or left.</p>  <p>23. Add “Legend”.</p>

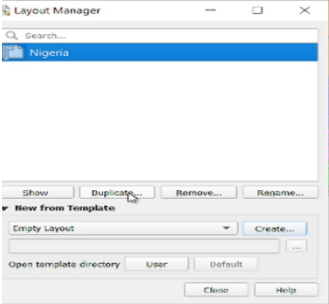
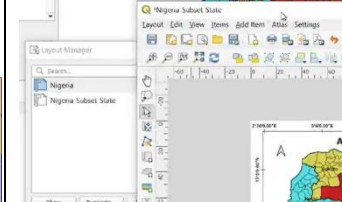
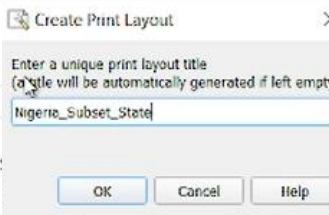
<p>menu bar).</p> 	<p>ive Map of Nigeria”.</p>  <p>16. Under horizontal and vertical alignment, select “Center” and “Middle” respectively. Click on “Font” and format accordingly.</p>		<p>On the properties panel, under “Title” type in “LEGEND”. Under “Legend Items” click deactivate “Auto update”. Select items not in the map by clicking on one, then holding down the “Shift” or “Ctrl” keys on the keyboard and clicking on the other maps.</p>
<p>24. Click on the “Remove selected items from legend” button  below the selected items box. (Repeat as necessary).</p>	<p>25. What is left is the administrative map. Click on the drop-down arrow to view its content.</p> 	<p>26. Click on the title, “nga_admbnda_adm2_ogof_20170222”, click the edit tool  and type in “Nigeria”. Click on the  button. You can do the same to “Federal Capital Territory” and replace with “FCT (Abuja)”.</p> <p>27. The legend extends beyond the map. Right-click on it, select “Copy”, paste with by holding down the “Ctrl” key on the keyboard and typing “V”.</p>	<p>28. Adjust the first legend and delete the section that extends outside the map as done in steps 23 and 24.</p> <p>29. For the second legend, delete the section that is part of the first legend. Position appropriately. Right-click</p>

			<p>on “Nigeria” in the second legend and select “Hidden”.</p>
<p>30. The legend can now be contained in the map window. If not, you can create a third column.</p>	<p>31. Activate “Lock Layer” [<input checked="" type="checkbox"/> Lock Layers] to ensure that changes in the map window would not affect the map layout.</p> <p>32. If you came this far, then you have generated your first map. We will move on from there.</p>		

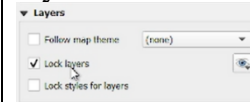
Self-Assessment Exercise

Display the administrative map of Nigeria.

8.3.4 Duplicating A Map Layout for The Generation of Other Maps with Similar Layouts

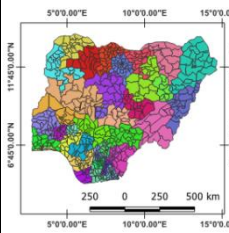
<p>1. Having created the map layout, when preparing a variation of the first map (as we will be doing in next section), you do not need to start the new layout from the scratch. Go back to the map window, click on “Project” in the menu bar and select “Layout Manager” from the context menu.</p>	<p>2. In the pop-up window, select the layout of interest and press the “Duplicate” button.</p> 	<p>3. The new layout is loaded.</p> 
<p>4. In the new pop-up window, type in an appropriate name and press “OK”.</p> 	<p>5. You can duplicate as many times as necessary. And when you edit and update the new layout, the first layout is still intact, so long as the “Lock Layers” option is activated.</p>	

8.3.5 Multiple Maps in The Print Layout

<p>1. Open the new (duplicate) map layout. Select the map and reduce its size until it covers a small section of layout window.</p>	<p>3. Make sure that the map layer is locked.</p>  <p>4. Go back to the QGIS map window and deactivate the map of Nigeria.</p>	<p>7. Both maps can share the same north arrow and cordiante system.</p> <p>8. Edit the map title to reflect the new realities (e.g., Adminstrative</p>	<p>11. You can add legend again. Better still, edit the existing legend. Move the legend back into the map layout window.</p> <p>12. Duplicate the second legend column (copy</p>
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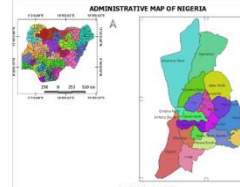
Move the legend out to free space for a new map.

2. Edit the map of Nigeria to make it more presentable using the knowledge acquired from section 3.3. You may have to deactivate the map with the labels.



Activate the Map of Anambra state or any other state of your choice.

5. Import the map of Anambra state the same way that you imported the map of Nigeria earlier.

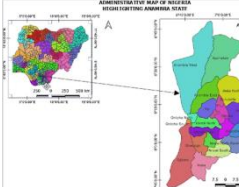


6. Format the map of Anambra state (particularly the grids and the scale bar), following the same steps employed in the course of formatting the map of Nigeria.

Map of Nigeria, Highlighting Anambra State).

9. You can have a specific title for the map of Anambra state.

10. Insert an arrow pointing from the general location of Anambra state in the administrative map of Nigeria, to the new Anambra map.



and paste as usual).

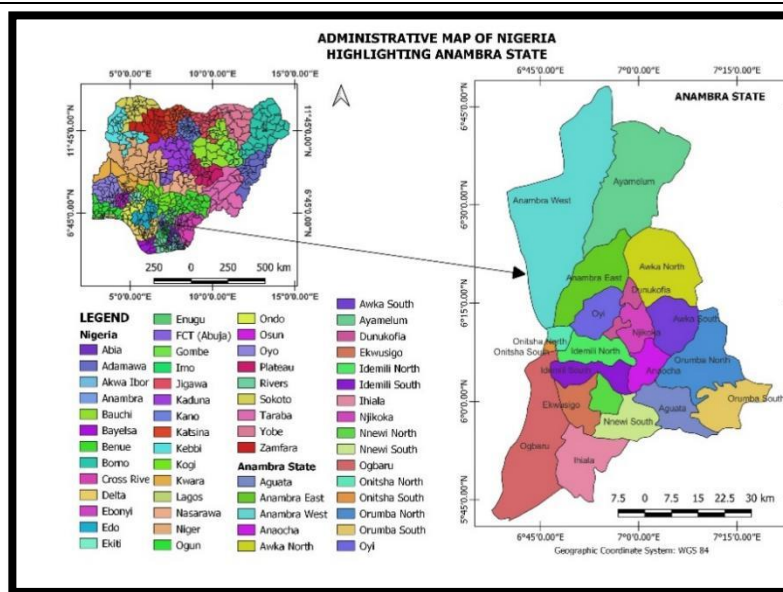
13. Delete the bottom items of the second legend column outside the map window.

14. Delete the top parts of the legend in the third column (that is now part of the second column).

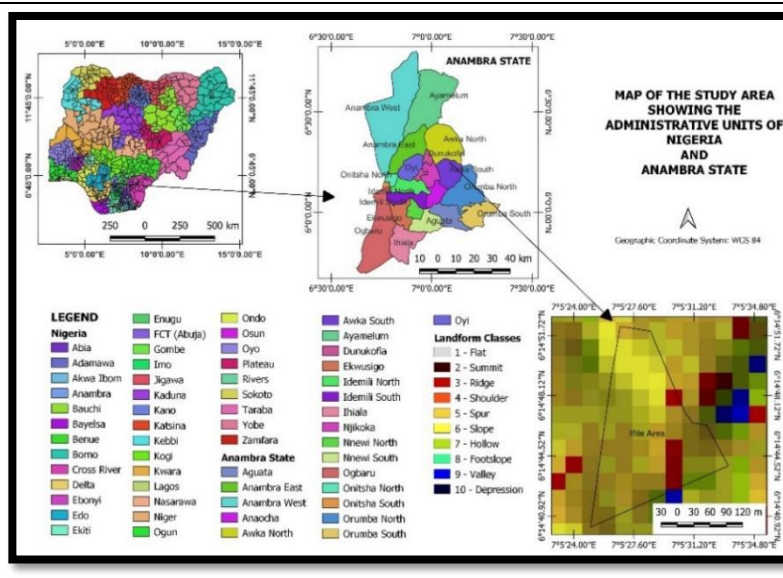
15. Add the Anambra state layer to the legend and format as you did with the Nigeria layer.



16. The new map should look like this:



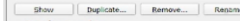
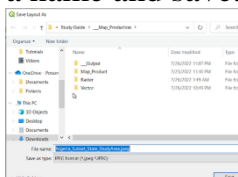
17. You can have 3 maps within the map window:



Self-Assessment Exercise

Display map with several map windows (study area map).

8.3.6 Exporting Map AS PDF or JPG

<p>1. Open the layout manager.</p>	<p>2. Select one or multiple map layouts and press the “Show” button.</p> 	<p>3. In the map layout window, press “Layout” on the menu bar, press the “Export Image”.</p>	<p>4. Browse to the appropriate location, type in a name and save.</p> 
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<p>5. Press “Save” in the pop-up window.</p> <p>The map is saved and can be opened in most common viewers (for images).</p>	<p>6. To export a PDF, select “Layout”, press “Export as PDF”.</p>	<p>7. Browse to an appropriate folder, type in a name and press the “Save” button.</p>	<p>8. Press the “Save” button in the pop-up window.</p> <p>The map is saved.</p>
<p>9. Repeat for all the other map layouts.</p>			

Self-Assessment Exercise

Show evidence that map was exported.

8.4 Conclusion

At the end of this unit, you would have acquired a basic understanding of the theory and practice of remote sensing, geographic information systems (GIS) and cartography. This course is meant to provide you to explore the topics and practice on your own. It is understood that this manual, particularly for the remote sensing/GIS section of the practical units, may not be easy for everyone to follow.

To improve your understanding of the of the topics, additional tutorials are provided in the following YouTube channel: McOnyeka Environment & Land Resources Consultants (https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists). Be sure to subscribe to the channel (by clicking the button) and ring the notification bell (🔔) to be able to get further updates on new practical tutorials.

8.5 Summary

From this unit, you have learnt about administrative maps. Some of the key things learnt include the following;

- Generate a map layout containing a single map design
- Generate a map layout containing multiple map designs
- Generate map layouts containing both raster and vector maps
- Duplicate a map layout for reuse.

8.6 Tutor-Marked Assignment

1. Present well-laid out maps of
 - a) Nigeria showing the different states
 - b) administrative map of Nigeria, alongside the administrative map of a state in Nigeria
 - c) administrative map of Nigeria, alongside the geomorphic/hydrologic maps of the state
 - d) administrative map of Nigeria, alongside the landform/hydrologic maps of the state
 - e) administrative map of Nigeria, alongside the hillshade/hydrologic maps of the state
 - f) administrative map of Nigeria, alongside the elevation (DEM)/hydrologic maps of the state
 - g) administrative map of Nigeria/target state showing your study area.

8.7 References/Further Reading/Web Resources

For audiovisual tutorials on terrain analysis in GRASS GIS and other related tutorials, consult and subscribe to the McOnyeka Environment & Land Resources Consultants YouTube Channel: https://www.youtube.com/channel/UCvuGu7P78fQeNcAZnR_Aexw/playlists.

Import Raster and Vector Data Generated in GRASS GIS into QGIS

<https://www.youtube.com/watch?v=rojEr3erwfw&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=30>

QGIS Print Layout: Preliminary Map Layout Operations

<https://www.youtube.com/watch?v=gtCcr3-3ZUc&list=PLSLmCvtQKVKMy7bhsK8kY1hXNwJXW2yJF&index=31>

QGIS Print Layout: Map Layout for Nigeria

<https://www.youtube.com/watch?v=0mwYz3RWXYE&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=32>

QGIS Print Layout: Two Map Layers in the Print Layout (Administrative Maps)

<https://www.youtube.com/watch?v=TmR65CkHB1c&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=33>

QGIS Print Layout: Two Map Layers in the Print Layout (Elevation Raster)

<https://www.youtube.com/watch?v=DuMmKohJe5A&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=34>

QGIS Print Layout: Two Map Layers in the Print Layout (Slope, Geomorphic Units, etc.)

<https://www.youtube.com/watch?v=I1ccrlWquas&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=35>

QGIS Print Layout: Three Maps Layers in the Print Layout

<https://www.youtube.com/watch?v=gq6ZfZGZdg8&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=36>

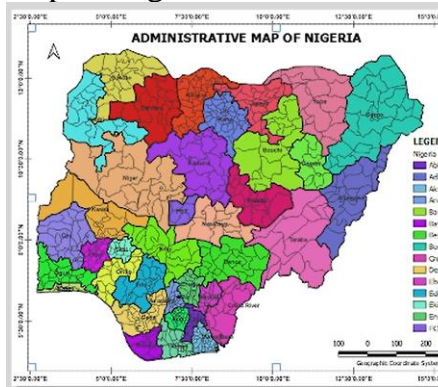
Exporting QGIS Maps in PDF and MPEG Formats

<https://www.youtube.com/watch?v=g-RAPL-d6As&list=PLSLmCvtQKVkMy7bhsK8kY1hXNwJXW2yJF&index=37>

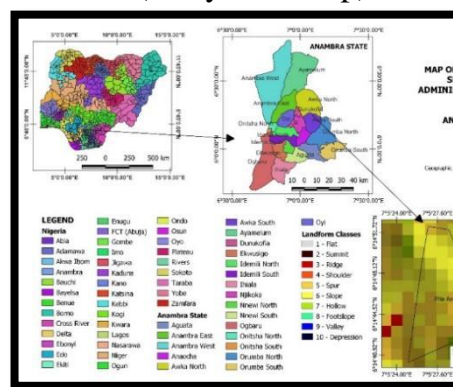
8.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. List five principal components of a map layout.
 - i) Title
 - ii) North Arrow
 - iii) Legend
 - iv) Scale Bar
 - v) Supplementary Text

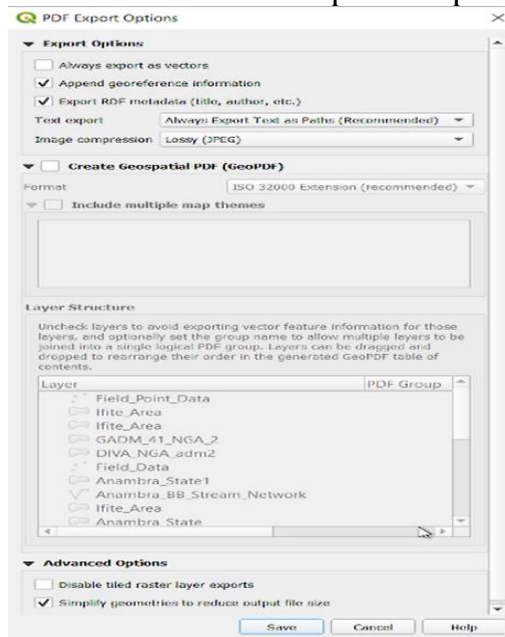
Display the administrative map of Nigeria



Display map with several map windows (study area map).



4. Show evidence that map was exported.



MODULE 7 INTRODUCTORY GEOSTATISTICS

Unit 1	Descriptive and Inferential Statistics
Unit 2	Geostatistics Concepts
Unit 3	Estimation Methods
Unit 4	Modeling
Unit 5	Spatial Modeling

UNIT 1 DESCRIPTIVE AND INFERENTIAL STATISTICS

Unit Structure

- 1.1 Introduction
- 1.2 Objectives
- 1.3 Main Content
 - 1.3.1 Population and Sample Statistics
 - 1.3.1.1 Population
 - 1.3.1.2 Sample
 - 1.3.2 Descriptive Statistics
 - 1.3.2.1 Distribution
 - 1.3.2.2 Central Tendency
 - 1.3.2.3 Variability
 - 1.3.3 Inferential Statistics
 - 1.3.3.1 Hypothesis Testing
 - 1.3.3.2 Confidence Intervals
 - 1.3.3.3 Regression and Correlation Analysis
 - 1.3.4 Practical Example
 - 1.3.5 Tutorial
- 1.4 Conclusion
- 1.5 Summary
- 1.6 Tutor-Marked Assignment
- 1.7 References/Further Reading/Web Resources
- 1.8 Possible Answers to Self-Assessment Exercise(s) within the content

1.1 Introduction

Statistics is the area of applied mathematics that has very broad application domain, ranging from arts to the sciences. It deals with the collection, organization, analysis, interpretation, and presentation of data. Descriptive and inferential statistics are different aspects of statistics. Descriptive statistics focuses on describing the visible characteristics of a dataset, while inferential statistics focus on making predictions or generalizations about a larger dataset, based on a sample of

that dataset. The basics of both statistics will be explored in this section. Finally, we will explore basic linear regression modeling.

1.2 Objectives

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

- Understand the difference between population and sample statistics
- Discuss descriptive and inferential statistics, with examples
- Perform some basic statistical analysis with Microsoft Excel

1.3 Main Content

1.3.1 Population and Sample Statistics

Statistics is the area of applied math that deals with the collection, organization, analysis, interpretation, and presentation of data. From science and psychology to marketing and medicine, the wide range of statistical techniques out there can be broadly divided into two categories: descriptive statistics and inferential statistics.

In a nutshell, **descriptive statistics focus on describing the visible characteristics of a dataset** (a population or sample). Meanwhile, **inferential statistics focus on making predictions or generalizations about a larger dataset, based on a sample** of those data.

Two basic but vital concepts in statistics are those of population and sample. We can define them as follows.

1.3.1.1 Population

Population is the entire group that you wish to draw data from (and subsequently draw conclusions about). While in day-to-day life, the word is often used to describe groups of people (such as the population of a country) in statistics, it can apply to any group from which you will collect information. This is often people, but it could also be cities of the world, animals, objects, plants, colors, and so on.

1.3.1.2 Sample

A **sample** is a representative group of a larger population. Random sampling from representative groups allows us to draw broad conclusions about an overall population. This approach is commonly used in polling. Pollsters ask a small group of people about their views on certain topics. They can then use this information to make informed judgments about

what the larger population thinks. This saves time, hassle, and the expense of extracting data from an entire population (which for all practical purposes is usually impossible).

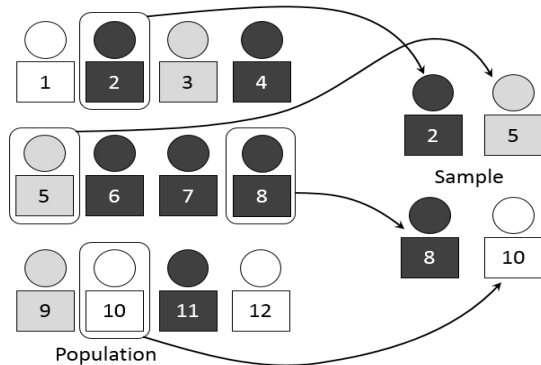


Figure 36: Sampling from a Population

Using random sample measurements from a representative group, we can estimate, predict, or infer characteristics about the larger population.

Self-Assessment Exercise

Define: a) Population b) Sample

1.3.2 Descriptive Statistics

Descriptive statistics are used to describe the characteristics or features of a dataset. The term ‘descriptive statistics’ can be used to describe both individual quantitative observations (also known as ‘summary statistics’) as well as the overall process of obtaining insights from these data. We can use descriptive statistics to describe either an entire population or an individual sample. Because they are merely explanatory, descriptive statistics are not heavily concerned with the differences between the two types of data. There are many descriptive statistics, but the most important ones are:

- Distribution
- Central tendency
- Variability

1.3.2.1 Distribution

Distribution shows us the frequency of different outcomes (or data points) in a population or sample. We can show it as numbers in a list or table, or we can represent it graphically. As a basic example, the following list shows the number of those with different hair colors in a dataset of 286 people.

- Brown hair: 130
- Black hair: 39
- Blond hair: 91
- Auburn hair: 13

- Gray hair: 13

We can also represent this information visually, for instance in a pie chart.

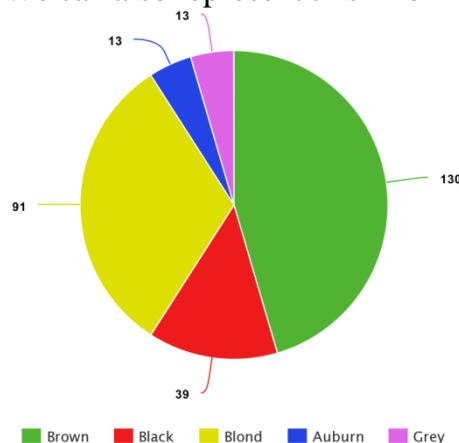


Figure 37: Distribution (Pie Chart)

Generally, using visualizations is common practice in descriptive statistics. It helps us more readily spot patterns or trends in a dataset.

1.3.2.2 Central Tendency

Central tendency is the name for measurements that look at the typical central values within a dataset. This does not just refer to the central value within an entire dataset, which is called the median. Rather, it is a general term used to describe a variety of central measurements. For instance, it might include central measurements from different quartiles of a larger dataset. Common measures of central tendency include:

- **The mean:** The average value of all the data points.

$$\bar{x} = \frac{\sum x}{n}$$

(Where \bar{x} = Mean, x = Data Values and n
= Number of Observations)

- **The median:** The central or middle value in the dataset.
- **The mode:** The value that appears most often in the dataset.

Once again, using our hair color example, we can determine that the mean measurement is 57.2 (the total value of all the measurements, divided by the number of values), the median is 39 (the central value) and the mode is 13 (because it appears twice, which is more than any of the other data points). Although this is a heavily simplified example, for many areas of data analysis these core measures underpin how we summarize the features of a data sample or population. Summarizing these kinds of statistics is the first step in determining other key characteristics of a dataset, for example, its variability. This leads us to our next point...

1.3.2.3 Variability

The variability, or dispersion, of a dataset, describes how values are distributed or spread out. Identifying variability relies on understanding the central tendency measurements of a dataset. However, like central tendency, variability is not just one measure. It is a term used to describe a range of measurements. Common measures of variability include:

- **Standard deviation:** This shows us the amount of variation or dispersion. Low standard deviation implies that most values are close to the mean. High standard deviation suggests that the values are more broadly spread out.

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

(Where σ = Population Standard Deviation, x_i = Each Value from the Population, μ = population mean, N = Size of the Population)

- **Minimum and maximum values:** These are the highest and lowest values in a dataset or quartile. Using the example of our hair color dataset again, the minimum and maximum values are 13 and 130 respectively.
- **Range:** This measures the size of the distribution of values. This can be easily determined by subtracting the smallest value from the largest.
- **Kurtosis:** This measures whether or not the tails of a given distribution contain extreme values (also known as outliers). If a tail lacks outliers, we can say that it has low kurtosis. If a dataset has a lot of outliers, we can say it has high kurtosis.

$$\text{Kurtosis} = \frac{\sum(x_i - \bar{x})^4}{n\sigma^4}$$

(Where σ = Population Standard Deviation, x_i = Each Value from the Population, \bar{x} = Population Mean, N = Size of the Population)

- **Skewness:** This is a measure of a dataset's symmetry. If you were to plot a bell-curve and the right-hand tail was longer and fatter, we would call this positive skewness. If the left-hand tail is longer and fatter, we call this negative skewness. This is visible in the following image.

$$\tilde{\mu}_3 = \frac{\sum_i^N (X_i - \bar{X})^3}{(N - 1) * \sigma^3}$$

($\tilde{\mu}_3$ = Skewness, X_i = Random Variable, \bar{X} = Population Mean, σ = Population Standard Deviation)

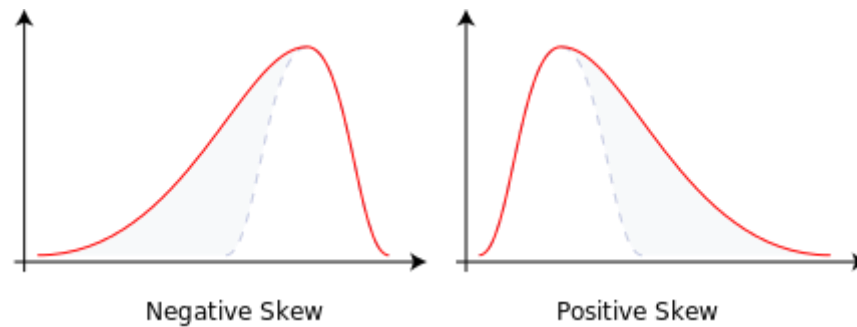


Figure 38: Negatively and Positively Skewed Distribution

Used together, distribution, central tendency, and variability can tell us a surprising amount of detailed information about a dataset. Within data analytics, they are very common measures, especially in the area of exploratory data analysis. Once you've summarized the main features of a population or sample, you're in a much better position to know how to proceed with it. And this is where inferential statistics come in.

Self-Assessment Exercise

List five common measures of variability.

1.3.3 Inferential Statistics

So, we've established that, descriptive statistics focus on summarizing the key features of a dataset. Meanwhile, inferential statistics focus on making generalizations about a larger population based on a representative sample of that population. Because inferential statistics focuses on making predictions (rather than stating facts) its results are usually in the form of a probability.

Unsurprisingly, the accuracy of inferential statistics relies heavily on the sample data being both accurate and representative of the larger population. To do this involves obtaining a random sample. If you've ever read news coverage of scientific studies, you'll have come across the term before. The implication is always that random sampling means better results. On the flipside, results that are based on biased or non-random samples are usually thrown out. Random sampling is very important for carrying out inferential techniques, but it is not always straightforward. Random sampling can be a complex process and often depends on the particular characteristics of a population. However, the fundamental principles involve:

1. **Defining a population:** This simply means determining the pool from which you will draw your sample. As we explained earlier, a population can be anything—it isn't limited to people. So, it could

- be a population of objects, cities, cats, pugs, or anything else from which we can derive measurements!
2. **Deciding your sample size:** The bigger your sample size, the more representative it will be of the overall population. Drawing large samples can be time-consuming, difficult, and expensive. Indeed, this is why we draw samples in the first place—it is rarely feasible to draw data from an entire population. Your sample size should therefore be large enough to give you confidence in your results but not so small that the data risk being unrepresentative (which is just shorthand for inaccurate). This is where using descriptive statistics can help, as they allow us to strike a balance between size and accuracy.
 3. **Randomly select a sample:** Once you've determined the sample size, you can draw a random selection. You might do this using a random number generator, assigning each value a number and selecting the numbers at random. Or you could do it using a range of similar techniques or algorithms (we won't go into detail here, as this is a topic in its own right, but you get the idea).
 4. **Analyze the data sample:** Once you have a random sample, you can use it to infer information about the larger population. It's important to note that while a random sample is *representative* of a population, it will never be 100% accurate. For instance, the mean (or average) of a sample will rarely match the mean of the full population, but it will give you a good idea of it. For this reason, it's important to incorporate your error margin in any analysis (which we cover in a moment). This is why, as explained earlier, any result from inferential techniques is in the form of a probability.

However, presuming we've obtained a random sample, there are many inferential techniques for analyzing and obtaining insights from those data. The list is long, but some techniques worthy of note include, hypothesis testing, confidence intervals and regression/correlation analysis.

1.3.3.1 Hypothesis Testing

Hypothesis testing involves checking that your samples repeat the results of your hypothesis (or proposed explanation). The aim is to rule out the possibility that a given result has occurred by chance. A topical example of this is the clinical trials for the covid-19 vaccine. Since it's impossible to carry out trials on an entire population, we carry out numerous trials on several random, representative samples instead.

The hypothesis test, in this case, might ask something like: 'Does the vaccine reduce severe illness caused by covid-19?' By collecting data

from different sample groups, we can infer if the vaccine will be effective. If all samples show similar results and we know that they are representative and random, we can generalize that the vaccine will have the same effect on the population at large. On the flip side, if one sample shows higher or lower efficacy than the others, we must investigate why this might be. For instance, maybe there was a mistake in the sampling process, or perhaps the vaccine was delivered differently to that group. In fact, it was due to a dosing error that one of the COVID vaccines actually **proved to be more effective than other groups in the trial...** This shows how important hypothesis testing can be. If the outlier group had simply been written off, the vaccine would have been less effective.

1.3.3.2 Confidence Intervals

Confidence intervals are used to estimate certain parameters for a measurement of a population (such as the mean) based on sample data. Rather than providing a single mean value, the confidence interval provides a range of values. This is often given as a percentage.

For example, let's say you've measured the tails of 40 randomly selected cats. You get a mean length of 17.5cm. You also know the standard deviation of tail lengths is 2cm. Using a special formula, we can say the mean length of tails in the full population of cats is 17.5cm, with a 95% confidence interval. Essentially, this tells us that we are 95% certain that the population mean (which we cannot know without measuring the full population) falls within the given range. This technique is very helpful for measuring the degree of accuracy within a sampling method.

1.3.3.3 Regression and Correlation Analysis

Regression and correlation analysis are both techniques used for observing how two (or more) sets of variables relate to one another.

Regression analysis aims to determine how one dependent (or output) variable is impacted by one or more independent (or input) variables. It's often used for hypothesis testing and predictive analytics. For example, to predict future sales of sunscreen (an output variable) you might compare last year's sales against weather data (which are both input variables) to see how much sales increased on sunny days.

Correlation analysis, meanwhile, measures the degree of association between two or more datasets. Unlike regression analysis, correlation does not infer cause and effect. For instance, ice cream sales and sunburn are both likely to be higher on sunny days—we can say that they are correlated. But it would be incorrect to say that ice cream causes sunburn.

What we've described here is just a small selection of a great many inferential techniques that you can use within data analytics. However, they provide a tantalizing taste of the sort of predictive power that inferential statistics can offer.

A linear regression line has an equation (which is the linear regression model) of the form:

$$Y = a + bX + \epsilon$$

(Y = dependent variable, X = independent (explanatory) variable, a = intercept, b = slope, ϵ = residual (error) [*for very good models, ϵ may be close to 0, in which case, it is ignored*])

Self-Assessment Exercise

Outline the fundamental principles of random sampling.

1.3.4 Practical Example

Let us try to solve a computational problem using Microsoft Excel. Let us assume that we currently have soil survey data for Anambra state. The data is extensive and comprehensive, yet it does not have data on saturated hydraulic conductivity. The government of Anambra state realized that flooding is a common phenomenon in certain parts of the state, which in turns results in increase in gully erosion and the attendant loss of lives and properties. They consequently decided that there is the need for state-wide drainage to prevent these hazards. The consultant subsequently looked at the available soil survey data and realized that data on saturated hydraulic conductivity, which is vital to the project, is not available.

This creates a dilemma. Does the government need to conduct a fresh soil survey of the entire state because it needs to evaluate one unavailable soil parameter? This would be a time-consuming, capital-intensive project. This is an unwarranted investment, especially given the cost of the project of interest is already overwhelming. Statistical modeling may become the perfect solution to the problem.

Several pilot sites may be selected in the state. 50 to 500 samples may be collected across these sites. These samples would be put through routine soil analysis, including saturated hydraulic conductivity, soil texture (sand, silt and clay), organic matter, bulk density and porosity. All of these soil properties are known to influence hydraulic conductivity. Equipped with these data, statistical analysis may be conducted to gain insight into the dynamics of soil within the state, enabling the modeling and prediction of saturated hydraulic conductivity for regions for which data is unavailable. For this, multiple linear regression may be the ideal option, but for ease of computation, we will focus on simple linear

regression, using one dependent variable (saturated hydraulic conductivity) and one dependent variable (clay content).

The table below shows values that reflect the expected relationship between clay and saturated hydraulic conductivity. It should be noted that these values were not generated experimentally; they are solely meant for instructional purposes. Calculate:

(a) Mean. (a) Standard deviation. (c) Construct the regression model. (d) Indicate whether the data is normally distributed. (e) Construct pie charts for both parameters.

Site	Saturated Hydraulic Conductivity (cm/hr)	Clay (%)
1	50	5
2	22	20
3	30	12
4	7	45
5	16	30
6	6	40
7	3	60
8	32	10
9	53	5
10	61	2
11	25	18
12	27	15
13	4	70
14	8	40
15	22	23
16	15	31
17	51	5
18	20	20
19	1	80
20	24	20
21	6	55
22	23	19
23	44	7
24	7	39
25	7	40
26	15	30
27	20	22
28	6	50
29	18	25
30	55	5

1.3.5 Tutorial

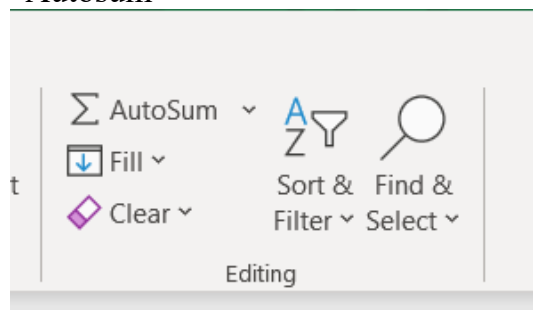
1. Select and copy the table
2. Open Microsoft Excel and paste the table

1.3.4.1 Mean

1. Select the entire column for which you want to compute the mean (saturated hydraulic conductivity, for instance), leaving out the heading

Site	Saturated Hydraulic Conductivity (cm/hr)	Clay (%)
1	50	5
2	22	20
3	30	12
4	7	45
5	16	30
6	6	40
7	3	60
8	32	10
9	53	5
10	61	2
11	25	18
12	27	15
13	4	70
14	8	40
15	22	23
16	15	31
17	51	5
18	20	20
19	1	80
20	24	20
21	6	55
22	23	19
23	44	7
24	7	39
25	7	40
26	15	30
27	20	22
28	6	50
29	18	25
30	55	5

2. On the top right-hand corner of the excel workbook you will see “Autosum”



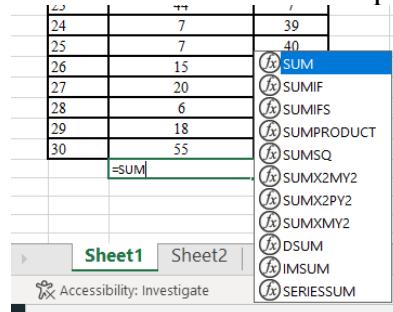
3. Click on the small arrow head in front of it
4. Select “Average” in the displayed menu
5. The mean is automatically computed

26	15	30
27	20	22
28	6	50
29	18	25
30	55	5
		22.6

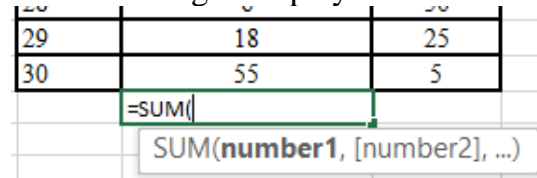
6. Repeat steps 1 to 5 to compute the mean for clay.

Alternatively, since you already know the formula for mean, you can calculate it in Excel

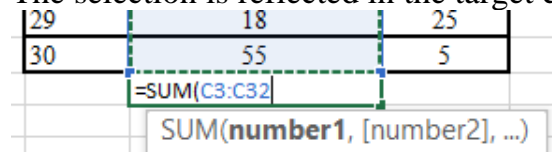
1. Type “=SUM” in the cell below the column of interest or where you want the results displayed.
2. A set of menus will be displayed, including “SUM”



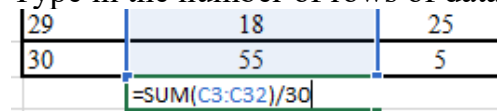
3. Double-click on “SUM”
4. The following is displayed



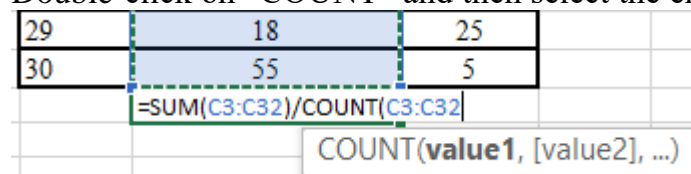
5. Scroll up and select the entire column of interest, leaving out the heading
6. The selection is reflected in the target cells as shown below



7. Type in the closing bracket symbol “)”
8. Type in the division sign, “/”
9. Type in the number of rows of data, in this case, “30”



10. Press the “Enter” key to automatically compute the mean
11. If on the other hand, you do not know the number of rows, you do not need to count individually. Progress from No. 8 to 12.
12. After the division sign, type “COUNT” to get another menu
13. Double-click on “COUNT” and then select the entire column



14. Close the bracket and press “Enter” to again compute the same results.
15. Repeat for the second column.

Self-Assessment Exercise

Compute the mean of:

- a) Clay b) Saturated hydraulic conductivity

1.3.4.2 Standard Deviation

To simplify and not mess up your previous calculation you have to create a new spreadsheet.

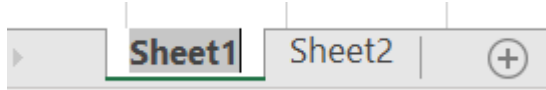
- At the bottom left of the window, you will see an indentation titled “Sheet”, beside which there is a “+” sign



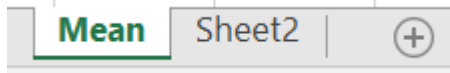
- Click the “+” to create a second sheet.



- There are now two sheets. You can create more in the same way. The sheet that is white is the active sheet. To select another, click on it.
- To make operations easy, you can label sheet1 as “Mean” and sheet2 as “Std. Dev.”
- To do so, double-click on the sheet name to highlight and make it editable



- Type in “Mean” and press the “Enter” key



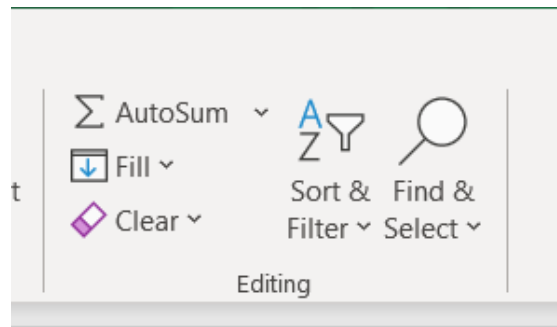
- Select Sheet2 and rename to “Std. Dev.”
- Copy the data table in sheet1, now titled “Mean” and paste it in the sheet titled “Std. Dev.”

The actual calculation can then begin in the new sheet

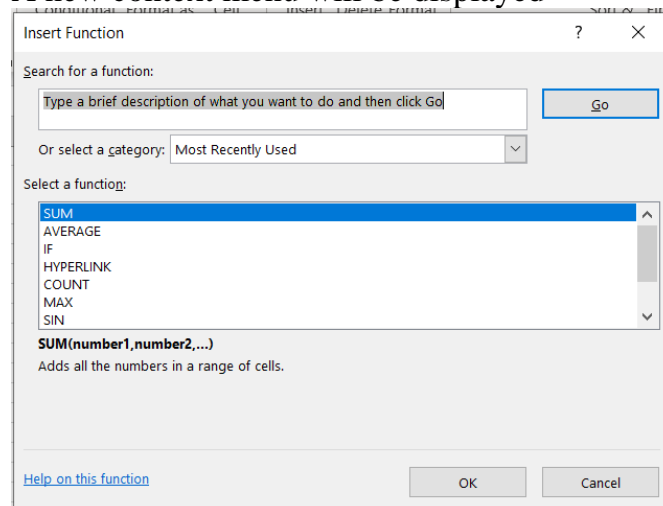
- Select the cell below the column of interest (saturated hydraulic conductivity, for instance)

29	18	25
30	55	5
Std. Dev.		

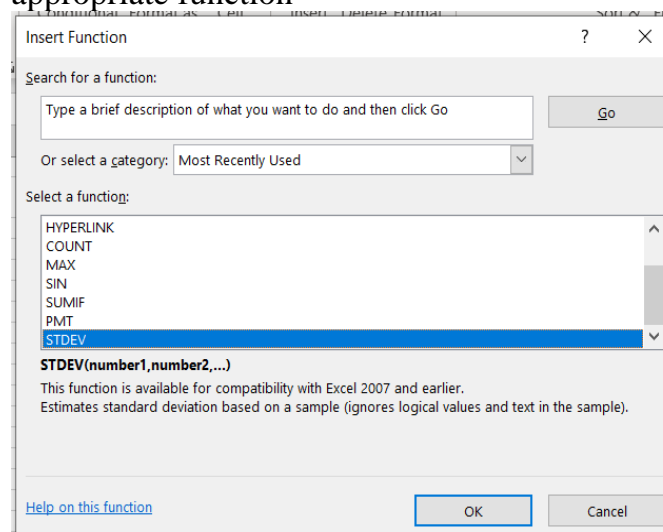
- On the top right-hand corner of the excel workbook you will see “Autosum”



3. Click on the small arrow head in front of it
4. Standard Deviation or STDEV would not be found on the list of options displayed
5. At the bottom of the options, you will see “More Functions”
6. A new context menu will be displayed



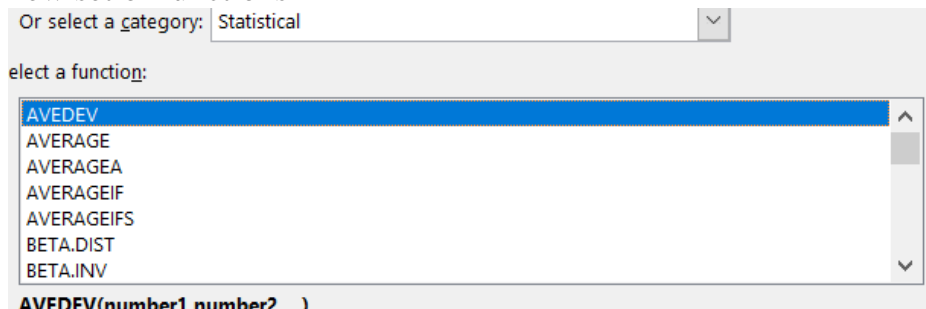
7. If you scroll down, you will find “STDEV”, but it is not the appropriate function



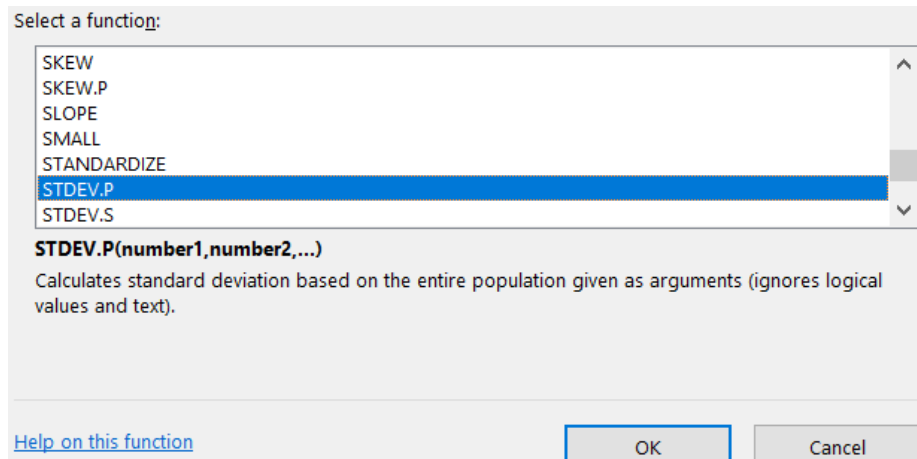
8. In the option for the “Most Recently Used” Click the downward pointing arrow



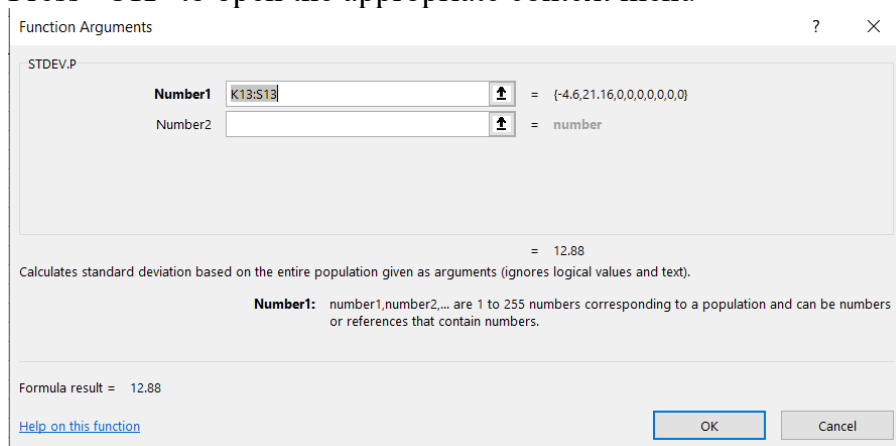
9. Select “Statistical” from the context menu and click to display a new set of functions



10. If “Statistical” is not there, you can type in “STDEV.P” search for a function, and click “GO” to find it. This will most probably not be a necessary step as you are likely to find the “Statistical” option.
11. Having selected the “Statistical” option, scroll down under “Select a function” to find and select “STDEV.P”



12. Press “OK” to open the appropriate context menu

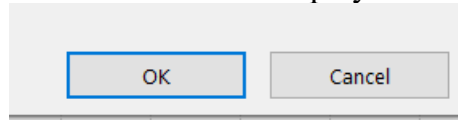


13. Click on the upward-pointing arrow in front of the cell titled “Number1”
14. Select the entire column of interest



15. Click the downward-pointing arrow at the right end of the context menu

- Click “OK” in the displayed context menu



- The standard deviation is automatically computed

30	55
Std. Dev.	17.12

- Repeat steps 1 to 17 for the second column to compute standard deviation for clay

Alternatively, since you already know the formula for standard deviation, you can compute it in the same way that you will calculate it manually on a piece of paper.

- Copy and paste the standard deviation formula in the MS Excel window

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

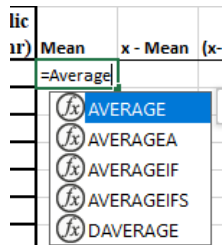
- Highlight and cut the second column (Clay)
- Paste it 6 columns to the right
- Type in new headings for the columns as shown below (in line with what is required in the formula)

Site	Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x-Mean)^2	N	Std. Dev.	Clay (%)
1	50						5

- You can equally copy the row of new titles and paste them in front of clay (as you will subsequently compute same for clay)

Dev.	Clay (%)	Mean	x - Mean	(x-Mean)^2	N	Std. Dev.
------	----------	------	----------	------------	---	-----------

- We will compute mean same way as before, but slightly differently
- Type in “=Average” in the first cell below the title “Mean”
- Double-click on “AVERAGE” in the context menu



- Select the entire column of interest and close the bracket

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean
50	=AVERAGE(C3:C32)	
22		
30		

- Press the “Enter” key on the keyboard to compute the mean

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x - Mean) ²
50	22.6		

11. If you check the previous sheet, you will see that the mean is same as before.
12. For the column titled, "x-Mean", you subtract the mean from each of the data values
13. Type "=", click on the first data value (50 in this case), type "-", then click on the mean value

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x - Mean) ²
50	22.6	=C3-D3	

14. If you press "Enter" the appropriate value will be computed, but you may run into issues later.
15. To forestall the issues mentioned, click in front of the second alphanumeric (D3 in this case) and type in the "\$" sign (hold down the "Shift" key on your keyboard and press the key for "4", on top of which, you will see the "\$" sign, or any other key associated with the "\$", depending on the computer brand in use). Again, type the "\$" sign between the alphabet (D) and the number (3).

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x - Mean) ²
50	22.6	=C3-\$D\$3	

16. Press "Enter" to compute

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x - Mean) ²
50	22.6	27.4	

17. I would say you should repeat for all other data value in that column, but that would be tedious and time-consuming
18. In the alternative, select the computed value again
19. Move the cursor to the bottom right edge of the cell
20. The cursor symbol at that corner changes to a "+" sign
21. Hold the mouse key and drag down to the cell corresponding to the last data value
22. Let go of the mouse key to automatically display the computation for all data values
23. You will notice that some values are negative, depending on the size of the data value, relative to the mean

Saturated Hydraulic Conductivity (cm/hr)	Mean	x - Mean	(x - Mean) ²
50	22.6	27.4	
22		-0.6	
30		7.4	
7		-15.6	
16		-6.6	

24. We do not need negative values, which is the reason for the next column
25. Select the first cell in the column titled, "(x-Mean)²"

- Type in "=", select the first cell in the "x-Mean" column, type the "^" sign (usually, you hold the "Shift" key and press key for the value, "6", above which you may see the symbol in question), then type "2"

x - Mean	(x-Mean)^2
27.4	=E3^2

- Press the "Enter" key to compute

x - Mean	(x-Mean)^2	N
27.4	750.76	

- Position the cursor at the bottom right corner of the cell till it turns to the "+" sign, hold and drag down as appropriate to compute all other values

- All the values are now positive, but much larger

(x-Mean)^2	N
750.76	
0.36	
54.76	
243.36	

- In the first cell of the "N" column, type in the number of data values (30). If number is unknown, implement the count function as done previously, with a slight variation

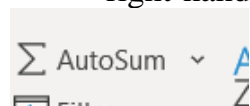
- Type in "+Count", double-click on "COUNT" from the context menu, select the entire column in question, close the bracket and press the "Enter" key.

- The result is displayed.

(x-Mean)^2	N	Si
750.76	30	

- Sum the entire values in the "(x-Mean)^2" column

- To do this, highlight the column and click "Autosum" on the top right-hand corner of the window




- If you look at the formula, you can see that you have computed both the denominator and the numerator of the formula.

- Under the "Std. Dev." Column, type in in "=sqrt", double-click on the "SQRT" option, type in another "(", the select the summation value for the "(x-Mean)^2" column, type in the division sign, "/", then select the "N" value. Close the bracket twice, "))."

2	N	Std. Dev.	(%)
76	30	=SQRT((F33/G3))	

- Press the "Enter" key on the keyboard to compute the standard deviation.

Std. Dev.
30 17.12

38. Repeat steps 1 to 37 to compute the standard deviation for the clay dataset.
39. Change the background of the standard deviation cell to grey or any other colour of your choice by selecting the cell, click the arrow in front of “” on the top leftward side of the window, and select an appropriate colour.
40. Embolden by clicking on the “**B**” icon on the top leftward side of the window.
41. Do the same for the Standard deviation computed with the previous method.
42. Compare the two sets of results. They should be the same.

Self-Assessment Exercise

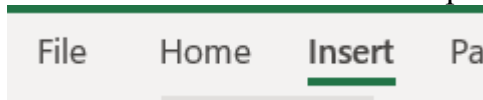
Compute the standard deviation of:

- a) Clay
- b) Saturated hydraulic conductivity

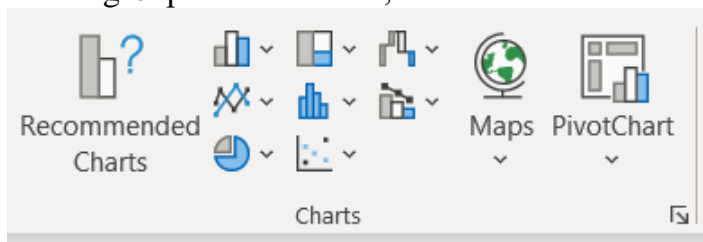
1.3.4.3 Construct the Regression Model

To construct the regression model, create a new tab and rename as “Regression”. Copy the data table and paste it in the new sheet. On a piece of paper or graph sheet, you would have been expected to plot a graph of saturated hydraulic conductivity on the Y-axis and clay on the X-axis. We will do the same with Microsoft Excel.

1. Highlight both columns (saturated hydraulic conductivity and clay) simultaneously, including the titles.
2. In the Menu bar at the top of the window, click “Insert”



3. Somewhat at the middle of the top of the window, you will see a group of icons titled, “charts”

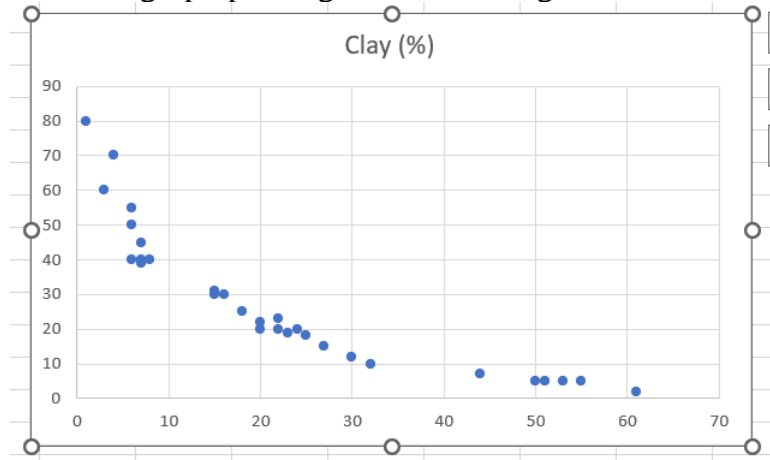


4. In your computer, you may see an option titled “Scatter Plots” when you gradually move your cursor over the icons. Alternatively, you may see a chart with dots congregated between 2 axes. I can see something like that on my screen.



5. Click on the icon

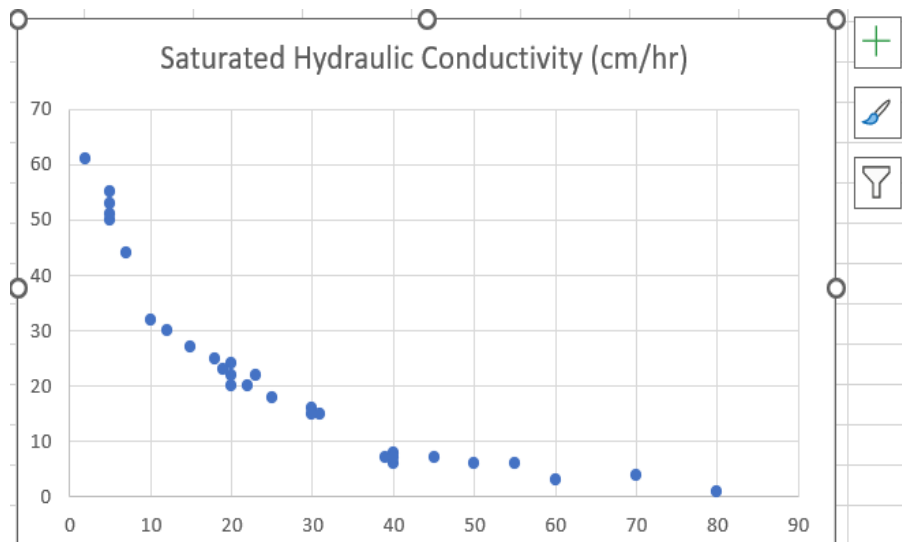
6. Out of the options displayed in the context menu, select and click the chart that is titled “Scatter”, when you hover the cursor over it.
7. A graph plotting the columns against each other is displayed.



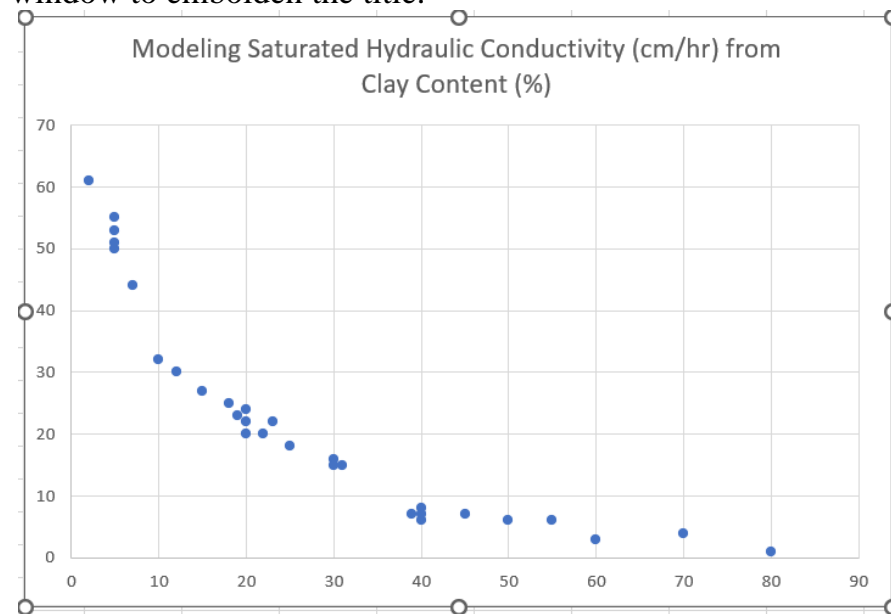
8. This is not the results that you need. You need to readjust it to suit your need. Observe that the maximum value on the Y-axis is 80 and the maximum on the X-axis is over 60.
9. Compare chart values with table to determine which values were plotted in the respective axes. You will notice that the maximum value for clay in the table is 80% and that of saturated hydraulic conductivity is 61 cm/hr. This means that you have clay on the Y-axis and saturated hydraulic conductivity on the X-axis. This is the reverse of what you want as the value of saturated hydraulic conductivity is meant to be predicted for Anambra state, which makes it the dependent variable, which is meant to be plotted on the Y-axis.
10. To reverse it, cut and paste the column for saturated hydraulic conductivity after the clay column. The new sequence should be as shown below.

Site	Clay (%)	Saturated Hydraulic Conductivity (cm/hr)
1	5	50

11. Repeat steps 1 to 9. A new chart is displayed



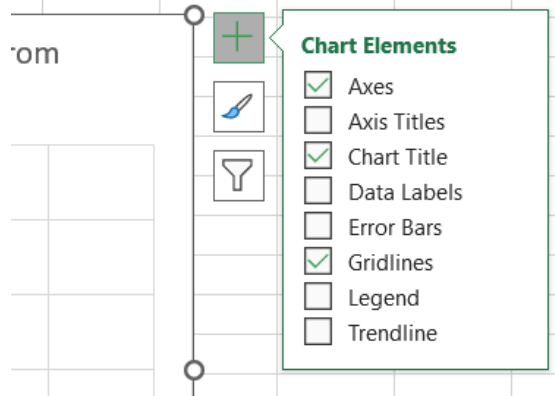
12. You can see that in the new chart, the trend is reversed to reflect the alignment of the axes. Delete the first chart.
13. Observation of the chart shows that it is still inadequate. The Y and the X axes have not title; the chart title is not a reflection of what the plot is all about; there is no line of best fit; there is no regression model (equation); you may not require all or any of the gridded lines, etc.
14. To start, click on the title, click again within the outline of the textbox so show the blinking cursor icon; highlight the texts in the title and type in “Modeling Saturated Hydraulic Conductivity (cm/hr) from Clay Content (%)” or edit as appropriate. And while still highlighted, press **B** tool on the top left corner of the window to embolden the title.



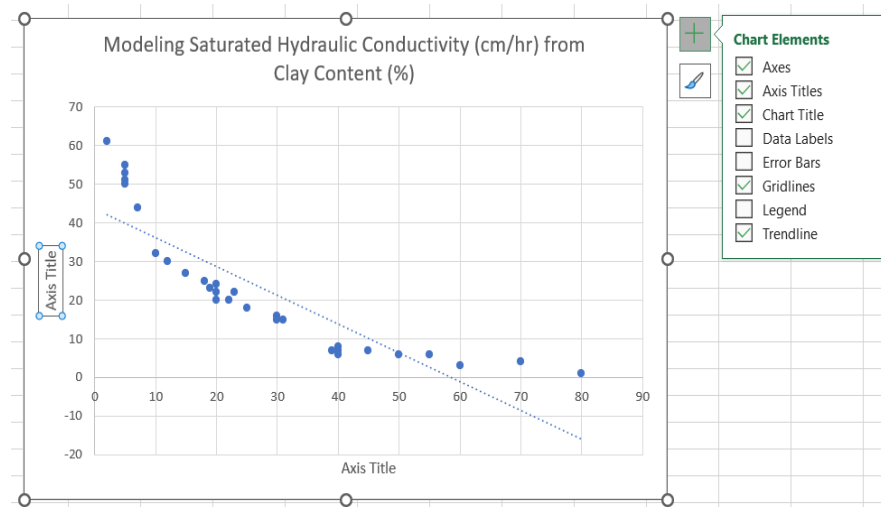
15. To update the chart, when you select the chart, three tools appear on the top right-hand corner.



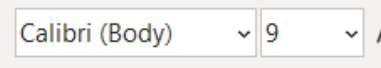
16. Click on the “+” sign to open a context menu

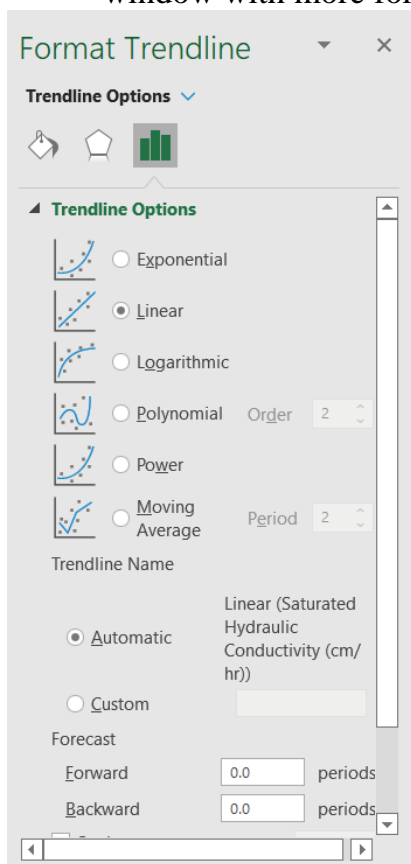


17. You can see that axes, chart title and gridlines are marked.
18. Click on the box next to axis titles and trendline to mark and add them to the chart

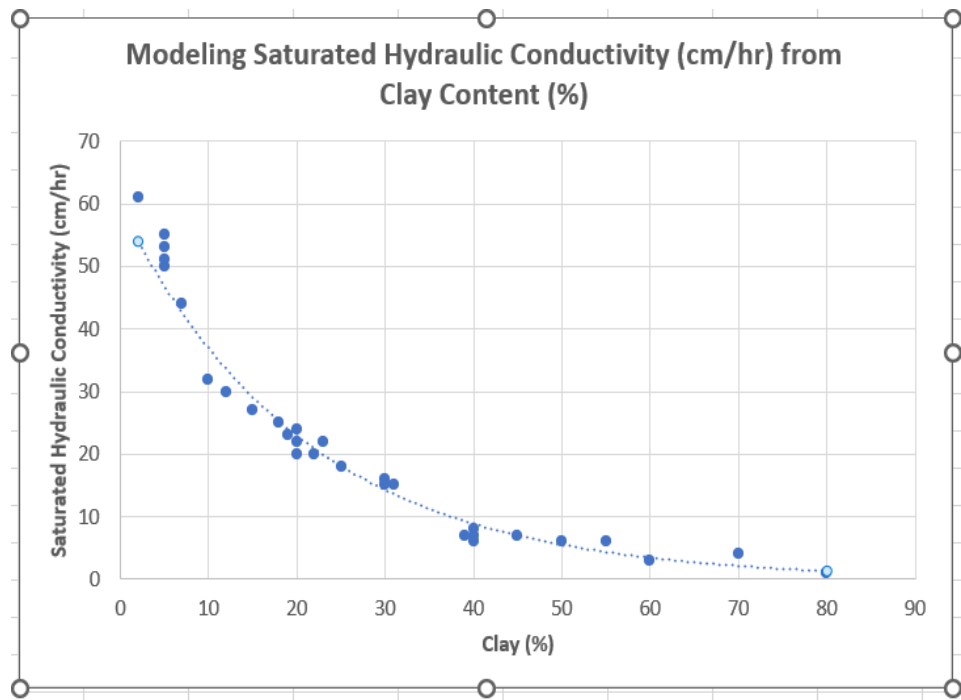


19. Click on the box next to trendline to remove the trendline
20. To label the axes appropriately, click on the Y-axis title, type “=” sign and click on the title of the appropriate column (saturated hydraulic conductivity), then press “Enter” key on the keyboard
21. The title is changed automatically. Press **B** tool on the top left corner of the window, while the title is still highlighted, to embolden the title.
22. Repeat 19 and 20 with minor adjustments for the X-axis.
23. You can also format the axes by clicking on one of the numbers to select the entire row (for the X-axis)

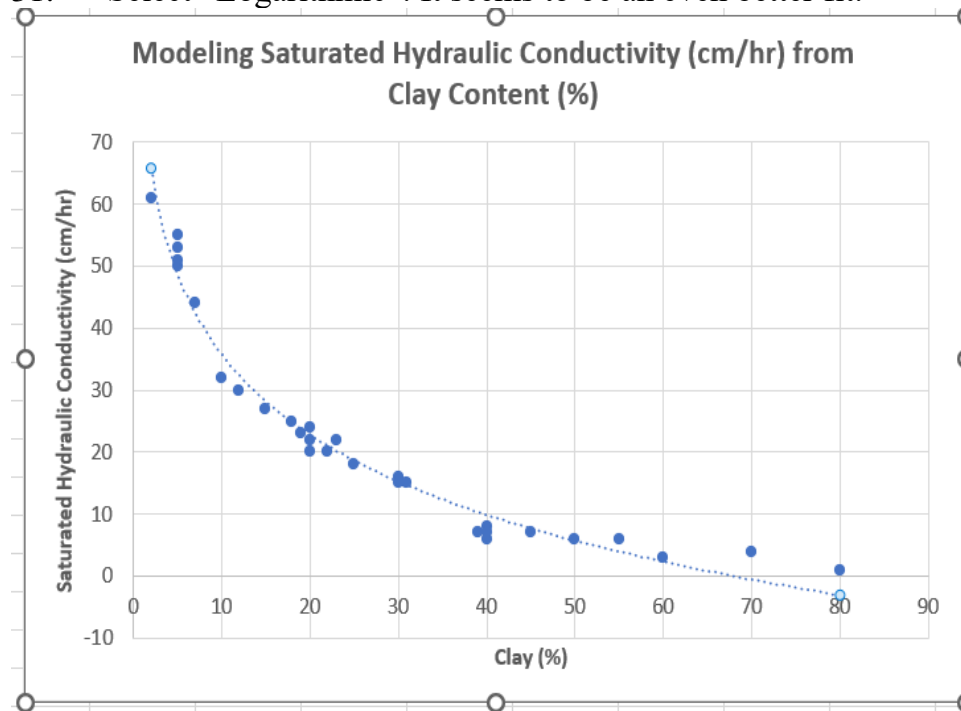
24. At the top left corner of the window, click the downward arrow in front of the font size tool –  – to expose other numbers, select the appropriate (for instance, 10) to increase the size of the text. You can embolden or reformat according to your needs.
25. Do the same for the Y-axis.
26. Now, it is time to format the trendline, load the model and the R-squared value.
27. Press the “+” sign on the chart and move your cursor down to the trendline. A leftward-pointing arrowhead appears. Click on that arrow to open a context menu.
28. As you move your cursor down the menu, the shape of the trendline changes in relation to the data points in the chart.
29. Click the “More Options” to open a sidebar on the right side of the window with more format options.



30. You will see that linear is currently selected. Select “Exponential” to view a new, better-fitting trendline (this fitting is relative to the current data; for another dataset, linear may be a better fit).

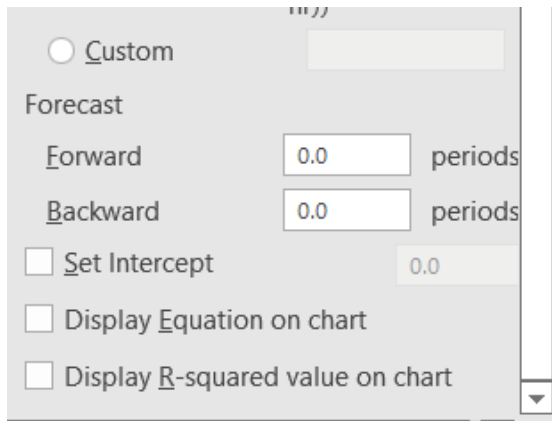


31. Select "Logarithmic". It seems to be an even better fit.

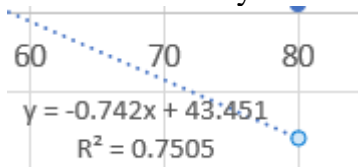


32. Try out the other trendlines. All these other trendlines have more complex underlying computations, so for this tutorial, we will stick to the simplest, "Linear". So, select "Linear" again

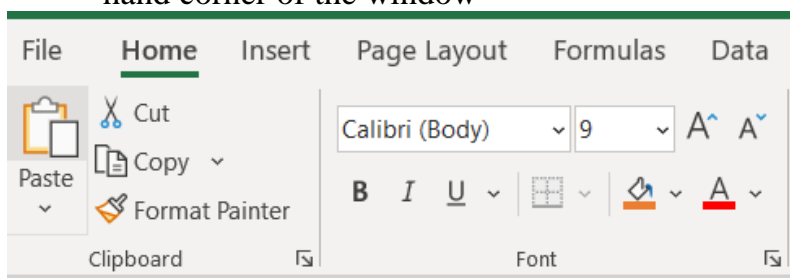
33. Scroll down on the side bar to view the last two menus



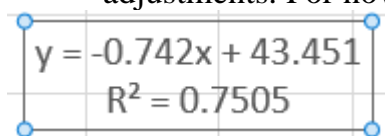
34. Mark the box next to “Display Equation on chart” to load the regression model onto the chart
35. Mark the box next to “Display R-squared value on chart” to load the R-squared value onto the chart
36. These may be located inappropriately on the chart or may be too small for your fancy, so you can format accordingly.



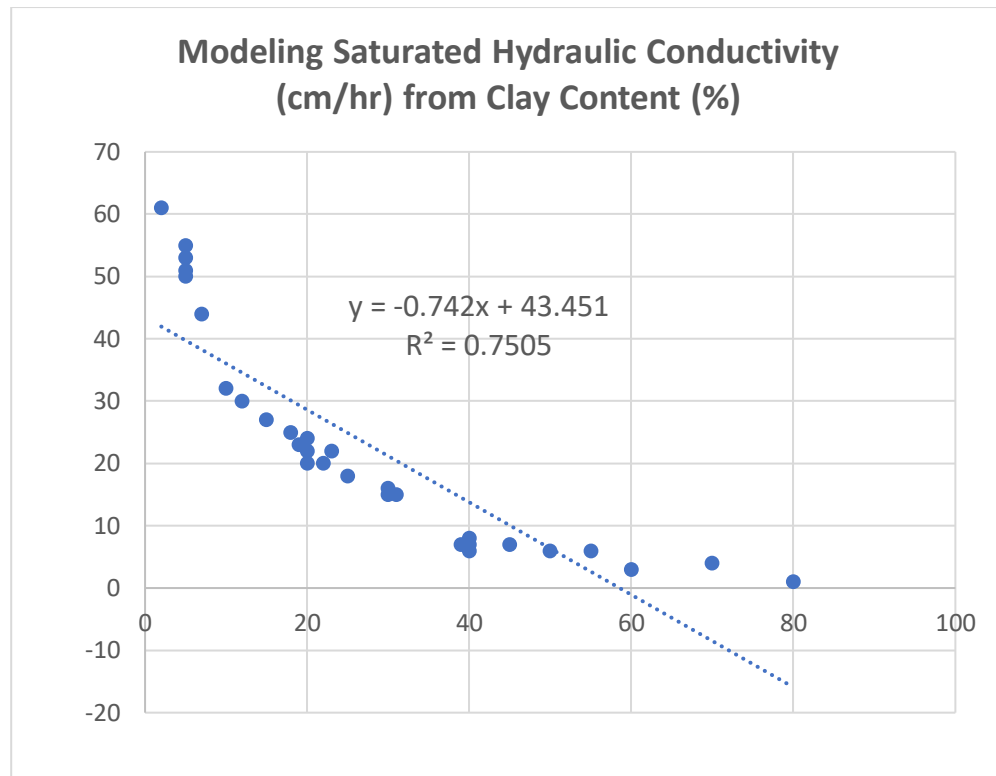
37. Click on the loaded values in the chart. Both will be selected simultaneously. Move towards any of the sides of the borderlines. When the selection cursor changes to a big plus sign, hold and drag to an appropriate position on the chart.
38. While still selected, press the “Home” menu bar on the top left-hand corner of the window



39. In the exposed menu, you can change the font type or even colour (background and/or font), increase the font size or make other font adjustments. For now, the font size may be increased to 12.



40. You can copy the final chart to Microsoft Word or any other application. To do so, right-click on the chart and select “Copy” in the context menu. Paste in any other application, like Microsoft Word.



Conclusion

1. The chart shows that both datasets are negatively correlated, i.e., as one increases, the other decreases.
2. The $R^2 = 0.7505$ implies that 75% of the variation in saturated hydraulic conductivity is related to variation in clay (note that the data is fictitious so this relationship may be stronger or weaker in real life).
3. $y = -0.742x + 43.451$

Self-Assessment Exercise

What is the importance of the computed linear regression model?

1.3.4.4 Indicate Whether the Data is Normally Distributed

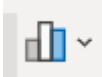
1. To do this, we may have to reorganize the data to create range (interval) data
2. Capture the data in the data within the range of 1-5, 6-10, 11-15, etc.
3. This results in the creation of a new table reflecting the number of times each range of data is recorded.

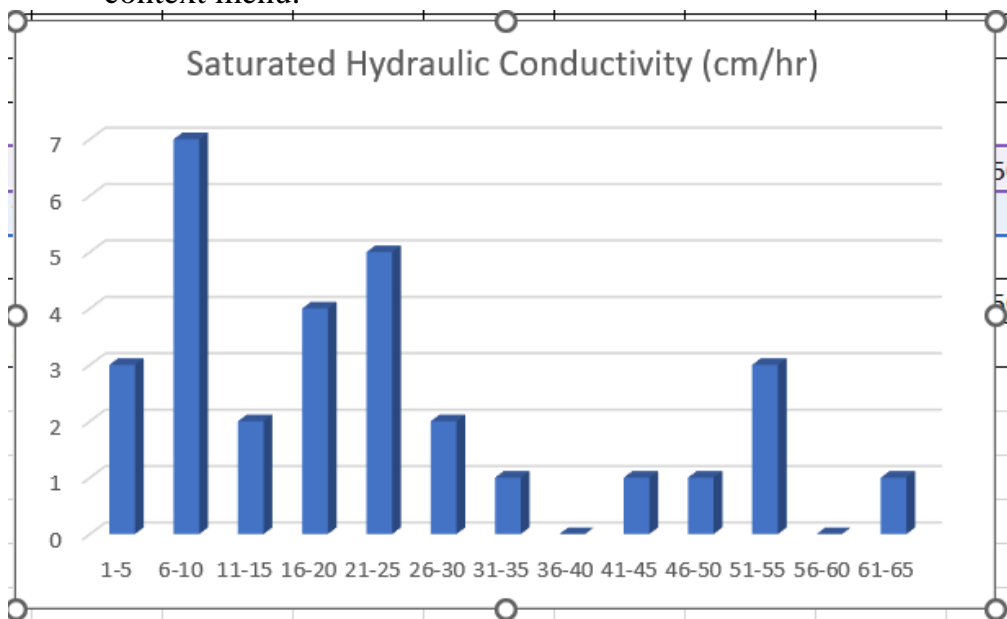
	1	6-	11	16	21	26	31	36	41	46	51	56	61	66	71	76
Range	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Ksat (cm/hr)	3	7	2	4	5	2	1	0	1	1	3	0	1			
Clay (%)	5	2	2	5	3	2	1	4	1	0	2	1	0	1	0	1

- Bar charts can be manually created representing the number of times each range of data is recorded for each dataset. We will however, do this automatically using bar charts in Microsoft Excel.
- Split the table into 2 tables with the range repeated for each

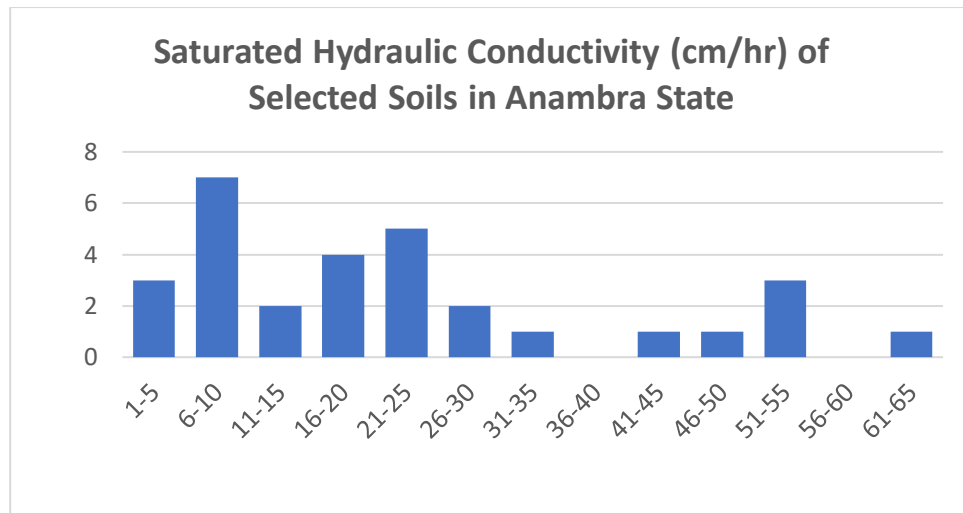
Range	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65
Saturated Hydraulic Conductivity (cm/hr)	3	7	2	4	5	2	1	0	1	1	3	0	1

Range	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80
Clay (%)	5	2	2	5	3	2	1	4	1	0	2	1	0	1	0	1

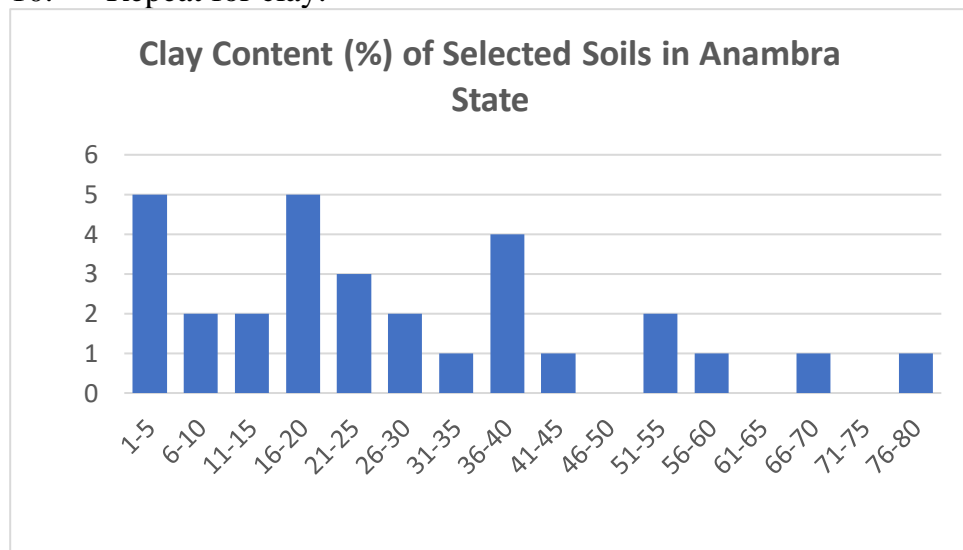
- Run through the steps under insert charts as outlined under regression
- This time, select the bar chart icon 
- Select "Clustered Columns" or "3-D Clustered Columns" from the context menu.



- Format chart as shown under regression to insert axes titles, and update axes format and chart title, etc.



10. Repeat for clay.



Conclusion

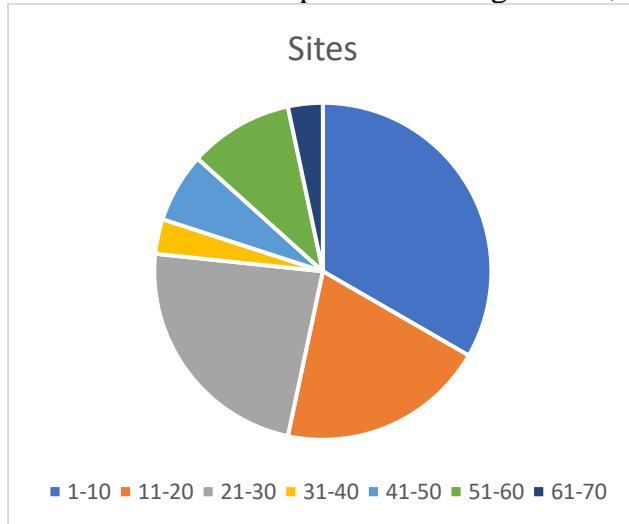
1. The charts show that the widespread hydraulic conductivity range recorded was 6 to 10 cm/hr, while the widespread clay ranges were 1 to 5 and 16 to 20 %. The least, medium, and general spatial dynamics can be deciphered from the charts.
2. Neither of the charts were bell-shaped, so both datasets were not normally distributed.
3. When a large number of such samples are collected, they tend to have a normal distribution. Inadequate number of samples may have been the cause of the absence of normality, but the major factor is that these data are fictitious data and do not reflect the actual reality in the field.

1.3.4.5 Construct Pie Charts for Both Parameters

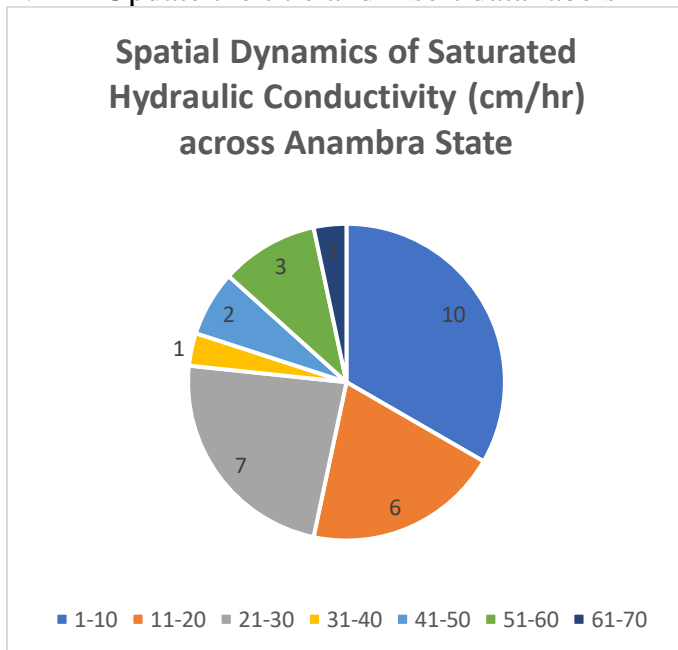
- To construct the pie charts and reduce their complexity, I will increase the range to 1-10, 11-20, 21-30, etc.

Saturated Hydraulic Conductivity (cm/hr) Range	1-10	11-20	21-30	31-40	41-50	51-60	61-70	
Sites	10	6	7	1	2	3	1	
Clay (%)	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
Sites	7	7	5	5	1	3	1	1

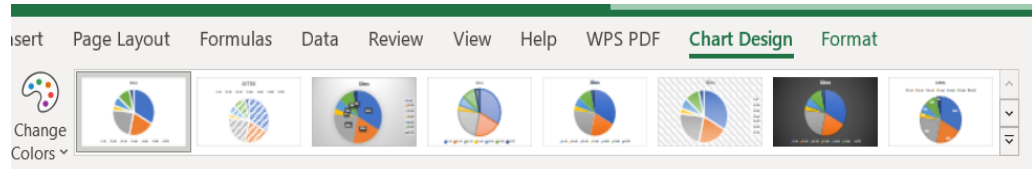
- Follow the steps for inserting a chart, but this time, select pie chart



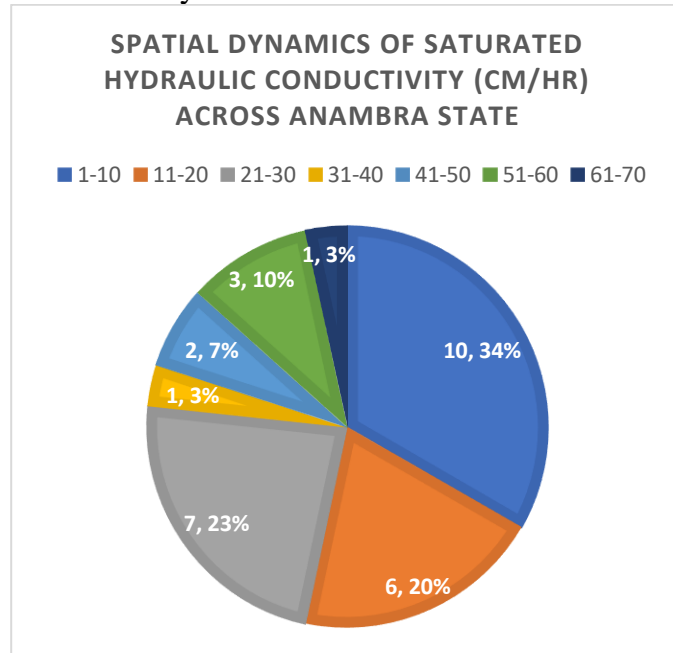
- This chart is still inadequate and the title does not provide good information on which dataset is on display.
- Update the title and insert data labels



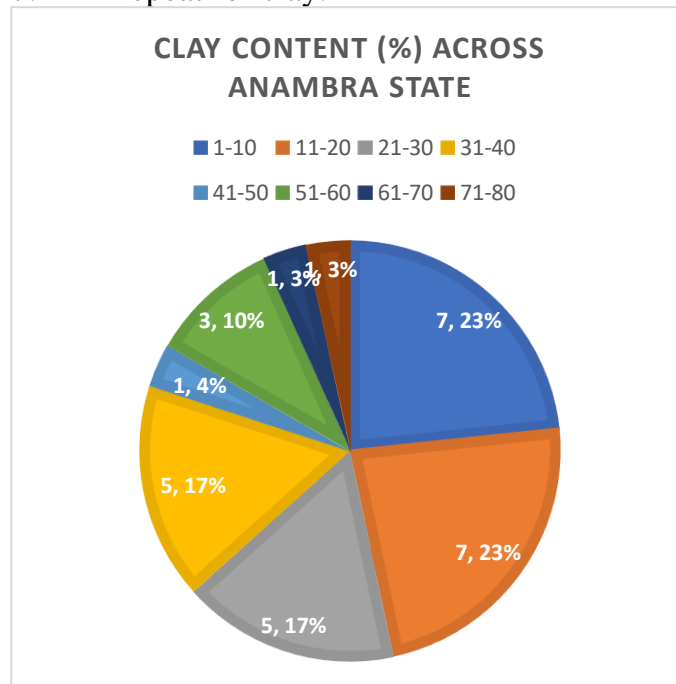
- This is good, but I want to know the proportion of the sites with specific data ranges. To do so, select the chart and click “Chart Design” in the menu bar to display various pie chart styles.



6. Select the charts one after the other, until you get the design that suits your need.



7. Repeat for clay.



Conclusion

1. The relative proportion/coverage of each concentration range can be deciphered at a glance.
2. The charts show that 34% of the sites had hydraulic conductivity range between 1 and 10 cm/hr, while each of the clay ranges of 1 to 10 and 11 to 20 % have spatial extent of 23 % of the sites. The least, medium, and general spatial dynamics can be deciphered from the charts.

Self-Assessment Exercise

Show the pie chart for

- a) Saturated Hydraulic Conductivity
- b) Clay

1.4 Conclusion

Basic statistics can be computed in Microsoft Excel. There pre-existing functions that would automatically generate the required solutions. Nevertheless, if you know and understand the statistical formula, you can compute the solutions manually in Excel. In this section, you did a little of that. But there are still more computations that can be articulated in Microsoft Excel. Having gone through these basics, it is hoped that on the long run, you will use the acquired knowledge as a springboard to learn more.

1.5 Summary

From this unit, you have learnt about the descriptive and inferential statistics. Some of the key things learnt include the following;

- Population and sample statistics
- Descriptive statistics
- Inferential statistics

1.6 Tutor-Marked Assignment

1. Differentiate between inferential and descriptive statistics, giving examples of each.
2. Follow the steps provided and solve the exercise in the tutorial section. Provide an Excel workbook as proof of completion.

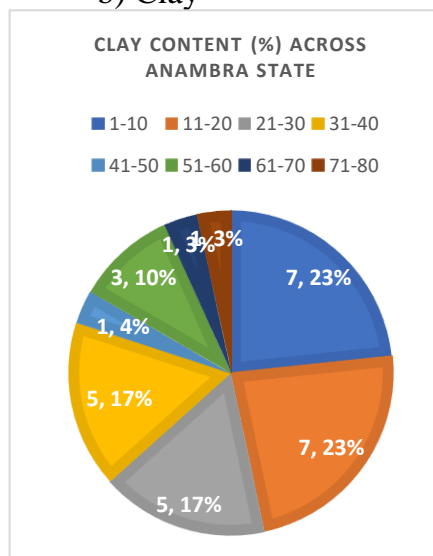
1.7 References/Further Reading/Web Resources

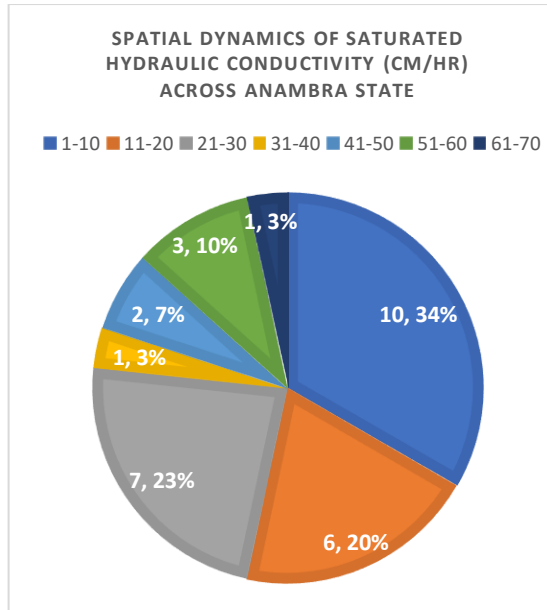
Bickel, P. Diggle, P. Fienberg, S., Gather, U., Olkin, I. and Zeger, S. (2005) *Lecture Notes in Statistics*. New York, USA: Springer.

Freeden, W., Nashed, M.Z. and Sonar, T. (2015) *Handbook of Geomathematics*. Berlin, Germany: Springer-Verlag.

1.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Define
 - a) Population
Population is the entire group that you wish to draw data from.
 - b) Sample
A sample is a representative group of a larger population
2. List five common measures of variability.
 - i) *Standard deviation*
 - ii) *Minimum and maximum values*
 - iii) *Range*
 - iv) *Kurtosis:*
 - v) *Skewness*
3. Outline the fundamental principles of random sampling.
 - i) *Defining a population*
 - ii) *Deciding your sample size*
 - iii) *Randomly select a sample*
 - iv) *Analyze the data sample*
4. Compute the mean of:
 - a) Clay = **28.1 %**
 - b) Saturated hydraulic conductivity = **22.6 cm/hr**
5. Compute the standard deviation of:
 - a) Clay = **19.99 %**
 - b) Saturated hydraulic conductivity = **17.12 cm/hr**
6. What is the importance of the computed linear regression model?
The model ($y = -0.742x + 43.451$, where $y =$ saturated hydraulic conductivity and $x =$ clay) would enable the prediction of saturated hydraulic conductivity in regions for which data is not available, but clay concentration data is accessible.
7. Show the pie chart for:
 - a) Saturated Hydraulic Conductivity
 - b) Clay





UNIT 2 GEOSTATISTICS CONCEPTS

Unit Structure

- 2.1 Introduction
- 2.2 Objectives
- 2.3 Main Content
 - 2.3.1 Geostatistics
 - 2.3.2 Main Tenets of Geostatistics
 - 2.3.3 Some Important Concepts
 - 2.3.3.1 Normal Distribution
 - 2.3.3.2 Minimum Mean-Square-Error
 - 2.3.3.3 Gauss–Markov Theorem
 - 2.3.3.4 Best Linear Unbiased Estimator
 - 2.3.3.5 Weighted Average
 - 2.3.3.6 Stochastic Dependence
 - 2.3.3.7 Covariances/Covariates
 - 2.3.3.8 Multivariate Data
 - 2.3.3.9 Semi-Variogram
 - 2.3.3.10 Spatial Autocorrelation
 - 2.3.3.11 Kriging Interpolation
- 2.4 Conclusion
- 2.5 Summary
- 2.6 Tutor-Marked Assignment
- 2.7 References/Further Reading/Web Resources
- 2.8 Possible Answers to Self-Assessment Exercise(s) within the content

2.1 Introduction

Having explored basic statistics in the previous section, we will take a closer look at geostatistics. Geostatistics is the class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena. It incorporates the spatial (and in some cases temporal) coordinates of the data within the analyses. In this unit, we will explore the main tenets of geostatistics, alongside common concepts like, normal distribution, minimum mean-square-error, gauss–markov theorem, best linear unbiased estimator, weighted average, stochastic dependence, covariances/covariates, multivariate data, semi-variogram and kriging interpolation.

2.2 Objectives

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

- Understand the concept of geostatistics
- Outline main tenets of geostatistics
- Describe some underlying concepts of geostatistics

2.3 Main Content

2.3.1 Geostatistics

Geostatistics is a class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena. It incorporates the spatial (and in some cases temporal) coordinates of the data within the analyses. Many geostatistical tools were originally developed as a practical means to describe spatial patterns and interpolate values for locations where samples were not taken. Those tools and methods have since evolved to not only provide interpolated values, but also measures of uncertainty for those values. The measurement of uncertainty is critical to informed decision making, as it provides information on the possible values (outcomes) for each location rather than just one interpolated value. Geostatistical analysis has also evolved from uni- to multivariate and offers mechanisms to incorporate secondary datasets that complement a (possibly sparse) primary variable of interest, thus allowing the construction of more accurate interpolation and uncertainty models. Geostatistics is widely used in many areas of science and engineering, for example:

- The mining industry uses geostatistics for several aspects of a project: initially to quantify mineral resources and evaluate the project's economic feasibility, then on a daily basis in order to decide which material is routed to the plant and which is waste, using updated information as it becomes available.
- In the environmental sciences, geostatistics is used to estimate pollutant levels in order to decide if they pose a threat to environmental or human health and warrant remediation.
- Relatively new applications in the field of soil science focus on mapping soil nutrient levels (nitrogen, phosphorus, potassium, and so on) and other indicators (such as electrical conductivity) in order to study their relationships to crop yield and prescribe precise amounts of fertilizer for each location in the field.
- Meteorological applications include prediction of temperatures, rainfall, and associated variables (such as acid rain).
- Most recently, there have been several applications of geostatistics in the area of public health, for example, the prediction of

environmental contaminant levels and their relation to the incidence rates of cancer.

In all of these examples, the general context is that there is some phenomenon of interest occurring in the landscape (the level of contamination of soil, water, or air by a pollutant; the content of gold or some other metal in a mine; and so forth). Exhaustive studies are expensive and time consuming, so the phenomenon is usually characterized by taking samples at different locations. Geostatistics is then used to produce predictions (and related measures of uncertainty of the predictions) for the unsampled locations.

Self-Assessment Exercise

What is geostatistics?

2.3.2 Main Basic Tenets of Geostatistics

The main basic tenets of geostatistics are:

1. The use of appropriate parametric distribution models when practical for confidence limits of estimates of the mean grade. Various nonparametric approaches have been developed, but face the common problem that the pattern of the observed point distribution accepted as the model can be misleading for the upper tail of the distribution unless a very large data base is available.
2. Spatial structures generally present in ore bodies and with characteristics associated with geological and mineralogical features.
3. The concepts of support sizes and types, the proportionally effect and models for estimating the SMU (Selected Mining Unit) block distribution parameters directly or indirectly from the point value distribution.
4. Kriging for block estimates. Many types of kriging have been developed but all allow to eliminate - or at least reduce - the conditional bias.
5. If block valuations are done before the actual selective mining stage - when the final data becomes available - the estimates will be smoothed and have to be post-processed. Meaningful post-processing techniques were set up after the early stages of the development of geostatistics, as well as the so-called non-linear geostatistics.

2.3.3 Some Important Concepts

2.3.3.1 Normal Distribution

Normal distribution, also known as the Gaussian distribution, is a probability distribution that is symmetric about the mean, showing that data near the mean are more frequent in occurrence than data far from the mean. In graph form, normal distribution will appear as a bell curve. It is perfectly symmetrical around its center.

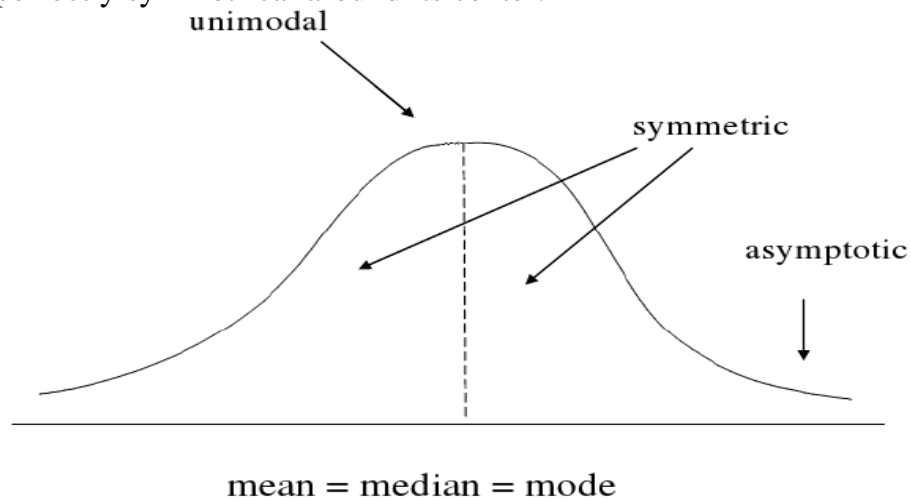


Figure 39: Normal Distribution

2.3.3.2 Minimum Mean-Square-Error

Mean squared error (MSE) or mean squared deviation (MSD) of an estimator (of a procedure for estimating an unobserved quantity) measures the average of the squares of the errors—that is, the average squared difference between the estimated values and the actual value.

Minimum mean square error (MMSE) estimator is an estimation method which minimizes the mean square error (MSE), which is a common measure of estimator quality, of the fitted values of a dependent variable.

2.3.3.3 Gauss–Markov Theorem

The Gauss–Markov theorem (or simply Gauss theorem for some authors) states that the ordinary least squares (OLS) estimator has the lowest sampling variance within the class of linear unbiased estimators, if the errors in the linear regression model are uncorrelated, have equal variances and expectation value of zero. The errors do not need to be normal, nor do they need to be independent and identically distributed (only uncorrelated with mean zero and homoscedastic with finite variance). The requirement that the estimator be unbiased cannot be dropped, since biased estimators exist with lower variance. See, for

example, the James–Stein estimator (which also drops linearity), ridge regression, or simply any degenerate estimator.

2.3.3.4 Best Linear Unbiased Estimator

The Gauss Markov Theorem Says That, Under Certain Conditions, The Ordinary Least Squares (Ols) Estimator Of The Coefficients Of A Linear Regression Model Is The Best Linear Unbiased Estimator (Blue), That Is, The Estimator That Has The Smallest Variance Among Those That Are Unbiased And Linear In The Observed Output Variables.

2.3.3.5 Weighted Average

Weighted Average Is A Calculation That Takes Into Account The Varying Degrees Of Importance Of The Numbers In A Data Set. In Calculating A Weighted Average, Each Number In The Data Set Is Multiplied By A Predetermined Weight Before The Final Calculation Is Made. A Weighted Average Can Be More Accurate Than A Simple Average In Which All Numbers In A Data Set Are Assigned An Identical Weight.

2.3.3.6 Stochastic Dependence

A Dependence Between Random Variables That Is Expressed By A Change Of The Conditional Distribution Of Any Of The Variables When The Other Variables Are Altered. There Are Many Forms Of Stochastic Dependence: If The Random Variables Are Not Mutually Independent, They Have To A Greater Or Lesser Degree The Property Of Stochastic Dependence. One Of The Most Common Types Of Stochastic Dependence Is Correlation Dependence (See Correlation (In Statistics); Regression)

2.3.3.7 Covariances/Covariates

Covariance Is Similar To Variance, But Where Variance Tells You How A Single Variable Varies, Co Variance Tells You How Two Variables Vary Together. In Probability Theory And Statistics, Covariance Is A Measure Of The Joint Variability Of Two Random Variables, I.E., How Much Two Random Variables Vary Together. If The Greater Values Of One Variable Mainly Correspond With The Greater Values Of The Other Variable, And The Same Holds For The Lesser Values (That Is, The Variables Tend To Show Similar Behavior), The Covariance Is Positive. In The Opposite Case, When The Greater Values Of One Variable Mainly Correspond To The Lesser Values Of The Other, (That Is, The Variables Tend To Show Opposite Behavior), The Covariance Is Negative. The Sign Of The Covariance Therefore Shows The Tendency In The Linear

Relationship Between The Variables. The Magnitude Of The Covariance Is Not Easy To Interpret Because It Is Not Normalized And Hence Depends On The Magnitudes Of The Variables. The Normalized Version Of The Covariance, The Correlation Coefficient, However, Shows By Its Magnitude The Strength Of The Linear Relation.

Covariates Are Variables That Affect A Response Variable, But Are Not Of Interest In A Study. In Statistics, Researchers Are Often Interested In Understanding The Relationship Between One Or More Explanatory Variables And A Response Variable. However, Occasionally There May Be Other Variables That Can Affect The Response Variable That Are Not Of Interest To Researchers. These Variables Are Known As Covariates. For Example, Suppose Researchers Want To Know If Three Different Studying Techniques Lead To Different Average Exam Scores At A Certain School. The Studying Technique Is The Explanatory Variable And The Exam Score Is The Response Variable. However, There's Bound To Exist Some Variation In The Student's Studying Abilities Within The Three Groups. If This Isn't Accounted For, It Will Be Unexplained Variation Within The Study And Will Make It Harder To Actually See The True Relationship Between Studying Technique And Exam Score. One Way To Account For This Could Be To Use The Student's Current Grade In The Class As A Covariate. It's Well Known That The Student's Current Grade Is Likely Correlated With Their Future Exam Scores.

2.3.3.8 Multivariate Data

Multivariate Data Analysis Is A Type Of Statistical Analysis That Involves More Than Two Dependent Variables, Resulting In A Single Outcome. Many Problems In The World Can Be Practical Examples Of Multivariate Equations As Whatever Happens In The World Happens Due To Multiple Reasons. One Such Example Of The Real World Is The Weather. The Weather At Any Particular Place Does Not Solely Depend On The Ongoing Season, Instead Many Other Factors Play Their Specific Roles, Like Humidity, Pollution, Etc. Just Like This, The Variables In The Analysis Are Prototypes Of Real-Time Situations, Products, Services, Or Decision-Making Involving More Variables.

2.3.3.9 Semi-Variogram

A Variogram Is Used To Display The Variability Between Data Points As A Function Of Distance. A Traditional Semi-Variogram Plots One-Half Of The Square Of The Differences Between Samples Versus Their Distance From One Another; It Measures The Degree Of Spatial Autocorrelation That Is Used To Assign Weights In Kriging Interpolation. A Semi-Variogram Model Is One Of A Series Of

Mathematical Functions That Are Permitted For Fitting The Points On An Experimental Variogram.

Tobler's First Law Of Geography States That "Everything Is Related To Everything Else, But Near Things Are More Related Than Distant Things." In The Case Of A Semi-Variogram, Closer Things Are More Predictable And Have Less Variability. While Distant Things Are Less Predictable And Are Less Related. For Example, The Terrain One Meter Ahead Of You Is More Likely To Be Similar Than 100 Meters Away.

2.3.3.10 Spatial Autocorrelation

Spatial Autocorrelation Is The Term Used To Describe The Presence Of Systematic Spatial Variation In A Variable And Positive Spatial Autocorrelation, Which Is Most Often Encountered In Practical Situations, Is The Tendency For Areas Or Sites That Are Close Together To Have Similar Values.

2.3.3.11 Kriging Interpolation

Interpolation Is A Statistical Method By Which Related Known Values Are Used To Estimate An Unknown Price Or Potential Yield Of A Security. Interpolation Is Achieved By Using Other Established Values That Are Located In Sequence With The Unknown Value. Interpolation Is At Root A Simple Mathematical Concept. If There Is A Generally Consistent Trend Across A Set Of Data Points, One Can Reasonably Estimate The Value Of The Set At Points That Haven't Been Calculated. Kriging Is An Interpolation Method That Makes Predictions At Unsourced Locations Using A Linear Combination Of Observations At Nearby Sampled Locations. The Influence Of Each Observation On The Kriging Prediction Is Based On Several Factors:

- 1) Its Geographical Proximity To The Unsourced Location,
- 2) The Spatial Arrangement Of All Observations (I.E., Data Configuration, Such As Clustering Of Observations In Oversampled Areas), And
- 3) The Pattern Of Spatial Correlation Of The Data.

The Development Of Kriging Models Is Meaningful Only When Data Are Spatially Correlated. Kriging Has Several Advantages Over Traditional Interpolation Techniques, Such As Inverse Distance Weighting Or Nearest Neighbor:

- 1) It Provides A Measure Of Uncertainty Attached To The Results (I.E., Kriging Variance);
- 2) It Accounts For Direction-Dependent Relationships (I.E., Spatial Anisotropy);

- 3) Weights Are Assigned To Observations Based On The Spatial Correlation Of Data Instead Of Assumptions Made By The Analyst For Idw;
- 4) Kriging Predictions Are Not Constrained To The Range Of Observations Used For Interpolation, And
- 5) Data Measured Over Different Spatial Supports Can Be Combined And Change Of Support, Such As Downscaling Or Upscaling, Can Be Conducted.

Self-Assessment Exercise

List Five Important Concepts In Geostatistics.

2.4 Conclusion

In This Unit, We Were Able Define Terms That Would Be Seen And Used In Subsequent Units Of This Study Guide. When These Terms Reappear, It Is Expected That We Be Able To Understand What They Mean; Or If Not, Refer Back To This Unit To Refresh Our Memory. The Terms In Question Include Normal Distribution, Minimum Mean-Square-Error, Gauss–Markov Theorem, Best Linear Unbiased Estimator, Weighted Average, Stochastic Dependence, Covariance, Covariates, Multivariate Data, Semi-Variogram And Kriging Interpolation.

2.5 Summary

From This Unit, You Have Learnt About the Geostatistics Concepts. Some Of the Key Things Leant Include the Following;

- Geostatistics
- Main Basic Tenets of Geostatistics
- Some Important Concepts, Like
 - Normal Distribution
 - Minimum Mean-Square-Error
 - Gauss–Markov Theorem
 - Best Linear Unbiased Estimator
 - Weighted Average
 - Stochastic Dependence
 - Covariances/Covariates
 - Multivariate Data
 - Semi-Variogram
 - Kriging Interpolation

2.6 Tutor-Marked Assignment

1. Outline The Main Tenets Of Geostatistics.
2. Write Short Notes On Any Five Of The Following
 - A) Normal Distribution
 - B) Minimum Mean-Square-Error
 - C) Gauss–Markov Theorem
 - D) Best Linear Unbiased Estimator
 - E) Weighted Average
 - F) Stochastic Dependence
 - G) Covariances/Covariates
 - H) Multivariate Data
 - I) Semi-Variogram
 - J) Kriging Interpolation.

2.7 References/Further Reading/Web Resources

Bickel, P. Diggle, P. Fienberg, S., Gather, U., Olkin, I. And Zeger, S. (2005) *Lecture Notes In Statistics*. New York, Usa: Springer.

Freeden, W., Nashed, M.Z. And Sonar, T. (2015) *Handbook Of Geomathematics*. Berlin, Germany: Springer-Verlag.

Goovaerts, P. (2019). Kriging Interpolation. *The Geographic Information Science & Technology Body Of Knowledge* (4th Quarter 2019 Edition), John P. Wilson (Ed.).
Doi: [10.22224/Gistbok/2019.4.4](https://doi.org/10.22224/Gistbok/2019.4.4)(Link Is External).

2.8 Possible Answers to Self-Assessment Exercise(S) Within The Content

1. What is geostatistics?
Geostatistics is a class of statistics used to analyze and predict the values associated with spatial or spatiotemporal phenomena.
2. List five important concepts in geostatistics.
 - i) *Kriging interpolation*
 - ii) *Spatial autocorrelation*
 - iii) *Semi-variogram*
 - iv) *Multivariate data*
 - v) *Covariance/covariates*

UNIT 3 ESTIMATION METHODS

Unit Structure

- 3.1 Introduction
- 3.2 Objectives
- 3.3. Main Content
 - 3.3.1 Simple Kriging
 - 3.3.2 Ordinary Kriging
 - 3.3.3 Kriging Variance
- 3.4 Conclusion
- 3.5 Summary
- 3.6 Tutor-Marked Assignment
- 3.7 References/Further Reading/Web Resources
- 3.8 Possible Answers to Self-Assessment Exercise(s) within the content

3.1 Introduction

Having learnt in the previous unit that interpolation is a statistical method by which related known values are used to estimate an unknown price or potential yield of a security; and that kriging is an interpolation method that makes predictions at unsampled locations using a linear combination of observations at nearby sampled locations, in this unit we will look at kriging in greater details. We will learn that kriging is a form of generalized linear regression for the formulation of an optimal spatial estimator in a minimum mean-square-error sense. We will learn that there are different types of kriging, including, simple kriging, ordinary kriging, universal kriging, lognormal kriging and indicator kriging. And some of these types of kriging will be discussed in greater details.

3.2 Objectives

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

- Describe kriging and outline pre-kriging operations
- Outline the types of kriging

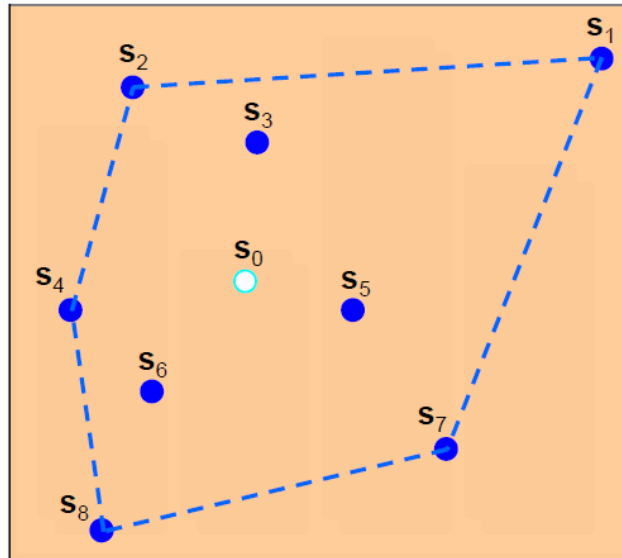
3.3 Main Content

3.3.1 Kriging

Kriging is a family of estimators used to interpolate spatial data. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. It is often used

in soil science and geology. Kriging is a form of generalized linear regression for the formulation of an optimal spatial estimator in a minimum mean-square-error sense.

Given some observations at locations S_i , kriging provides an estimate and a standard error at locations, such as S_0 , typically not considered in the sampling. In contrast to classical linear regression, kriging takes into account observation volume and stochastic dependence among data. The method works best inside the convex hull determined by the peripheral data.



Kriging predicts the value of a function at a given point by computing a weighted average of the known values of the function in the neighborhood of the point. The method is closely related to regression analysis. Both theories derive a best linear unbiased estimator based on assumptions on covariances, make use of Gauss–Markov theorem to prove independence of the estimate and error, and use very similar formulae. Even so, they are useful in different frameworks: kriging is made for estimation of a single realization of a random field, while regression models are based on multiple observations of a multivariate data set.

For instance, if a weatherman makes a forecast saying it's going to rain tomorrow, the question may arise as to how sure one is that it is going to rain? In other words, instead of just predicting how much rain will fall at specific locations, kriging also tells you the probability of how much rainfall at a specific location. You use your input data to build a mathematical function with a semi-variogram, create a prediction surface, and then validate your model with cross-validation. As such, not only does geostatistics provides an optimal prediction surface, but it also delivers a measure of confidence of how likely that prediction will be true.

Self-Assessment Exercise

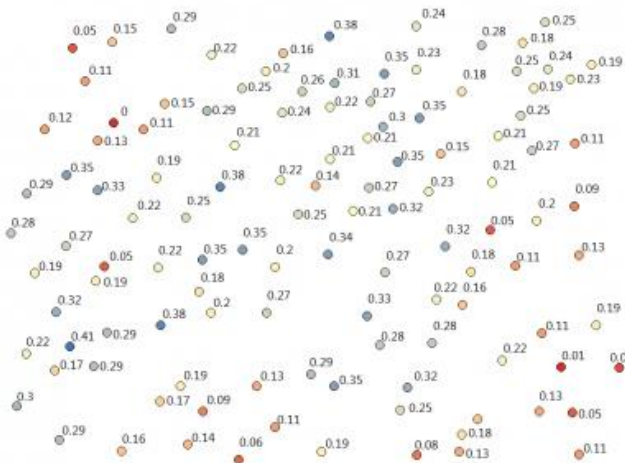
What is kriging?

3.3.1.1 Pre-Kriging Operations

Before you even start kriging, your data needs to fit certain specific criteria. Indeed, kriging is the optimal interpolation technique if your data meets certain criteria. But if they don't meet those criteria, you can massage it or choose a different interpolation technique altogether.

- Your data needs to have a normal distribution
- The data needs to be stationary
- Your data cannot have any trends

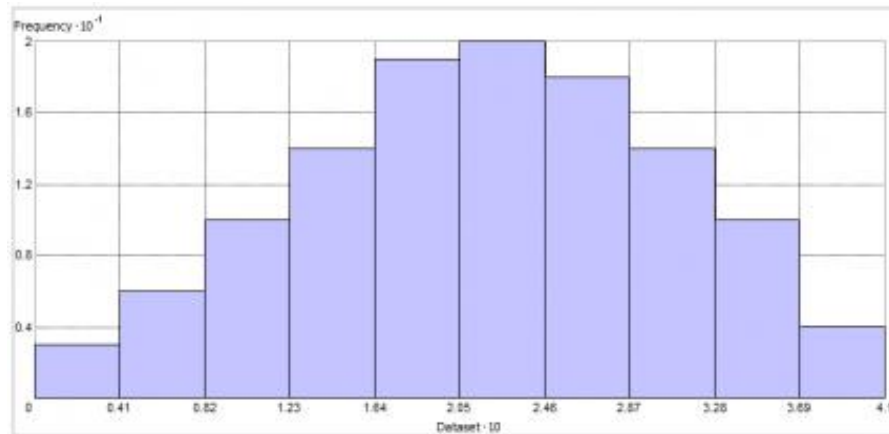
The following steps are ways to check your data to see if they fit these criteria. First, we suggest plotting out your points and symbolizing them from low to high. In our example, we use soil moisture samples taken in an agriculture field:



Assumption 1. Your data has a normal distribution

While we are not exploring the *spatial* properties in this test, we are only checking that the values are fairly normally distributed. In other words, do the values of your data fit a bell-curve shape?

At this point, you can check the histogram for any outliers and how much it looks like a bell curve. In our case, it looks like it has a fairly good normal distribution.



Assumption 2. Your data is stationary

This means that local variation doesn't change in different areas of the map. For example, 2 data points 5 meters apart in different locations should have **similar differences** in your measured value. The variance is fairly constant in different areas of the map. Kriging is not optimal for abrupt changes and break lines.

Assumption 3. Your data doesn't have trends

Trends are systematic changes in data across an entire study area.

There are several forms of kriging, each making different assumptions to adjust to different styles of attribute fluctuations.

- Simple kriging
- Ordinary kriging
- Universal kriging
- Lognormal kriging
- Indicator kriging

The last two types are simply any of the first three forms of kriging applied to transformed data.

3.3.2 Simple Kriging

This is a kriging method in which the weights of the values do not sum to unity. Simple kriging uses the average of the entire dataset, which is less accurate than ordinary kriging but produces a smoother result.

Similar to ordinary kriging except that the simple kriging uses the average of the entire data set while ordinary kriging uses a local average (the average of the scatter points in the kriging subset for a particular interpolation point). As a result, simple kriging can be less accurate than ordinary kriging.

3.3.3 Ordinary Kriging

Ordinary kriging is the most general and widely used of the kriging methods and is the default. It assumes the constant mean is unknown. This is a reasonable assumption unless there is a scientific reason to reject it. This is a kriging method in which the weights of the values sum to unity. It uses an average of a subset of neighboring points to produce a particular interpolation point.

1. A geostatistical approach to modeling. Instead of weighting nearby data points by some power of their inverted distance, ordinary kriging relies on the spatial correlation structure of the data to determine the weighting values.
2. Ordinary Kriging is the type of kriging method in which the weights of the values sum to unity. It uses an average of a subset of neighboring points to produce a particular interpolation point.

3.3.4 Universal Kriging

Universal kriging is used to estimate spatial means when the data have a strong trend and the trend can be modeled by simple functions. It assumes that there is an overriding trend in the data—for example, a prevailing wind—and it can be modeled by a deterministic function, a polynomial. This polynomial is subtracted from the original measured points, and the autocorrelation is modeled from the random errors. Once the model is fit to the random errors and before making a prediction, the polynomial is added back to the predictions to give meaningful results. Universal kriging should only be used when you know there is a trend in your data and you can give a scientific justification to describe it.

Self-Assessment Exercise

List five types of kriging.

3.4 Conclusion

In this unit, in addition to learning about kriging and its various types, we learned that there are specific criteria that data must meet before it can be effectively used in a kriging operation. As such, even though there are several commercial and open-source GIS software packages that can perform kriging interpolation, the user must be aware that the kriging procedure is highly sensitive to these specifications. Mis-specification of the variogram model will consequently lead to erroneous weights of the Kriging Interpolator and Inaccurate Interpolations.

3.5 Summary

From this unit, you have learnt about the estimation methods. Some of the key things learnt include the following;

- Kriging
- Pre-kriging operations
- Simple kriging
- Ordinary kriging
- Universal kriging

3.6 Tutor-Marked Assignment

1. Briefly discuss the operations that may need to be conducted prior to any kriging operation.
2. Write short notes on:
 - a) Simple kriging
 - b) Ordinary kriging
 - c) Universal kriging

3.7 References/Further Reading/Web Resources

Bickel, P. Diggle, P. Fienberg, S., Gather, U., Olkin, I. and Zeger, S. (2005) *Lecture Notes in Statistics*. New York, USA: Springer.

Freedon, W., Nashed, M.Z. and Sonar, T. (2015) *Handbook of Geomathematics*. Berlin, Germany: Springer-Verlag.

3.8 Possible Answers to Self-Assessment Exercise(S) Within The Content

1. What is kriging?
Kriging is an interpolation method that makes predictions at unsampled locations using a linear combination of observations at nearby sampled locations.
2. List five types of kriging.
 - i) *Simple kriging*
 - ii) *Ordinary kriging*
 - iii) *Universal kriging*
 - iv) *Lognormal kriging*
 - v) *Indicator kriging*

UNIT 4 MODELING

Unit Structure

- 4.1 Introduction
- 4.2 Objectives
- 4.3 Main Content
 - 4.3.1 Statistical Modeling Techniques
 - 4.3.1.1 Statistical Modeling Methods
 - 4.3.1.2 Types of Statistical Models
 - 4.3.2 Regression Model
 - 4.3.2.1 Types of Regression Models
 - 4.3.3 Simple Linear Regression Example
- 4.4 Conclusion
- 4.5 Summary
- 4.6 Tutor-Marked Assignment
- 4.7 References/Further Reading/Web Resources
- 4.8 Possible Answers to Self-Assessment Exercise(s) within the content

4.1 Introduction

In this unit we will take a closer look at what modeling really is. Usually, when the word modeling is mentioned, we become jittery because we think it is one complex, incomprehensible operation. Think back to your secondary school mathematics when you were made to plot straight line graphs between two variables, and then you were asked, “what is the value of y if x is 20. To answer this, you found the value for x on the x -axis, traced it vertically to the plotted line, then horizontally to the y -axis. You presented the value that you hit on the y -axis as the predicted value for y . What you were basically doing at that time, in secondary school, was modeling. With modeling, you do not always need to have the graph, having generated the graph for the first time, you can generate a model, which is a mathematical equation that relates the values on the y -axis with those on the x -axis, such that when you have an x -value but not a y -value, you can compute the y -value using the equation. This phenomenon will be explored further in this unit.

4.2 Objectives

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

- Outline the statistical modeling methods
- Describe the types of statistical models
- Discuss the regression model
- Make predictions using basic linear regression models

4.3 Main Content

4.3.1 Statistical Modeling Techniques

Statistical modeling is the use of mathematical models and statistical assumptions to generate sample data and make predictions about the real world. A statistical model is a collection of probability distributions on a set of all possible outcomes of an experiment. It is a mathematical relationship between one or more random variables and other non-random variables. The application of statistical modeling to raw data helps data scientists approach data analysis in a strategic manner, providing intuitive visualizations that aid in identifying relationships between variables and making predictions.

Self-Assessment Exercise

What is statistical modeling?

4.3.1.1 Statistical Modeling Methods

The most common statistical modeling methods for analyzing this data are categorized as either supervised learning or unsupervised learning. Some popular statistical model examples include logistic regression, time-series, clustering, and decision trees.

1. **Supervised Learning Techniques:** This includes regression models and classification models:
 - **Regression model:** A type of predictive statistical model that analyzes the relationship between a dependent and an independent variable. Common regression models include logistic, polynomial, and linear regression models. Use cases include forecasting, time series modeling, and discovering the causal effect relationship between variables.
 - **Classification model:** A type of machine learning in which an algorithm analyzes an existing, large and complex set of known data points as a means of understanding and then appropriately classifying the data; common models include models include decision trees, Naive Bayes, nearest neighbor, random forests, and neural networking models, which are typically used in Artificial Intelligence.
2. **Unsupervised Learning Techniques:** This includes clustering algorithms and association rules:
 - **K-means clustering:** Aggregates a specified number of data points into a specific number of groupings based on certain similarities.
 - **Reinforcement learning:** An area of deep learning that concerns models iterating over many attempts, rewarding moves that

produce favorable outcomes and penalizing steps that produce undesired outcomes, therefore training the algorithm to learn the optimal process.

Self-Assessment Exercise

List two types of each of the following statistical modelling methods:

- a) Supervised Learning Techniques
- b) Unsupervised Learning Techniques

4.3.1.2 Types of Statistical Models

There are three main types of statistical models: parametric, nonparametric, and semiparametric:

1. **Parametric Models:** This is a family of probability distributions that has a finite number of parameters. A Parametric Model is a concept used in statistics to describe a model in which all its information is represented within its parameters. In short, the only information needed to predict future or unknown values from the current value is the parameters. Parametric models often deal with discrete values, whereas non-parametric models will frequently incorporate continuous values and are described as having infinite dimensions.
2. **Non-parametric Models:** These are models in which the number and nature of the parameters are flexible and not fixed in advance. Non-parametric Models are statistical models that do not often conform to a normal distribution, as they rely upon continuous data, rather than discrete values. Non-parametric statistics often deal with ordinal numbers, or data that does not have a value as fixed as a discrete number. The term non-parametric does not mean that the value lacks inherent parameters, but rather that the parameters are flexible and can vary. One may turn to non-parametric statistics when dealing with ranked data, in which some of the value of the variables is the order in which they are organized.
3. **Semi-parametric Models:** The parameter has both a finite-dimensional component (parametric) and an infinite-dimensional component (nonparametric).

Self-Assessment Exercise

Enumerate the three main types of statistical models.

4.3.2 Regression Model

A regression model determines a relationship between an independent variable and a dependent variable, by providing a function. Formulating a regression analysis helps you predict the effects of the independent variable on the dependent one.

Example: we can say that age and height can be described using a linear regression model. Since a person's height increases as its age increases, they have a linear relationship.

Regression models are commonly used as a statistical proof of claims regarding everyday facts. In this article we will take a deeper look at regression model and its types.

4.3.2.1 Types of Regression Models

1. **Linear regression model:** A linear regression model is used to depict a relationship between variables which are proportional to each other. Meaning, the dependent variable increases/decreases with the independent variable.

In the graphical representation, it has a straight linear line plotted between the variables. Even if the points are not exactly in a straight line (which is always the case) we can still see a pattern and make sense out of it.

Example: As the age of a person increases, the level of glucose in their body increases as well.

2. **Multiple regression model:** A multiple regression model is used when there is more than one independent variable affecting a dependent variable. While predicting the outcome variable, it is important to measure how each of the independent variables moves in their environment and how their changes will affect the output or target variable.

Example: Chances of a student failing their test can be dependent on various input variables like hard work, family issues, health issues, etc.

3. **Non-linear regression model:** In the non-linear regression model, the graph doesn't show a linear progression. Depending on how the response variable reacts to the input variable, the line will rise or fall showing the height or depth of the effect of the response variable.

To know that a non-linear regression model is the best fit for your scenario, make sure you look into your variables and their patterns. If you see that the response variable is showing not so constant output to the input variable, you can choose to use a non-linear model for your problem.

Example: A patient's response to treatment can be good or bad depending on their body tendency and willpower.

- 4. Stepwise regression modelling:** Unlike the above-mentioned regression model types, stepwise regression modelling is more of a technique used when various input variables are affecting one output variable. The analyst will automatically proceed to measure the variable that is directly correlated input variable and build a model out of it. The rest of the variables come into the picture when he decides to perfect the model.

The analyst may add the remaining inputs one after the other based on their significance and the extent to which it affects the target variable.

Example: vegetable prices have increased in a certain area. The reason behind the event can be anything from natural calamities to transport and supply chain management. When an analyst decides to put it out on a graph, he will pick up the most obvious reason, heavy rainfall in the agricultural regions. Once the model is built, he can then add the rest of the affecting input variables into the picture based on their occurrence and significance.

Self-Assessment Exercise

Outline the four major types of regression models.

4.3.3 Simple Linear Regression Example

Recall that we generated a fictitious regression model geared predicting the saturated hydraulic conductivity of soils in Anambra state using clay data. In this section, we will use the model to predict saturated hydraulic conductivity. The table below is a representation of some of the previously available clay data that is not accompanied by the much-needed saturated hydraulic conductivity information.

Site	1	2	3	4	5	6	7	8	9	10	11	12	13
Clay (%)	7	41	23	8	58	33	47	3	56	49	37	18	25
Ksat (cm/hr)													

Ksat = Saturated Hydraulic Conductivity

Given that Saturated Hydraulic Conductivity is unknown as shown in the table above, we have to predict its value using the already existing regression model ($y = -0.742x + 43.451$). Note that in this case $x = \text{clay}$ and $y = \text{saturated hydraulic conductivity}$. As such, for each site, substitute x with the value for clay and you will be able to compute the predicted value for saturated hydraulic conductivity.

This can be calculated with a simple calculator, but in cases where you have hundreds or thousands of values, working with Microsoft Excel may be your best option. As such, we will make the computation in with Microsoft Excel.

1. Copy the table above and paste in Microsoft Excel. Also copy and paste the model on the same Excel sheet.

Model:	$y = -0.742x + 43.451$												
Site	1	2	3	4	5	6	7	8	9	10	11	12	13
Clay (%)	7	41	23	8	58	33	47	3	56	49	37	18	25
Ksat (cm/hr)													

Ksat = Saturated Hydraulic Conductivity

2. Click on the first empty cell for saturated hydraulic conductivity and type “ $=(-0.742*$ ” then click on the clay value for the cell

Model:	$y = -0.742x + 43.$	
Site	1	2
Clay (%)	7	41
Ksat (cm/hr)	$=(-0.742$	
	$*C5$	

3. Close the bracket with “)”, then type the “+” sign, then 43.451. For that cell, the full formula would then be $=(-0.742*7)+43.451$

Model:	$y = -0.742x +$	
Site	1	2
Clay (%)	7	4
Ksat (cm/hr)	$=(-0.742$	
	$*C5)+$	
	43.451	

4. Press the “Enter” key on the keyboard to compute.

Model:	$y = -0.742x +$	
Site	1	2
Clay (%)	7	4
Ksat (cm/hr)	38.257	

5. You would naturally repeat this for all other values. The easier way, if you recall, is to move your cursor to the bottom right-hand corner of the cell. As soon as it changes to the “+” sign, hold down

and drag rightwards until you get to the space for the last value, then release the mouse key. The saturated hydraulic conductivity for all the cells will automatically be computed.

Mod

el: $y = -0.742x + 43.451$

Site	1	2	3	4	5	6	7	8	9	10	11	12	13
Clay (%)	7	41	23	8	58	33	47	3	56	49	37	18	25
Ksat (cm/hr)	38.26	13.03	26.39	37.52	0.42	18.97	8.58	41.23	1.90	7.09	16.00	30.10	24.90

Ksat = Saturated Hydraulic Conductivity

Conclusion

This way, the unassessed saturated hydraulic conductivity can be predicted. It is however, noteworthy that this is not a substitute for field observations as model estimates are simply approximations of reality, and should not be regarded as perfect replicas of reality.

4.4 Conclusion

In this unit, we have explored different types and methods of statistical modeling. We subsequently zeroed in on regression models and talked about the different types. We also used a basic linear regression model to make predictions. In the succeeding unit, we will discuss spatial and the non-spatial models.

4.5 Summary

From this unit, you have learnt about modeling. Some of the key things learnt include the following;

- Statistical modeling techniques
 - Statistical modeling methods
 - Types of statistical models
- Regression model
 - Types of regression models

4.6 Tutor-Marked Assignment

1. Briefly discuss the statistical modeling methods.
2. Enumerate the types of statistical models.
- 3a. What is the regression model?
- 3b. Discuss the types of regression model.
4. Follow the steps in the tutorial and compute saturated hydraulic conductivity for the available table in the example.

4.7 References/Further Reading/Web Resources

Bickel, P. Diggle, P. Fienberg, S., Gather, U., Olkin, I. and Zeger, S. (2005) *Lecture Notes in Statistics*. New York, USA: Springer.

Freeden, W., Nashed, M.Z. and Sonar, T. (2015) *Handbook of Geomathematics*. Berlin, Germany: Springer-Verlag.

4.8 Possible Answers to Self-Assessment Exercise(S) Within The Content

1. What is statistical modeling?
Statistical modeling is the use of mathematical models and statistical assumptions to generate sample data and make predictions about the real world.
2. List two types of each of the following statistical modelling methods:
 - a) Supervised Learning Techniques
 - i) *Regression model*
 - ii) *Classification model*
 - b) Unsupervised Learning Techniques
 - i) *K-means clustering*
 - ii) *Reinforcement learning*
3. Enumerate the three main types of statistical models.
 - i) *Parametric Models*
 - ii) *Non-parametric Models*
 - iii) *Semi-parametric Models*
4. Outline the four major types of regression models.
 - i) *Linear regression model*
 - ii) *Multiple regression model*
 - iii) *Non-linear regression model*
 - iv) *Stepwise regression modelling*

UNIT 5 SPATIAL MODELING

Unit Structure

- 5.1 Introduction
- 5.2 Objectives
- 5.3 Main Content
 - 5.3.1 Spatial vs. Non-spatial Models
 - 5.3.1.2 Non-spatial Data/Models
 - 5.3.1.1 Spatial Data/Models
 - 5.3.2 SoilGrids250m as a Product of Spatial Modeling
 - 5.3.2.1 Soil Properties
 - 5.3.2.2 Environmental Covariates
 - 5.3.2.3 SoilGrids250m Data
- 5.4 Conclusion
- 5.5 Summary
- 5.6 Tutor-Marked Assignment
- 5.7 References/Further Reading/Web Resources
- 5.8 Possible Answers to Self-Assessment Exercise(s) within the content

5.1 Introduction

In this section, we will talk about spatial and non-spatial data. But before we progress further, it is noteworthy that spatial and non-spatial models may not be mutually exclusive. For instance, if I want to develop a non-spatial model saturated hydraulic conductivity of soils from clay content, I may collect thousands or hundreds of thousands of saturated hydraulic conductivity and clay measurements from different researches conducted in Nigeria, without bothering with the geographic coordinates or the location of the study sites. The model that I generate from these data is non-spatial. Say that subsequently, I come across extensive spatial (with site coordinates) clay content data for Anambra. I can still apply this non-spatial model data to my spatial clay data to generate a spatially distributed data of saturated hydraulic conductivity for Anambra state.

5.2 Objectives

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

- Understand the difference between spatial and non-spatial models
- Describe SoilGrids250m as the product of a spatial modeling operation

5.3 Main Content

5.3.1 Spatial Vs. Non- Spatial Models

5.3.1.1 Non-Spatial Data/Models

Non-spatial data is data that is **independent** of geographic location. Non-spatial data, simply, is data that contains ‘what’ instead of ‘where’. Indeed, it cannot be referenced or identified, to any location on earth or its surrounding atmosphere. It is just numbers, characters, or logical statements. A non-spatial model consequently predicts the value of a variable, but not with reference to any particular location on earth. For instance, let’s say you collected data to tree height and cation exchange capacity of the soil from different places (locations unknown) and you want to know how both variables are related so that so that wherever you see a tree you would be able to predict the cation exchange capacity of the soil (within a margin of error). If you construct a regression model between both variables, the resultant equation can be used to predict one variable or the other for other, for a dataset for which only one of the variables is available.

Nevertheless, non-spatial data can also provide information about a spatial data. This is usually called “attribute data”. For instance, if you have data on the location of a school (spatial data), you can attach information about the name of the school, subjects offered in the school, student population, etc. These are basically attributes of the spatial data, hence the name, attribute data.

5.3.1.2 Spatial Data/Models

Spatial data, also known as geospatial data, is a term used to describe any data **related** to or containing information about a **specific location** on the Earth’s surface. In other words, the geographic coordinates (longitude and latitude) of the site of interest should be known. Spatial models generate information related to specific locations on the earth surface. Even if the model generates global data, the dataset is usually gridded (raster), such that each grid cell has a specific data value and specific geographic coordinates indicating the location of the site. Figure 40 depicts the types of spatial data (vector and raster). It is noteworthy that most spatial models yield raster data. The SoilGrids250m is an example of a spatial modeling that yielded global soil and allied environmental data.

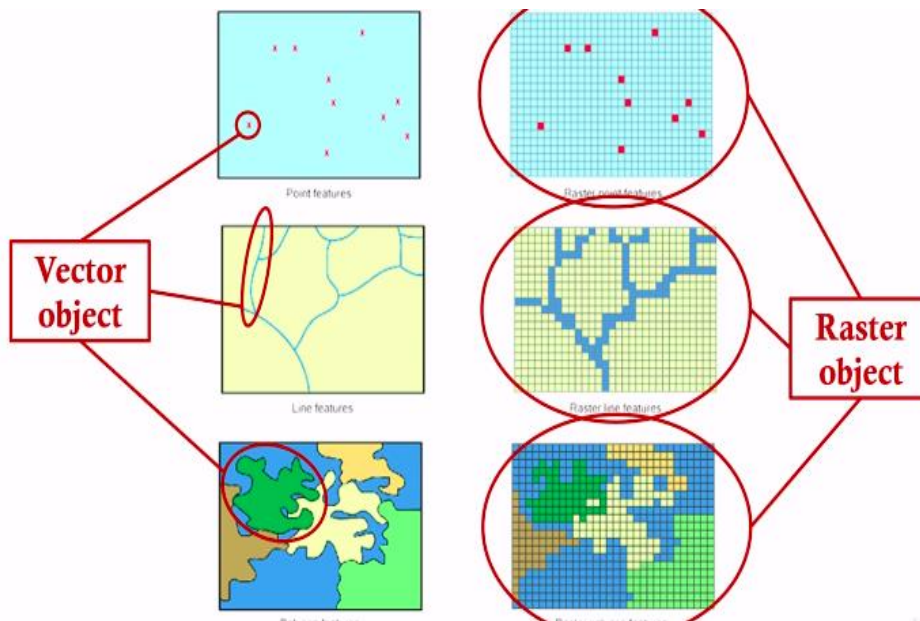


Figure 40: Spatial Data

Self-Assessment Exercise

Differentiate spatial from non-spatial data.

5.3.2 Soilgrids250m as a Product of Spatial Modeling

SoilGrids produces maps of soil properties for the entire globe at medium spatial resolution (250 m cell size) using state-of-the-art machine learning methods to generate the necessary models. It takes as inputs soil observations from about 240 000 locations worldwide and over 400 global environmental covariates describing vegetation, terrain morphology, climate, geology and hydrology. The workflow of the methodological approach of the modeling process is shown in Figure 41.

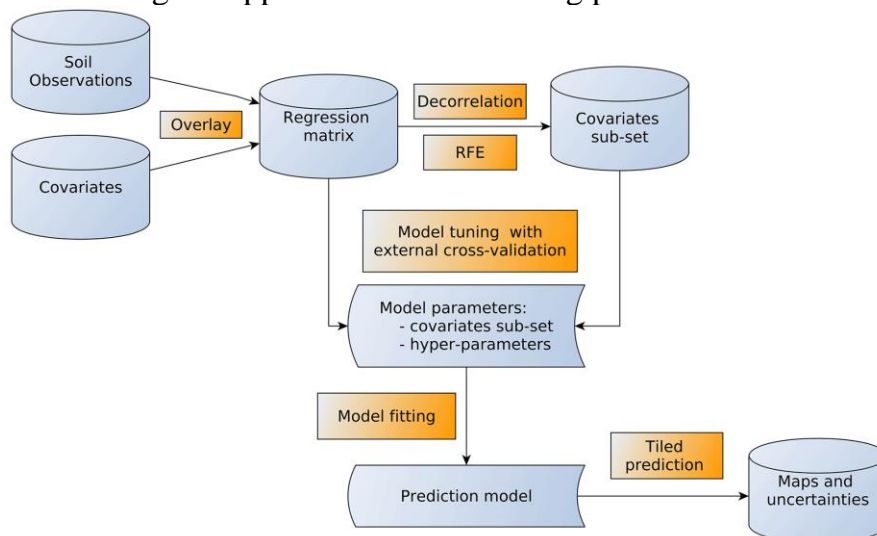


Figure 41: Workflow of the methodological approach

5.3.2.1 Soil Properties

For the purposes of SoilGrids, “soil” is up to 2 m thick unconsolidated material at the Earth's epidermis in direct contact with the atmosphere; thus, subaqueous and tidally exposed soils are not considered here. Neither are materials deeper than 2 m. This decision has consequences for computations of total stocks, in particular soil organic carbon.

Table 3 describes the soil properties that are considered in this version of SoilGrids: organic carbon content, total nitrogen content, soil pH (measured in water), cation exchange capacity, soil texture fractions and proportion of coarse fragments. These properties were modelled for the six standard depths intervals: 0–5, 5–15, 15–30, 30–60, 60–100 and 100–200 cm. Figure 42 shows the observation density of these soil parameters.

Table 3: Modeled Soil Properties

Soil property	Acronym	Units	Mapped units	Description
Bulk density	BDOD	kg/dm ³	cg/cm ³	Bulk density of the fine earth fraction oven dry
Cation exchange capacity	CEC	cmol(c)/kg	mmol(c)/kg	Capacity of the fine earth fraction to hold exchangeable cations
Coarse fragments	CFVO	cm ³ /100 cm ³ (volume %)	cm ³ /dm ³	Volumetric content of fragments larger than 2 mm in the whole soil
Nitrogen	N	g/kg	cg/kg	Sum of total nitrogen (ammonia, organic and reduced nitrogen) as measured by Kjeldahl digestion plus nitrate–nitrite
pH (water)	pH	–	10*	Negative common logarithm of the activity of hydronium ions (H ⁺) in water
Organic carbon concentration	SOC	g/kg	dg/kg	Gravimetric content of organic carbon in the fine earth fraction of the soil
Soil texture fraction	STF	%	g/kg	Gravimetric contents of sand, silt and clay in the fine earth fraction of the soil

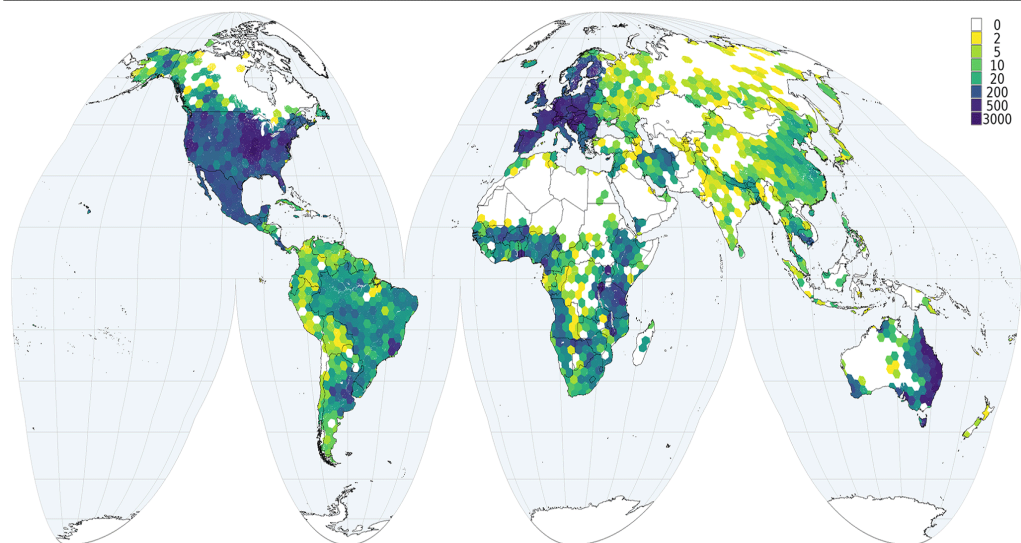


Figure 42: Observation Density of the Soil Parameters

Self-Assessment Exercise

What are the different SoilGrids depth intervals available?
List four soil properties whose data are available on SoilGrids.

5.3.2.2 Environmental Covariates

Over 400 geographic layers were available as environmental covariates for this work. These were chosen for their presumed relation to the major soil forming factors, including long-term soil conditions, i.e., the “time” factor. The layers considered can be grouped as follows.

1. **Climate:** temperature, precipitation, snowfall, cloud cover, solar radiation, wind speed;
2. **Ecology:** bioclimatic zones and eco-physiographic regions;
3. **Geology:** soil and sedimentary thickness, rock types;
4. **Land use and cover:** from sources such as the European Space Agency (ESA) and U.S. Geological Survey (USGS);
5. **Elevation and terrain morphology:** including numerous morphology indexes and landform classes;
6. **Vegetation indexes:** such as the normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and net primary production (NPP);
7. **Raw bands from Landsat and MODIS products;**
8. **Hydrography:** global water table, inundation and glacier extent, and surface water change.

The average and standard deviation of climatic variables and vegetation indices over 15 years (2001–2015) were computed from monthly data to capture their seasonal dynamics.

All covariates were projected to a common coordinate reference system (CRS), i.e., Goode's homolosine projection for land masses applied to the WGS84 datum. This projection was selected since among the equal-area projections supported by open-source software it is the most effective minimizing distortions over land (Poggio et al., 2021). The projected covariates were imported to GRASS GIS in a normalized raster structure with cells of 250 m by 250 m. Covariates, and hence mapped areas, were restricted to land areas without built-up, water and glacier areas using a mask created from the ESA Land Cover layer for 2015 (Poggio et al., 2021). Thus, properties of urban and subaqueous soils are not considered.

Self-Assessment Exercise

Outline five groups of layers that were used as environmental covariates in the SoilGrids modelling process.

5.3.2.3 Soilgrids250m Data

The mathematical equations generated from the random forest regression between the data from the known sites (Figure 43) and the covariates is then used to generate data for the entire globe. This was achieved because the covariates (mostly remote sensed data) had global coverage; the unknown (dependent variable) is the soil data, which can then be calculated using the mathematical formula.

The final outputs were maps of the soil properties shown in Table 3, for different depths. In general, the least sampled areas present the highest prediction uncertainties. Figure 43 shows a resultant maps of mean soil organic carbon content (dg/kg) and uncertainties in the 5 to 15 cm depth interval.

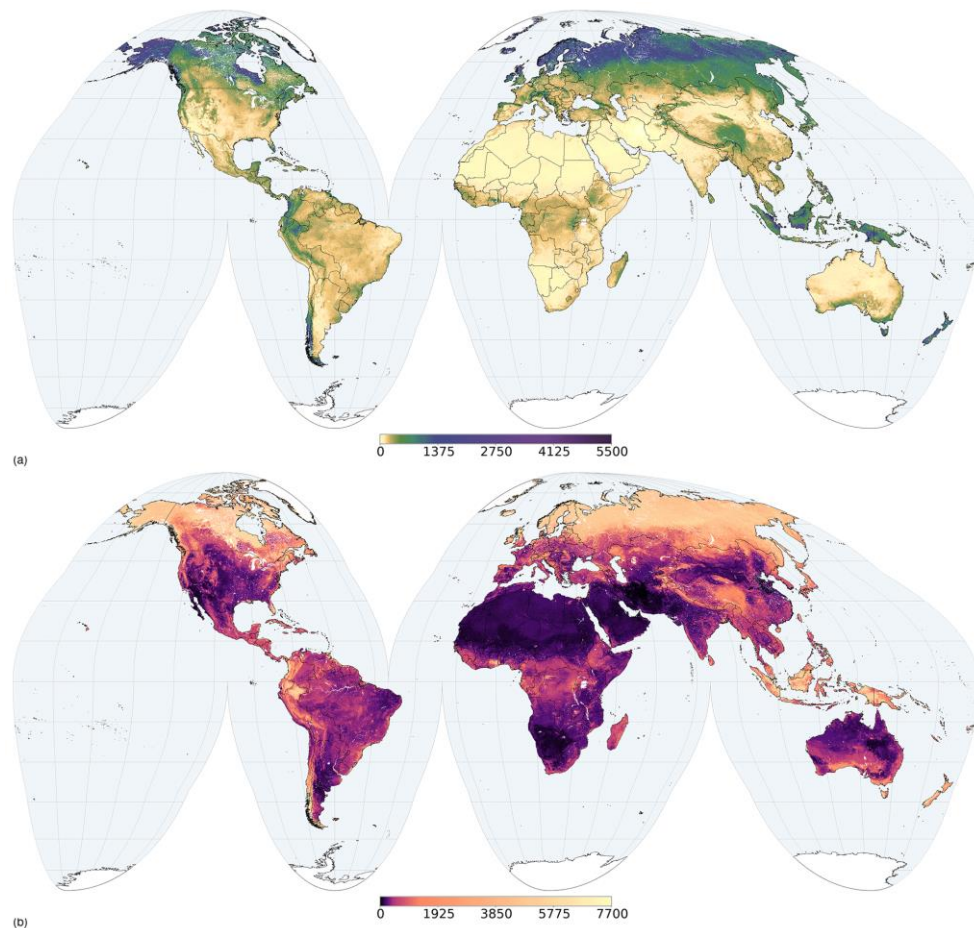


Figure 43: Mean soil organic carbon content (dg/kg) prediction in the 5 to 15 cm depth interval, (a) for prediction and (b) for interquartile range.

5.4 Conclusion

The SoilGrids250m data is a global online soil database containing raster maps of soil classes and properties at a spatial resolution of 250m. It was designed and managed by the International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands. The data can be downloaded from <https://soilgrids.org/>. It is worthy of note that the data may not be an accurate representation of soil properties around the world, but it is an approximate representation of field measurements. As such, for regions where soil data is scarce, inadequate or unavailable, the SoilGrids250m data can be used in lieu of field-generated soil data. The accuracy is however, not uniform across the globe. It is more accurate in regions from which the denser collection of soil profile data were collected in the course of building the model. To improve the accuracy of the dataset, it may need to be calibrated for specific sites using field-generated data.

5.5 Summary

From this unit, you have learnt about the spatial modeling. Some of the key things learnt include the following;

- Non-spatial data/models
- Spatial data/models
- SoilGrids250m as a product of spatial modeling
- Soil properties
- Environmental covariates
- SoilGrids250m data

5.6 Tutor-Marked Assignment

1. Briefly discuss:
 - a) Non-spatial models
 - b) Spatial models.
2. Discuss the operations of the SoilGrids250m from the perspectives of
 - a) Soil properties
 - b) Environmental covariates
 - c) SoilGrids250m data

5.7 References/Further Reading/Web Resources

Bickel, P. Diggle, P. Fienberg, S., Gather, U., Olkin, I. and Zeger, S. (2005) *Lecture Notes in Statistics*. New York, USA: Springer.

Freeden, W., Nashed, M.Z. and Sonar, T. (2015) *Handbook of Geomathematics*. Berlin, Germany: Springer-Verlag.

Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., and Rossiter, D. (2021) SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty, *SOIL*, 7, 217–240, <https://doi.org/10.5194/soil-7-217-2021>.

5.8 Possible Answers to Self-Assessment Exercise(S) Within the Content

1. Differentiate spatial from non-spatial data.
Spatial data (also known as geospatial data), is a term used to describe any data related to or containing information about a specific location on the Earth's surface, while non-spatial data is data that is independent of geographic location.
- 2a. What are the different SoilGrids depth intervals available?
 - i) 0–5
 - ii) 5–15
 - iii) 15–30
 - iv) 30–60
 - v) 60–100
 - vi) 100–200 cm
- b. List four soil properties whose data are available on SoilGrids.
 - i) *Cation Exchange Capacity*
 - ii) *Organic Carbon*
 - iii) *Sand*
 - iv) *Silt*
 - v) *Clay*
3. Outline five groups of layers that were used as environmental covariates in the SoilGrids modelling process.
 - i) *Climate*
 - ii) *Ecology*
 - iii) *Geology*
 - iv) *Land use/land cover*
 - v) *Elevation data.*