UPR316

PRINCIPLES OF GIS AND AUTOCAD

Course code: URP 316
Course title: Principles of GIS and AutoCAD
Course credit load: 2 Units

List of Series:

- **Series 1:** Fundamentals and Components of GIS
- Series 2: Spatial Data Models and Database Structures
- Series 3: GIS Operations, Editing and Accuracy
- Series 4: Integration of Remote Sensing, GPS and GIS
- Series 5: Traditional Urban Design in Accuracy Cities

1 Fundamentals and Components of GIS

Series Outline

- **Part 1 (1.1):** Introduction to Geographic Information Systems
  - **Sub-Part 1.1.1:** Definition, nature, and scope of GIS
  - **Sub-Part 1.1.2:** GIS and related technologies: distinctions and relationships
  - **Sub-Part 1.1.3:** Applications of GIS in urban and regional planning
- **Part 2 (1.2):** Components of a GIS
  - **Sub-Part 1.2.1:** Hardware components of a GIS
  - **Sub-Part 1.2.2:** Software components of a GIS
  - **Sub-Part 1.2.3:** Data, people, and procedures as GIS components
- **Part 3 (1.3):** Coordinate Systems and Map Projections
  - **Sub-Part 1.3.1:** Geographic coordinate systems
  - **Sub-Part 1.3.2:** Projected coordinate systems
  - **Sub-Part 1.3.3:** Map projections used in Nigerian mapping
- **Part 4 (1.4):** GIS Software and Data Sources
  - **Sub-Part 1.4.1:** GIS software: types and common platforms
  - **Sub-Part 1.4.2:** Primary and secondary GIS data sources
  - **Sub-Part 1.4.3:** Data quality, metadata, and standards

Introduction

Geographic Information Systems have transformed the way planners, engineers, and policy-makers understand and manage the built and natural environment. A GIS does far more than display a map on a screen it integrates spatial data with descriptive information, enabling users to ask complex questions about where things are, why they are there, and what might happen if conditions change. For urban and regional planners working in Nigeria, command of GIS is no longer optional; it is a professional necessity.

The aim of this Series is to introduce you to the fundamental concepts, components, and technical foundations of Geographic Information Systems, equipping you to understand what a GIS is, how it is structured, and how it is applied in planning practice.

We shall commence this Series by introducing GIS its definition, nature, scope, and relationship to related technologies. Next, we will examine the five components of a GIS: hardware, software, data, people, and procedures. Following that, we will explore coordinate systems and map projections, with particular attention to the systems used in Nigerian mapping. Finally, we will examine GIS software platforms and the primary and secondary data sources available to planners, concluding with the concepts of data quality and metadata.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define GIS and describe its nature, scope, and relationship to related technologies,
- **SLO 1.2** explain the five components of a GIS (Hardware, Software, Data, People, and Procedures) and describe their roles in spatial analysis,
- **SLO 1.3** explain the concepts of coordinate systems and map projections and identify those used in Nigerian mapping,
- **SLO 1.4** identify common GIS software platforms, describe the principal sources of GIS data, and explain the importance of data quality and metadata.

1.1 Introduction to Geographic Information Systems

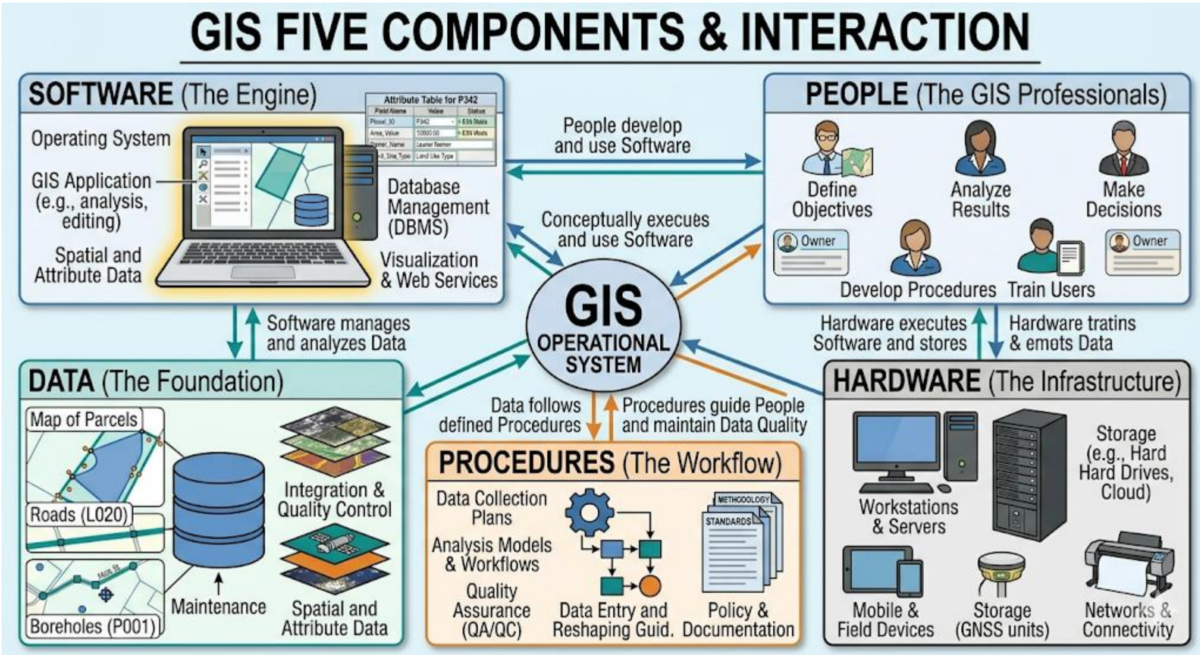
1.1.1 Definition, nature, and scope of GIS

Geographic Information Systems (GIS) is an integrated system of hardware, software, data, people, and procedures designed to capture, store, manage, analyse, and display all forms of geographically referenced information. Unlike a simple digital map, which merely displays spatial features, a GIS links every spatial feature to an **attribute table** a database of descriptive information enabling users to query, analyse, and model spatial relationships.

The **nature** of GIS is integrative: it brings together geography, database management, and analytical computing into a single working environment. The **scope** of GIS extends from small-scale site analysis to national and continental datasets. A GIS can answer questions such as: Where is the nearest water main to a proposed development? Which residential areas fall within a 500-metre flood risk zone? How has land use in a city changed over 20 years?

GIS may be classified by its operational context. **Desktop GIS** (such as ArcGIS Pro and QGIS) runs on a workstation and provides full analytical capabilities. **Web GIS** delivers map and analysis services through a browser, enabling wider distribution of spatial information to non-specialist users. **Mobile GIS** applications support field data collection and real-time spatial queries on handheld devices.

Fill in the blank: Unlike a simple digital map, GIS links spatial features to an __________ table that stores descriptive information about each feature.



Short description: Diagram illustrating the five components of a GIS: hardware, software, data, people, and procedures, arranged to show how they interact within a complete GIS system.

Figure 1.1 The five components of a GIS and their interrelationships

1.1.2 GIS and related technologies: distinctions and relationships

GIS is frequently confused with related but distinct technologies. Understanding the differences and relationships is essential for professional practice.

- **GIS and CAD (Computer-Aided Design):** CAD is used to produce precise technical drawings of individual structures and engineering components. It represents geometry without geographic coordinates or attribute databases. GIS, by contrast, positions all features in geographic space and links them to queryable databases. CAD data can be imported into GIS once it has been georeferenced.
- **GIS and Remote Sensing:** Remote sensing collects data about the Earth's surface from sensors mounted on aircraft or satellites. The imagery and data produced by remote sensing are among the most important inputs to a GIS, providing current land cover, terrain elevation, and change detection data that cannot easily be collected by field survey alone.
- **GIS and GPS:** The **Global Positioning System (GPS)** is a satellite-based system that determines the precise geographic coordinates latitude, longitude, and elevation of points on the Earth's surface. GPS provides the field data collection capability that feeds locational information into a GIS database.
- **GIS and Database Management Systems (DBMS):** GIS relies on DBMS technology to store and manage the attribute data linked to spatial features. Modern GIS platforms such as ArcGIS and QGIS use spatial database engines including PostgreSQL/PostGIS to manage large, multi-user datasets.

Fill in the blank: GPS technology determines precise geographic __________ of points on the Earth's surface and provides field data collection capability for GIS.

1.1.3 Applications of GIS in urban and regional planning

GIS has become an indispensable tool in urban and regional planning practice. Its capacity to integrate, analyse, and visualise large volumes of spatially referenced data makes it applicable across every stage of the planning process.

- **Land use mapping and management:** GIS enables planners to map current land use, monitor changes over time, and assess compliance with approved development plans.
- **Infrastructure planning:** Road networks, utility corridors, drainage systems, and public facilities can be mapped, modelled, and optimised using GIS network analysis tools.
- **Environmental assessment:** GIS supports environmental impact analysis by overlaying proposed development footprints with environmental sensitivity maps, flood zones, and protected areas.
- **Population and demographic analysis:** Census and survey data can be spatially disaggregated to analyse population distribution, density, access to services, and patterns of growth.
- **Development control:** Planning applications can be assessed against zoning plans and land use policies held in a GIS database, improving the consistency and transparency of decisions.
- **Disaster risk management:** GIS is used to map hazard zones, model evacuation routes, and coordinate emergency response a growing priority in flood-prone and rapidly urbanising areas of Nigeria.

Fill in the blank: GIS supports environmental impact analysis by overlaying proposed development areas with environmental sensitivity maps and __________ zones.

Pilot questions 1.1

1. Define GIS and state two ways in which it differs from a simple digital map.
2. Distinguish between GIS and CAD, explaining the primary function of each.
3. State three applications of GIS in urban and regional planning.
4. *Fill in the blank: GPS technology determines precise geographic __________ of points on the Earth's surface and provides field data collection capability for GIS.*

1.2 Components of a GIS

1.2.1 Hardware components of a GIS

GIS hardware comprises all the physical devices used to input, process, store, and output spatial data. A GIS installation may range from a single workstation to a networked enterprise system serving many simultaneous users.

Input devices collect and transfer data into the GIS environment:

- **GPS receivers:** Handheld or vehicle-mounted GPS units collect precise point, line, and area coordinates in the field for direct import into GIS.
- **Digitizing tablets:** A **digitizer** (or digitising tablet) is a flat electronic board used to trace features from paper maps and convert them into digital vector coordinates.
- **Scanners:** Flatbed and drum scanners convert paper maps and aerial photographs into digital raster images for georeferencing and analysis.
- **Total stations and GNSS receivers:** Survey-grade instruments used for precise topographic and cadastral data collection.

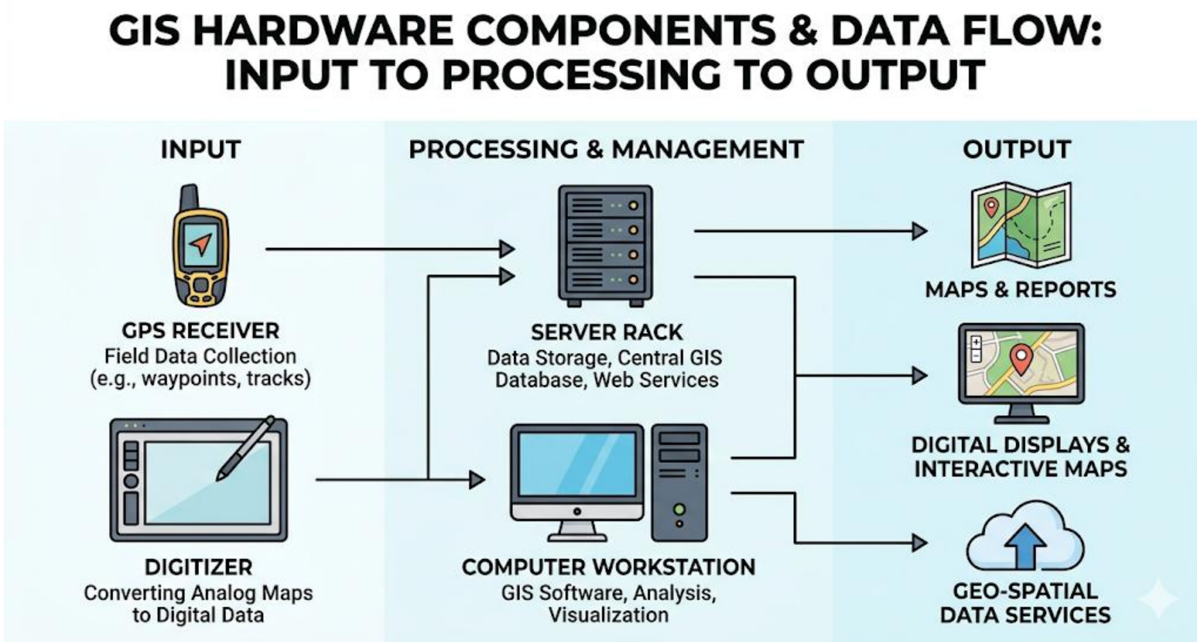
Processing and storage devices form the computational core of a GIS:

- **Workstations and servers:** High-performance computers with sufficient RAM (typically 16–64 GB for professional GIS), multi-core processors, and dedicated graphics cards to handle large spatial datasets and rendering operations.
- **Network infrastructure:** Local area networks (LAN) and internet connectivity allow GIS data and services to be shared between users and offices.
- **Storage systems:** Large-capacity hard drives, RAID arrays, and cloud storage hold spatial databases that may run to hundreds of gigabytes or terabytes.

Output devices communicate GIS results:

- **Plotters and large-format printers:** Produce paper maps and plans at A0 and larger formats required for planning presentations and public exhibitions.
- **Monitors:** High-resolution displays allow fine spatial detail and colour discrimination essential for map interpretation.

Fill in the blank: A digitizing tablet is used to trace features from paper maps and convert them into digital __________ coordinates.



Short description: Diagram showing the hardware components of a GIS system: a computer workstation, GPS receiver, digitizer, and server rack, arranged to show data flow through the system.

Figure 1.2 Hardware components of a GIS: input, processing, storage, and output devices

1.2.2 Software components of a GIS

GIS software provides the tools and interface through which users interact with spatial data. Modern GIS packages consist of several functional modules:

- **Data input and editing module:** Tools for digitising, importing, and editing spatial features and their attribute data.
- **Data storage and management module:** Manages the spatial database, handles projections and coordinate transformations, and enforces **topology** rules the geometric relationships (adjacency, connectivity, containment) that ensure data integrity.
- **Spatial analysis module:** Provides geoprocessing tools such as buffering, overlay, spatial query, network analysis, and terrain analysis.
- **Data output and display module:** Controls cartographic rendering, map production, and export to formats such as PDF, shapefile, and KML.

The most widely used GIS platforms include **ArcGIS** (Esri), the industry-standard proprietary platform used by most government agencies and large consulting firms; **QGIS**, the leading open-source GIS platform available free of charge and widely used in Nigerian universities and smaller planning offices; and **MapInfo**, a proprietary platform with a strong presence in local government and utility sectors.

Fill in the blank: Topology rules in GIS enforce geometric __________ between spatial features such as adjacency, connectivity, and containment, ensuring data integrity.

1.2.3 Data, people, and procedures as GIS components

Data is the most critical component of any GIS. Without accurate, current, and well-documented spatial data, even the most sophisticated hardware and software will produce misleading results. GIS data has two inseparable parts:

- **Spatial data:** Describes the location, shape, and extent of geographic features, stored as either **vector** (points, lines, polygons) or **raster** (grid cells) data models.
- **Attribute data:** Descriptive information linked to each spatial feature through the attribute table for example, the population of a ward, the width of a road, or the zoning classification of a land parcel.

People are the users who design, operate, and maintain a GIS. They include GIS analysts, planners, database administrators, field surveyors, and senior decision-makers who commission spatial analyses. The skill and judgement of the people operating a GIS determines the quality and usefulness of its outputs.

Procedures are the documented methods, workflows, and standards that govern how a GIS is operated consistently and correctly. In Nigerian planning agencies, well-defined procedures are essential because staff turnover, inconsistent data collection practices, and the absence of documentation have historically led to data loss and incompatible datasets. Procedures cover data naming conventions, projection standards, quality checking, backup schedules, and access permissions.

Fill in the blank: The three additional components of a GIS beyond hardware and software are data, people, and __________.

Pilot questions 1.2

1. Name four hardware input devices used in a GIS and state the primary function of each.

2. What is the difference between desktop GIS and web GIS?

3. *Fill in the blank: The three additional components of a GIS beyond hardware and software are data, people, and __________.*

4. Why are procedures described as essential to effective GIS use in Nigerian planning agencies?

5. State two core functional modules found in most GIS software packages.

1.3 Coordinate Systems and Map Projections

1.3.1 Geographic coordinate systems

A **coordinate system** is a reference framework that defines the position of every point on the Earth's surface using numerical values. Every GIS dataset must be associated with a defined coordinate system; without this, spatial data from different sources cannot be correctly overlaid or measured.

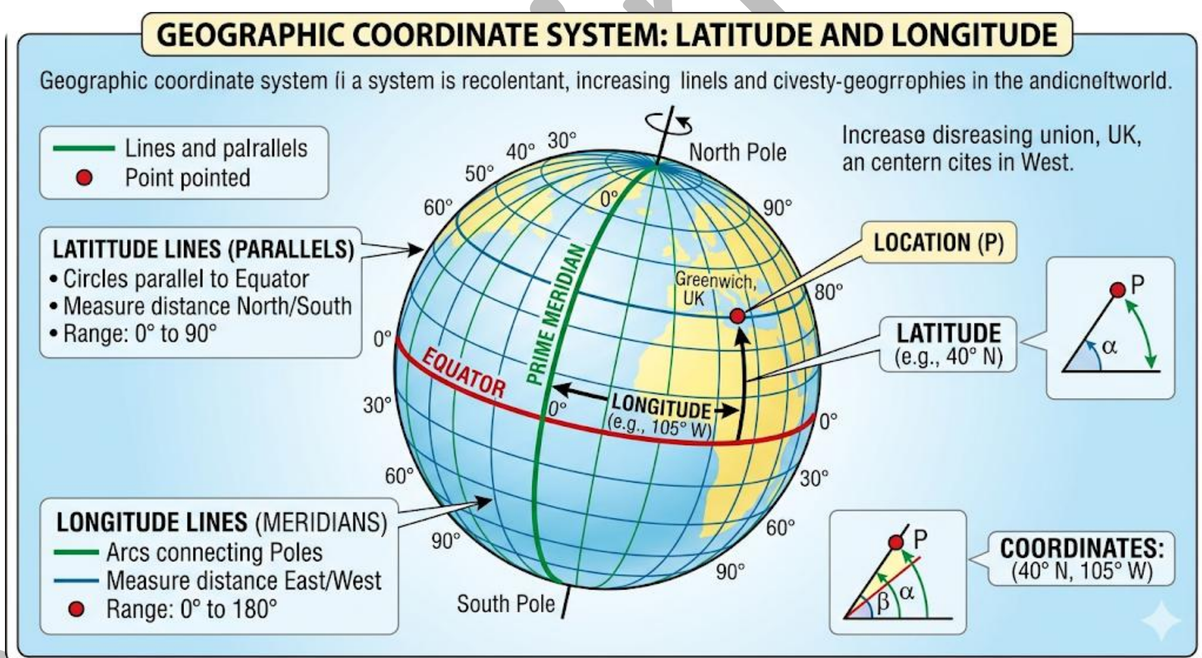
The **geographic coordinate system (GCS)** uses angular measurements **latitude** and **longitude** to locate positions on the three-dimensional surface of the Earth, modelled as a sphere or ellipsoid:

- **Latitude:** Angular distance north or south of the **Equator**, measured in degrees from 0° (Equator) to 90° (North or South Pole).
- **Longitude:** Angular distance east or west of the **Prime Meridian** (passing through Greenwich, England), measured in degrees from 0° to 180°.

Geographic coordinates identify any location on Earth uniquely. Nigeria's territory extends approximately from latitude 4°N to 14°N and from longitude 3°E to 15°E. The **datum** is the mathematical model of the Earth's shape and size that underlies a coordinate system. Two datums are important in Nigeria:

- **Minna datum:** Nigeria's national geodetic datum, based on the Clarke 1880 ellipsoid, used in all historical Surveyor-General maps and many legacy GIS datasets.
- **WGS84 (World Geodetic System 1984):** The global datum on which GPS and most modern satellite-derived datasets are based. All new GIS work in Nigeria should reference WGS84 or its equivalent, ITRF.

Fill in the blank: Nigeria's national geodetic datum, based on the Clarke 1880 ellipsoid and used in historical Surveyor-General maps, is called the __________ datum.



Short description: Diagram of the Earth showing latitude, longitude, the Prime Meridian, and the Equator, with angular measurements illustrating the geographic coordinate system.

Figure 1.3 The geographic coordinate system: latitude, longitude, Equator, and Prime Meridian

1.3.2 Projected coordinate systems

A **map projection** is a mathematical transformation that converts the curved surface of the Earth onto a flat (two-dimensional) plane. Because the Earth is curved, no flat map can represent all of distance, area, shape, and direction simultaneously without distortion; different projections make different trade-offs.

A **projected coordinate system (PCS)** uses linear units (metres or feet) rather than angular degrees, making it suitable for accurate distance and area calculations. The most important projected coordinate system in Nigerian GIS practice is the **Universal Transverse Mercator (UTM)** system:

- UTM divides the world into 60 numbered zones, each 6 degrees of longitude wide.
- Coordinates within each zone are expressed as **Easting** (distance east of the zone's central meridian, with a false easting of 500,000 m to avoid negative values) and **Northing** (distance north of the Equator).
- The **scale factor** at the central meridian is 0.9996, meaning distortion is minimised near the zone centre.

Fill in the blank: The Universal Transverse Mercator projection divides the world into __________ numbered zones each 6 degrees of longitude wide.

1.3.3 Map projections used in Nigerian mapping

Nigeria spans three UTM zones. Understanding which zone applies to a dataset is essential before any spatial measurement or overlay operation is performed.

Feature	Zone 31N	Zone 32N	Zone 33N
Central Meridian	3° E	9° E	15° E
Longitude Range	0° E to 6° E	6° E to 12° E	12° E to 18° E
False Easting (Origin)	500,000 m	500,000 m	500,000 m
False Northing (Origin)	0 m (Equator)	0 m (Equator)	0 m (Equator)
Scale Factor at CM	0.9996	0.9996	0.9996
Approx. Area Covered	Western Nigeria: Lagos, Abeokuta, Ibadan, Ilorin.	Central/Major Nigeria: Abuja, Kano, Kaduna, Port Harcourt.	Eastern border: Parts of Borno, Adamawa, Taraba.

Box 1.1 UTM zones covering Nigeria and their coordinate system parameters
Short description: A table summarising the three UTM zones covering Nigeria (31N, 32N, and 33N), showing for each zone the central meridian, easting and northing origin, and the approximate area of Nigeria covered.

Pilot questions 1.3

1. Define latitude and longitude and explain how together they identify a location on the Earth's surface.

2. What is a map projection and why is it necessary for displaying geographic data on a flat surface?

3. Fill in the blank: The Universal Transverse Mercator projection divides the world into __________ numbered zones each 6 degrees of longitude wide.

4. What is the Minna datum and why is it important for GIS work in Nigeria?

5. Why is it essential to identify the datum and projection of every GIS dataset before use?

1.4 GIS Software and Data Sources

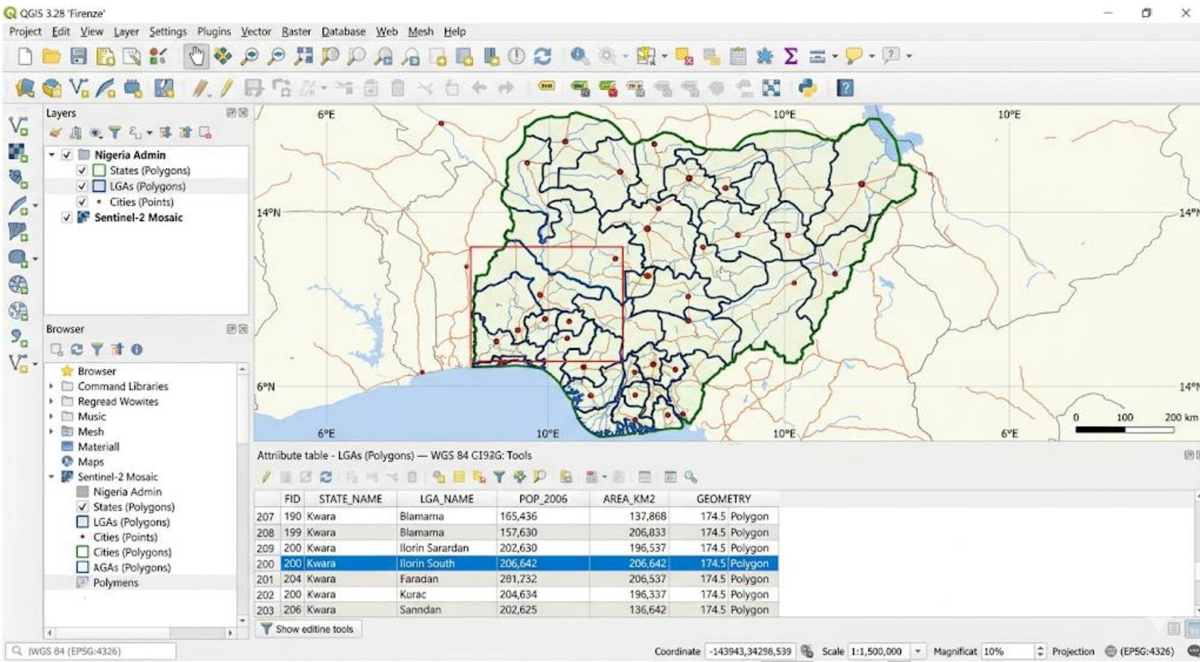
1.4.1 GIS software: types and common platforms

GIS software may be divided into two broad categories based on licensing and cost:

- **Proprietary GIS software:** Commercially licensed platforms sold by private companies. The market leader is **ArcGIS** (Esri), which offers a comprehensive suite of desktop, server, and web GIS tools. **MapInfo Pro** is another widely used proprietary platform, particularly in local government and utility sectors. Proprietary software is usually preferred by large government agencies and international consulting firms because of its technical support, comprehensive documentation, and established workflows.
- **Open-source GIS software:** Free-to-use platforms developed and maintained by communities of developers. **QGIS** is the most widely used open-source GIS, offering a full range of spatial analysis, data management, and cartographic tools. **GRASS GIS** provides advanced analytical capabilities for terrain analysis and environmental modelling. Open-source GIS is particularly important in Nigeria, where software licensing costs can be prohibitive for smaller planning offices and universities.

Both categories include **spatial analysis** tools, **geodatabase** management, and integration with remote sensing and GPS workflows. The choice between proprietary and open-source GIS should be based on institutional capacity, data formats, and budget, not on software loyalty.

Fill in the blank: GIS software may be divided into proprietary platforms (such as ArcGIS) and __________ platforms (such as QGIS) that are available free of charge.



Short description: A detailed screenshot of a QGIS or ArcGIS interface showing the layers panel, attribute table, and a map of Nigeria with administrative boundaries.

Plate 1.1 GIS software interface showing map display, layer panel, and attribute table

1.4.2 Primary and secondary GIS data sources

GIS data may be obtained from primary or secondary sources, each with distinct advantages and limitations.

Primary data sources are data collected directly by the user or organisation for a specific purpose:

- **GPS survey:** Field collection of point, line, and area coordinates using GPS or GNSS receivers. Produces highly accurate, current locational data but is time-consuming and costly for large areas.
- **Aerial photography and drone surveys:** High-resolution imagery captured by aircraft or unmanned aerial vehicles (UAVs). Supports feature extraction, orthophoto production, and 3D terrain modelling.
- **Field surveys and interviews:** Systematic enumeration, measurement, and community-level data collection that captures socioeconomic and environmental attributes not recorded in existing datasets.

Secondary data sources are data originally collected by other organisations for other purposes:

- **Government maps and datasets:** Topographic maps, cadastral plans, and administrative boundary data produced by Nigeria's Office of the Surveyor-General of the Federation (OSGOF) and state Ministries of Lands and Survey.

- **Satellite imagery:** Freely available imagery from platforms such as Landsat, Sentinel, and SRTM Digital Elevation Models (DEM) provides current land cover and terrain data at national and regional scales.
- **OpenStreetMap (OSM):** A collaborative, open-access spatial database of roads, buildings, land use, and amenities that provides valuable baseline mapping, particularly in areas with limited official coverage.
- **Census and statistical data:** Population counts, housing surveys, and socioeconomic indicators from the National Population Commission and National Bureau of Statistics can be linked to spatial units in a GIS.

Fill in the blank: OpenStreetMap is a collaborative, open-access spatial database of roads, buildings, and land use that is described as a __________ data source because it was collected independently of any single planning study.

1.4.3 Data quality, metadata, and standards

Data quality describes the fitness of a GIS dataset for its intended purpose. It has several key dimensions:

- **Positional accuracy:** How closely the mapped location of a feature matches its true location on the ground.
- **Attribute accuracy:** The correctness of the descriptive information stored in the attribute table.
- **Completeness:** The extent to which all required features and attributes are present in the dataset.
- **Consistency:** The absence of contradictions within the dataset for example, roads that do not connect where they should, or polygon boundaries that do not close.
- **Currency (Temporal accuracy):** Whether the data reflects the current state of the geographic features it represents.

Metadata is data about data: structured documentation that describes the content, source, date, coordinate system, accuracy, and limitations of a GIS dataset. Every dataset used in professional GIS work should be accompanied by metadata so that subsequent users can assess its suitability for their purposes. In Nigeria, poor metadata practices have been a significant barrier to data sharing between agencies and to the reuse of expensive survey data.

Fill in the blank: __________ is structured documentation that describes the content, source, date, coordinate system, accuracy, and limitations of a GIS dataset.

Pilot questions 1.4

1. What is the difference between proprietary and open-source GIS software?

2. Name two primary and two secondary sources of GIS data relevant to planning work in Nigeria.

3. Define data quality and name three of its principal dimensions.

4. What is metadata and why is it important in GIS?

5. Fill in the blank: Metadata describes the content, source, date, coordinate system, accuracy, and __________ of a GIS dataset, enabling subsequent users to assess its suitability.

Series Summary

This Series has introduced you to the fundamental concepts and technical foundations of Geographic Information Systems. We began by defining GIS distinguishing it from related technologies such as CAD, remote sensing, and GPS and identifying its principal applications in urban and regional planning, including land use mapping, infrastructure planning, environmental assessment, and development control.

We then examined the five components of a GIS: hardware (input, processing, storage, and output devices); software (including the data input, storage, analysis, and output modules of platforms such as ArcGIS and QGIS); data (spatial and attribute data in vector and raster formats); people (analysts, planners, field surveyors, and decision-makers); and procedures (documented workflows and standards essential for data consistency and institutional continuity).

Next, we explored coordinate systems and map projections, distinguishing between geographic coordinate systems which use latitude and longitude referenced to datums such as the Minna datum (Clarke 1880) and WGS84 and projected coordinate systems such as the **Universal Transverse Mercator (UTM)**, which expresses positions in metres and covers Nigeria across three zones (31N, 32N, and 33N). Finally, we examined GIS software platforms, contrasting proprietary (ArcGIS, MapInfo) and open-source (QGIS, GRASS) options, and described primary data sources GPS survey, aerial photography, and field survey alongside secondary sources including government maps, satellite imagery, OpenStreetMap, and census data. We concluded by explaining **data quality** dimensions and the critical role of **metadata** in ensuring that datasets can be correctly interpreted, shared, and reused.

By engaging with these topics, you should now be able to define GIS and distinguish it from related technologies, explain the five GIS components and their roles, identify the coordinate systems and datums used in Nigerian mapping, and evaluate GIS software and data sources for planning applications as outlined in the Series Learning Outcomes.

Glossary of Terms

- **Attribute table:** A database table linked to a GIS layer in which each row represents a spatial feature and each column stores a descriptive attribute of that feature.
- **Coordinate system:** A reference framework that defines the position of every point on the Earth's surface using numerical values, based on a defined datum and projection.
- **Datum:** A mathematical model of the Earth's shape and size that forms the basis of a coordinate system. Important examples in Nigeria include the Minna datum (Clarke 1880) and WGS84.
- **Desktop GIS:** GIS software installed and run on a single workstation, providing full spatial analysis and cartographic capabilities without requiring internet connectivity.
- **Digitizer:** An input device (digitising tablet) used to trace features from paper maps and convert them into digital vector coordinates for use in a GIS.

- **Easting:** The horizontal coordinate in a projected coordinate system, representing the distance east of a defined origin or central meridian, expressed in metres.
- **Geographic coordinate system (GCS):** A coordinate system that uses latitude and longitude (angular measurements) to locate positions on the three-dimensional surface of the Earth.
- **Geographic Information System (GIS):** An integrated system of hardware, software, data, people, and procedures for capturing, storing, managing, analysing, and displaying geographically referenced information.
- **Georeferencing:** The process of assigning geographic coordinates to a raster image (such as a scanned map or aerial photograph) so that it aligns correctly with other spatial data in a GIS.
- **Map projection:** A mathematical transformation that converts the curved three-dimensional surface of the Earth onto a flat two-dimensional plane for mapping and analysis.
- **Metadata:** Structured documentation that describes the content, source, date, coordinate system, accuracy, and limitations of a GIS dataset.
- **Minna datum:** Nigeria's national geodetic datum, based on the Clarke 1880 ellipsoid, used as the basis for all historical Surveyor-General topographic and cadastral mapping.
- **Northing:** The vertical coordinate in a projected coordinate system, representing the distance north of a defined origin (typically the Equator), expressed in metres.
- **Raster:** A spatial data model that represents the world as a regular grid of cells (pixels), each assigned a single value. Used for continuous data such as elevation, satellite imagery, and land cover.
- **Spatial query:** An operation in a GIS that selects features based on their spatial relationship to other features for example, selecting all buildings within 200 metres of a proposed road.
- **Topology:** The geometric rules that define and enforce spatial relationships between GIS features, such as adjacency (features share a boundary), connectivity (lines connect at nodes), and containment (a point lies within a polygon).
- **Universal Transverse Mercator (UTM):** A projected coordinate system that divides the world into 60 zones each 6 degrees of longitude wide, expressing positions in metres of Easting and Northing.
- **Vector:** A spatial data model that represents geographic features as discrete geometric objects points (for locations), lines (for linear features), and polygons (for area features).
- **Web GIS:** GIS services delivered through a web browser, enabling spatial data and analysis tools to be shared with a wide audience without requiring specialist desktop software.
- **WGS84 (World Geodetic System 1984):** The global geodetic datum used by GPS and most modern satellite-derived datasets, adopted as the standard for all new GIS work in Nigeria.

Concept Check Questions 1

Objective Questions

1. Define GIS and state two differences from a digital map. (Linked to SLO 1.1)

2. Name the five GIS components and describe the role of each. (Linked to SLO 1.2)

3. Fill in the blank: The global geodetic datum on which GPS coordinates are based is __________. (Linked to SLO 1.3)

4. State one advantage of open-source GIS for Nigerian planning agencies. (Linked to SLO 1.4)

Short-Answer Questions

5. Distinguish between geographic and projected coordinate systems, and explain why projected coordinates are preferred for measuring distances and areas. (Linked to SLO 1.3)

6. Describe the five components of a GIS, noting which component most directly affects the quality of GIS outputs. (Linked to SLO 1.2)

7. Compare primary and secondary GIS data sources relevant to planning work in Nigeria, giving two examples of each with their advantages and limitations. (Linked to SLO 1.4)

8. Identify three principal dimensions of GIS data quality and explain why metadata is essential for professional GIS practice. (Linked to SLO 1.4)

Long-Answer Questions

9. Explain why coordinate systems and map projections are fundamental to GIS practice, describe the systems used in Nigerian mapping, and discuss the problems that arise when datasets in different coordinate systems are combined without transformation. (Linked to SLO 1.3)

10. Evaluate the strengths and limitations of open-source and proprietary GIS software for planning practice in Nigeria, considering cost, functionality, technical support, and institutional capacity. (Linked to SLO 1.4)

Answers to Concept Check Questions 1

Objective Questions

1. GIS integrates hardware, software, data, people, and procedures to capture, store, analyse, and display spatial data. Unlike a digital map, GIS links attributes to spatial features and enables spatial queries and analysis.

2. Hardware: physical devices for input, processing, storage, and output. Software: tools for analysis and display. Data: spatial and attribute information. People: users who design, operate, and interpret. Procedures: documented workflows and standards.

3. WGS84.

4. Open-source GIS (e.g., QGIS) is free of licensing costs, making it accessible to smaller planning offices and universities that cannot afford proprietary licences.

Short-Answer Questions

5. Geographic coordinate systems use latitude and longitude on the Earth's curved surface. Projected systems flatten this into metres, making distance and area calculations easier.

6. Hardware runs processes, software provides tools, people operate and interpret, procedures ensure consistency. Data is most critical—poor data gives poor results.

7. Primary sources: GPS (accurate, costly), aerial photos (detailed, expensive). Secondary sources: government maps (wide coverage, outdated), OpenStreetMap (free, variable accuracy).

8. Data quality: accuracy, completeness, currency. Metadata records origin, date, coordinate system, and limitations; without it, data may be misused.

Long-Answer Questions

9.

- **Basic response:** Coordinate systems allow GIS datasets to align correctly. In Nigeria, older maps use the Minna datum, while modern GPS and satellite data use WGS84. The country falls within UTM zones 31N, 32N, and 33N. Mixing datasets without proper transformation causes positional errors that can invalidate analysis.
- **Value-added response:** Extend the discussion by explaining transformation methods (datum transformation parameters, Helmert transformation), noting that Minna-to-WGS84 transformation errors in Nigeria can reach 50–100 metres if incorrect parameters are used. Discuss the implications for cadastral boundary disputes, infrastructure alignment, and development control decisions.

10.

- **Basic response:** Proprietary GIS (ArcGIS) offers comprehensive tools, technical support, and established workflows but requires expensive licences. Open-source GIS (QGIS) is free and increasingly capable but may have less institutional support and a steeper learning curve for complex workflows. In Nigeria, cost is a major consideration for smaller agencies.
- **Value-added response:** Discuss interoperability both platforms support standard data formats (shapefile, GeoPackage, GeoTIFF), reducing lock-in. Consider the growing QGIS plugin ecosystem, which provides specialist tools for planning analysis. Address the training and institutional capacity needed to maintain either platform, and propose a hybrid approach where appropriate: QGIS for routine analysis and data management, and web-based ArcGIS Online for sharing outputs with stakeholders and the public.

Answers to Pilot Questions 1

Part 1.1

1. GIS captures, stores, analyses, and displays spatial data; unlike digital maps, it links attributes and supports queries.
2. CAD makes precise drawings without geographic coordinates or databases; GIS uses geographic space with linked attributes for analysis.
3. Any three: land use mapping, infrastructure planning, environmental assessment, development control, population analysis, disaster management.
4. Coordinates: latitude, longitude, elevation.

Part 1.2

1. Any four: GPS receiver, digitising tablet, scanner, total station, aerial photography.

2. Desktop GIS: full tools on one computer, offline. Web GIS: browser-based, wider access.
3. Procedures.
4. In Nigeria, poor documentation and turnover caused data loss; procedures ensure consistency.
5. Any two: input/editing, storage/management, spatial analysis, output/display.

Part 1.3

1. Latitude: distance north/south of Equator. Longitude: distance east/west of Prime Meridian. Together locate any point.
2. Map projection: transforms Earth's curved surface to flat plane for display and measurement.
3.

60.

4. Minna datum (Clarke 1880) used in historic maps; mixing with WGS84 without transformation causes errors.
5. Different datums/projections misalign datasets, leading to analysis and planning errors.

Part 1.4

1. Proprietary GIS: licensed, full support, costly. Open-source GIS: free, community-driven, requires capacity.
2. Primary: GPS, aerial/drone survey. Secondary: government maps, OpenStreetMap.
3. Any three: positional accuracy, attribute accuracy, completeness, consistency, currency.
4. Metadata records source, date, CRS, accuracy, limitations; ensures correct use.
5. Limitations.

References and Attributions 1

Course Content References

- Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Hoboken, NJ: Wiley.
- Esri. (2023). *ArcGIS Pro documentation.* Retrieved from https://pro.arcgis.com/en/pro-app/latest/help/main/welcome-to-the-arcgis-pro-app-help.htm
- QGIS Development Team. (2024). *QGIS user guide.* Retrieved from https://docs.qgis.org
- Federal Surveys of Nigeria. (1966). *Topographic maps of Nigeria (1:50,000 series, Minna datum).* Lagos: Federal Surveys.

Illustrations

- *Figure 1.1* The five components of a GIS and their interrelationships.
  - AI-generated prompt: "Generate a diagram showing the five components of a GIS hardware, software, data, people, and procedures arranged to show how they interact within a complete GIS system."
  - Suggested OER search string: "GIS five components hardware software data people procedures diagram OER."
- *Figure 1.2* Hardware components of a GIS: input, processing, storage, and output devices.

- AI-generated prompt: "Generate a diagram showing a computer workstation, GPS receiver, digitizer, and server rack as hardware components of a GIS, with arrows showing data flow from input to processing to output."
- Suggested OER search string: "GIS hardware components workstation GPS receiver digitizer server diagram OER."

- *Figure 1.3* The geographic coordinate system: latitude, longitude, Equator, and Prime Meridian.
  - AI-generated prompt: "Generate a diagram of a globe showing latitude lines, longitude lines, the Equator, the Prime Meridian, and the angular measurement of a specific location by its latitude and longitude coordinates."
  - Suggested OER search string: "geographic coordinate system latitude longitude equator prime meridian globe diagram OER."
- *Box 1.1* UTM zones covering Nigeria and their coordinate system parameters.
  - AI-generated prompt: "Generate a map of Nigeria showing the three UTM zones (31N, 32N, and 33N) as coloured bands with their central meridians and approximate area coverage labelled."
  - Suggested OER search string: "UTM zones Nigeria map 31N 32N 33N coordinate system OER."
- *Plate 1.1* GIS software interface showing map display, layer panel, and attribute table.
  - AI-generated prompt: "Generate a detailed screenshot of a QGIS or ArcGIS interface showing the layers panel on the left, a map of Nigeria with administrative boundaries in the centre, and an open attribute table at the bottom."
  - Suggested OER search string: "QGIS ArcGIS interface screenshot layers panel attribute table Nigeria map OER."

Attributions

- All AI prompts are intended for use with generative tools to create original illustrations.
- Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.

Course code: URP 316
Course title: Principles of GIS and AutoCAD
Course credit load: 2 Units

List of Series:

- Series 1: Fundamentals and Components of GIS
- **Series 2: Spatial Data Models and Database Structures**
- Series 3: GIS Operations, Editing and Accuracy Assessment
- Series 4: Integration of Remote Sensing, GPS and GIS
- Series 5: GIS Applications in Urban and Regional Planning

2 Spatial Data Models and Database Structures

Series outline

- **Part 1 (2.1): Vector Data Model**
  Sub-Part 2.1.1: Principles of the vector data model
  Sub-Part 2.1.2: Points, lines, and polygons
  Sub-Part 2.1.3: Topology in vector GIS
- **Part 2 (2.2): Raster Data Model**
  Sub-Part 2.2.1: Principles of the raster data model
  Sub-Part 2.2.2: Raster resolution, cell size, and data types
  Sub-Part 2.2.3: Vector and raster compared
- **Part 3 (2.3): Spatial Database Structures**
  Sub-Part 2.3.1: File-based and geodatabase formats
  Sub-Part 2.3.2: Relational database concepts in GIS
  Sub-Part 2.3.3: Spatial indexing and query
- **Part 4 (2.4): Attribute Data and Table Management**
  Sub-Part 2.4.1: Attribute tables and field types
  Sub-Part 2.4.2: Joining and relating tables
  Sub-Part 2.4.3: Data classification and symbology

Introduction

Every map you see in a planning report, on your phone, or in a GIS application is underpinned by one of two fundamental ways of encoding geographic reality in digital form. Before GIS can analyse data, generate maps, or answer spatial questions, it must first represent the real world as structured digital information and the choice of how to do this profoundly affects what you can see, measure, and analyse. Understanding spatial data models is therefore not a technical detail to be memorised; it is the conceptual foundation upon which all GIS work rests.

The aim of this Series is to introduce you to the principal spatial data models used in GIS the Vector and Raster models the database structures through which spatial data is organised, and the principles of attribute data management and cartographic classification.

We shall commence this Series by examining the **Vector Data Model** describing its principles and the three fundamental geometry types of point, line, and polygon, and explaining the role of topology in ensuring spatial integrity. Next, we will explore the **Raster Data Model** covering how continuous surfaces are encoded as grids of cells, how resolution and cell size affect the level of detail captured, and how vector and raster approaches compare. Following that, we will examine **Spatial Database Structures** contrasting file-based formats such as the shapefile with modern geodatabase containers, and introducing the relational database concepts and SQL queries that power GIS data management. Finally, we will wrap up by exploring **Attribute Data and Table Management** covering field types, table joins and relates, and the classification and symbology techniques used to communicate spatial patterns through maps.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** describe the vector data model and identify the three fundamental geometry types and the role of topology,
- **SLO 2.2** explain the principles, resolution, and applications of the raster data model,

- **SLO 2.3** describe the principal spatial database structures and explain the relational database concepts used in GIS,
- **SLO 2.4** manage attribute data in a GIS, including creating and editing tables, performing joins, and applying data classification and symbology.

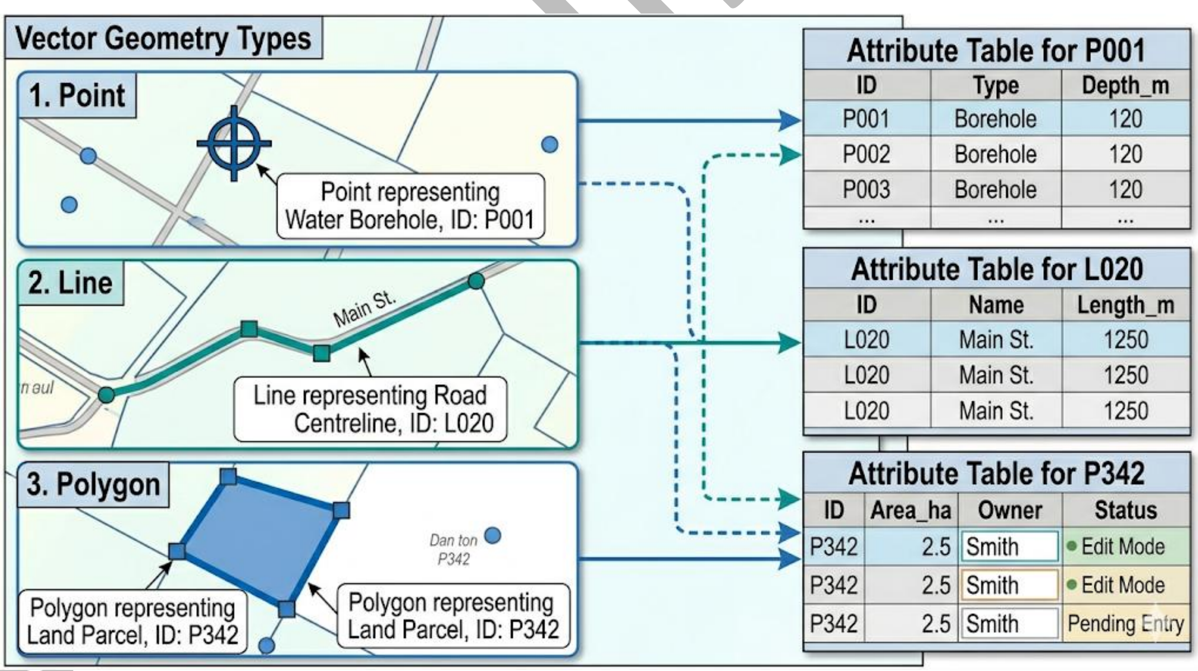
2.1 Vector Data Model

2.1.1 Principles of the vector data model

The **vector data model** represents geographic features as precisely defined geometric objects located in two-dimensional or three-dimensional space. Unlike approaches that approximate the world as a grid of equal-sized cells, the vector model encodes features as **discrete objects** each with a defined shape, a precise location, and a set of descriptive attributes stored in a linked table. This makes it ideally suited to representing features that have sharp, definable boundaries: a property parcel, a road centreline, a building footprint, an administrative boundary.

In the vector model, every feature is defined by its **coordinates** pairs of x and y values (or x, y, z for three-dimensional data) that fix positions in a defined coordinate reference system. The model is efficient because it stores only the coordinates that define the shape of a feature, not the empty space around it. A single road, for example, may be stored as a sequence of just a few dozen coordinate pairs rather than as thousands of cells.

Fill in the blank: The vector data model represents features as discrete __________ objects, each defined by coordinates and linked to descriptive attributes.



Short description: Diagram showing examples of the three vector geometry types: a point representing a borehole, a line representing a road, and a polygon representing a land parcel, each with an associated attribute table.

Figure 2.1 The three vector geometry types: point, line, and polygon with attribute tables

2.1.2 Points, lines, and polygons

All vector features belong to one of three fundamental geometry types: **points**, **lines** (also called polylines), and **polygons**. These three types are sufficient to represent any geographic phenomenon that has a definable location and boundary.

A point is defined by a single x,y coordinate pair. Points represent features whose area is too small to be mapped at a given scale, or whose location rather than extent is the primary attribute of interest. In urban and regional planning, points typically represent features such as boreholes, utility poles, school locations, or spot heights on a contour survey.

A line (or polyline) is defined by an ordered sequence of x,y coordinate pairs called **vertices**, connected by straight segments. Lines represent linear features such as roads, rivers, pipelines, electricity transmission lines, and cadastral boundaries. The accuracy of a line feature depends on the density of vertices: more vertices capture greater geometric complexity, but also increase file size.

A polygon is a closed line a sequence of vertices in which the first and last coordinates are identical, enclosing an area. Polygons represent features with measurable extent: land parcels, land use zones, administrative areas, building footprints, and conservation areas. Each polygon has both an interior (the area enclosed) and a boundary (the perimeter line), and may carry attributes describing the characteristics of the enclosed area.

Fill in the blank: In vector GIS, a polygon is a closed line whose first and last __________ are identical, enclosing a measurable area.

2.1.3 Topology in vector GIS

Topology is the set of rules that defines the spatial relationships between vector features specifying how points, lines, and polygons connect, share boundaries, and relate to one another. Topological rules do not define what features look like; they define how they must behave relative to each other in order to represent the real world correctly.

Common topological rules in GIS include: polygons must not overlap; polygon boundaries must not have gaps; lines must connect at nodes (not cross without connecting); and points must lie inside their designated polygon. When these rules are violated, the resulting errors overlapping parcels, gaps between administrative boundaries, disconnected roads produce incorrect analysis results and unreliable maps.

A key topological concept is the **node** a point where two or more line features meet or connect. In a road network, for example, nodes occur at junctions, dead ends, and intersections. Network analysis (finding the shortest route, modelling traffic flow, determining service areas) depends entirely on topologically correct node-arc relationships. A road network with topological errors will produce incorrect routing results regardless of the analytical method applied.

Fill in the blank: Topological rules ensure that polygon boundaries have no __________ and that adjacent polygons do not overlap.

Pilot questions 2.1

1. Define the vector data model and state two types of features it is well suited to represent.
2. What is the difference between a point, a line, and a polygon in vector GIS?
3. Why might the same geographic feature be represented as a point on one map and a polygon on another?
4. *Fill in the blank: Topological rules ensure that polygon boundaries have no __________ and that polygons do not overlap.*

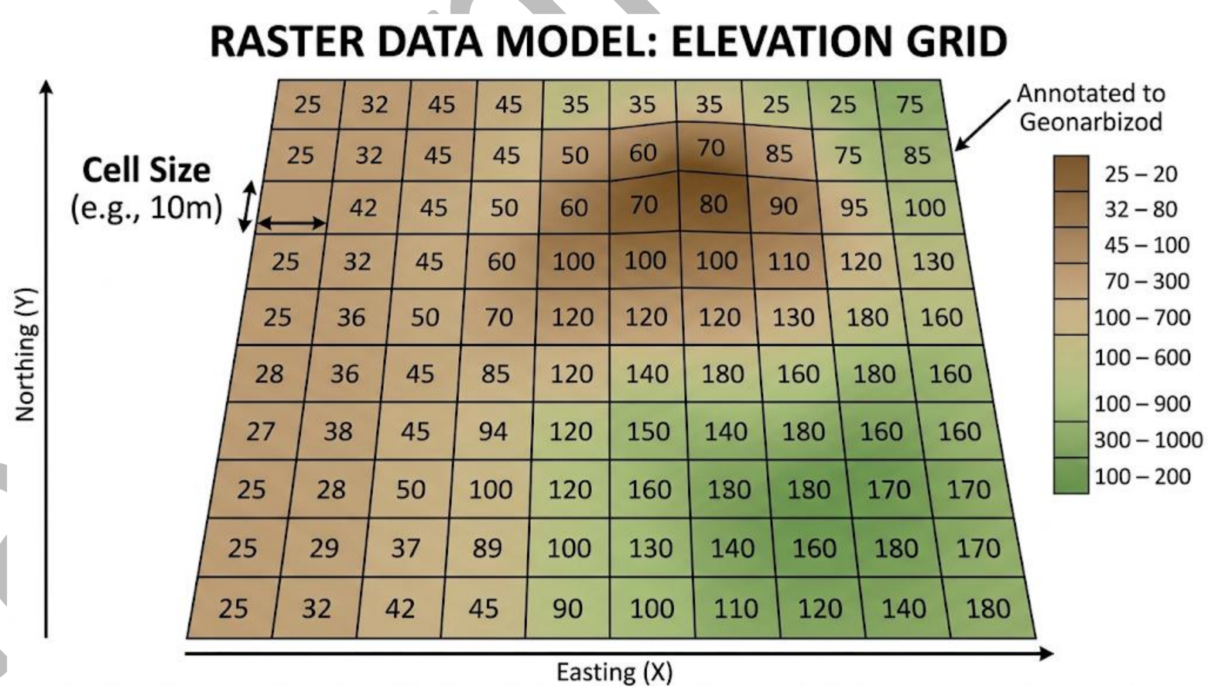
2.2 Raster Data Model

2.2.1 Principles of the raster data model

The **raster data model** represents geographic space as a regular grid of equal-sized cells, sometimes called **pixels**. Each cell occupies a defined area on the ground and holds a single numeric value representing the characteristic of that location an elevation, a temperature, a land cover category, or a spectral reflectance value. The raster model excels at representing **continuous surfaces**: phenomena that vary gradually across the landscape without sharp boundaries, such as elevation, slope, rainfall, soil moisture, and air temperature.

Where the vector model stores the precise coordinates of feature boundaries, the raster model stores the value at every location in a defined grid, regardless of whether the values change. This makes raster datasets well suited to surface analysis calculating slope and aspect from a digital elevation model, modelling flood inundation, identifying areas of high suitability using weighted overlay but less efficient for features with sharp, precisely defined boundaries.

Fill in the blank: The raster data model represents geographic space as a regular grid of equal-sized __________, each holding a single numeric value.



Short description: Diagram illustrating the raster data model as a regular grid of cells, showing how a continuous elevation surface is represented by cells of equal size each containing a single elevation value, with the cell size labelled.

Figure 2.2 The raster data model: a regular grid of cells each holding a single value

2.2.2 Raster resolution, cell size, and data types

The most important parameter of any raster dataset is its **spatial resolution**, defined by the **cell size** the ground dimension represented by a single cell, expressed in the units of the coordinate system (typically metres). A raster dataset with a cell size of 10 m means that each cell represents a 10 m × 10 m square on the ground. Smaller cell sizes produce finer resolution and capture greater spatial detail, but also create substantially larger files.

Resolution must be chosen to match the scale of the analysis. A digital elevation model (DEM) used for national-scale flood risk modelling might use 90 m cells; a DEM used to design drainage in an urban neighbourhood might require 1 m cells. Using a coarse resolution for fine-scale analysis introduces errors; using a fine resolution adds processing overhead without improving the result if the source data does not support it.

Raster datasets store values as different **data types**: integer values represent categorical data (land cover classes, administrative zones); floating-point values represent continuous measurements (elevation in metres, temperature in degrees Celsius). Cells where data is absent or outside the study boundary are assigned **NoData** values a special designation that tells the GIS to exclude those cells from calculations.

Fill in the blank: Raster cells where data is absent or invalid are assigned __________ *values, which instruct GIS software to exclude them from analysis.*

2.2.3 Vector and raster compared

Both the vector and raster models are valid representations of geographic reality. The choice between them depends on the nature of the features being mapped, the type of analysis required, and the available data.

Vector advantages include precise boundary representation, compact file sizes for discrete features, direct linkage to rich attribute tables, and suitability for network analysis and cadastral applications. **Vector limitations** include difficulty representing gradual spatial variation, and the complexity of topological editing when boundaries do not align.

Raster advantages include natural representation of continuous surfaces, simple data structure supporting efficient mathematical operations (map algebra), and compatibility with remotely sensed imagery. **Raster limitations** include blocky representation of sharp boundaries, large file sizes at fine resolution, and loss of attribute detail each cell stores only one value.

In planning practice, you will routinely work with both. A land use map and a parcel layer will be stored as vector data; a satellite image or an elevation model will be stored as raster. **Rasterisation** converts vector to raster; **vectorisation** converts raster to vector. Modern GIS platforms support both conversions and allow vector and raster layers to be combined in a single analysis.

Fill in the blank: Converting a vector layer to a grid of cells is called __________, while the reverse process extracting vector boundaries from a raster is called vectorisation.

Pilot questions 2.2

1. Define the raster data model and state two types of geographic phenomena it is well suited to represent.
2. What is spatial resolution in a raster dataset and how does cell size affect the level of detail captured?
3. *Fill in the blank: Raster cells where data is absent or invalid are represented using __________ values.*
4. State two advantages of vector data over raster data and two advantages of raster data over vector data.
5. Give one example of a planning application that would use vector data and one that would use raster data.

2.3 Spatial Database Structures

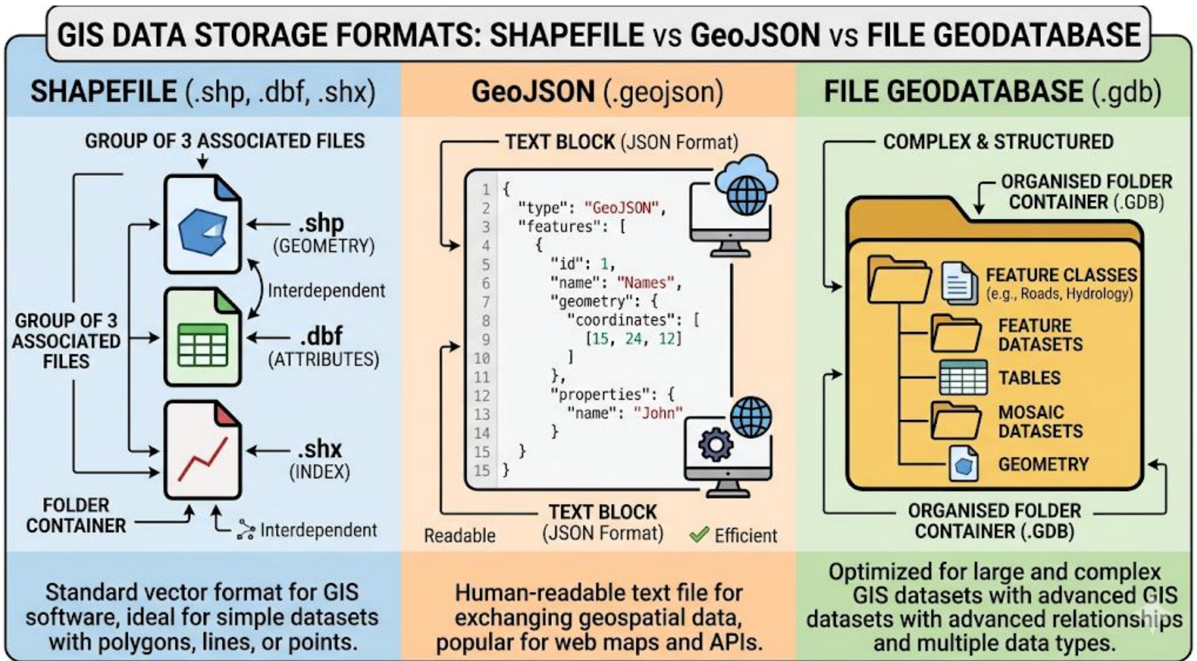
2.3.1 File-based and geodatabase formats

Before GIS can analyse spatial data, that data must be stored in a format that the software can read. Over the decades, a range of **spatial data formats** has been developed, broadly divided into **file-based formats** and **geodatabase formats**.

The most widely used file-based vector format is the **shapefile**, developed by Esri and now an industry standard supported by virtually every GIS platform. A shapefile is actually a collection of associated files at minimum a .shp (geometry), .dbf (attributes), and .shx (index) stored together in a folder. Despite its ubiquity, the shapefile has significant limitations: attribute field names are restricted to ten characters; the format cannot store more than 2 GB of data; and null values are handled inconsistently. The **GeoJSON** format stores both geometry and attributes in a plain-text structure, making it ideal for web mapping applications.

The **geodatabase** is a more sophisticated spatial data container. An Esri **File Geodatabase (.gdb)** stores multiple feature classes, raster datasets, and relationship tables in a single folder-based container, supports field names of up to 64 characters, handles large datasets, and enforces topological rules. The **GeoPackage (.gpkg)** is an open-standard alternative based on SQLite, supporting both vector and raster data and widely used with open-source GIS platforms such as QGIS.

Fill in the blank: A shapefile consists of at minimum three associated files: the .shp file storing __________, the .dbf file storing attributes, and the .shx file providing an index.



Short description: Diagram comparing three GIS data storage formats: the shapefile as a set of associated files, the GeoJSON as a text structure, and the geodatabase as an organised container, with brief notes on the use of each.

Figure 2.3 GIS spatial data formats: shapefile, GeoJSON, and geodatabase compared

2.3.2 Relational database concepts in GIS

Most GIS platforms organise attribute data using the principles of the **relational database model**. In a relational database, data is stored in **tables** organised as rows (records) and columns (fields). Each table represents a single theme, and tables are linked to one another through shared **key fields**.

The **primary key** is a field that uniquely identifies each record in a table for example, a parcel identification number in a land registry dataset. The **foreign key** is a matching field in a related table that links records between tables. When the primary key of one table matches the foreign key of another, the GIS can join the tables, combining attribute information from multiple sources into a single analytical dataset.

The **Structured Query Language (SQL)** is the standard language for querying and managing relational databases. In GIS, SQL queries are used to select features meeting defined attribute criteria for example, selecting all parcels within a flood zone, all roads classified as primary routes, or all buildings constructed before 1980. A simple SQL query takes the form:

SELECT * FROM parcels WHERE land_use = 'Residential' AND area > 500

This query retrieves all records from the parcels table where the land use field equals *'Residential'* and the area field exceeds 500 square metres.

Fill in the blank: In a relational database, the __________ key is a field that uniquely identifies each record within a table.

2.3.3 Spatial indexing and query

A **spatial index** is a data structure that organises the spatial extent of features in a dataset, enabling GIS software to rapidly identify which features occupy a given location or intersect a given area without having to examine every record in the dataset. Without spatial indexing, every spatial query would require a sequential scan of the entire dataset an approach that becomes prohibitively slow as datasets grow.

Common spatial indexing methods include the **R-tree** (which organises features by their bounding rectangles in a hierarchical structure) and the **quadtree** (which recursively divides the study area into quadrants). In practice, GIS users rarely need to manage spatial indexes directly most GIS platforms create and maintain them automatically but understanding their purpose helps you diagnose slow query performance in large datasets.

Spatial queries extend attribute queries by adding geometric criteria. A spatial query might ask: which parcels lie within 500 m of a flood-risk zone? Which road segments intersect a proposed development site? Which schools fall within a defined catchment area? These queries combine **attribute filters** (SQL-style conditions on field values) with **spatial predicates** (geometric relationships such as contains, intersects, within, and touches).

*Fill in the blank: A SQL query that retrieves all records from a parcel layer where the area exceeds 500 square metres would be written as SELECT * FROM parcels WHERE area __________ 500.*

Pilot questions 2.3

1. Name two file-based GIS vector formats and state one advantage of each.
2. What is a primary key in a relational database and what is its role in a GIS attribute table?
3. *Fill in the blank: A SQL query that retrieves all records from a parcel layer where the area exceeds 500 square metres would be written as SELECT * FROM parcels WHERE area __________ 500.*
4. What is spatial indexing and why is it important for large GIS datasets?
5. Give one example of a spatial query used in planning practice and state what it enables the planner to determine.

2.4 Attribute Data and Table Management

2.4.1 Attribute tables and field types

Every vector feature in a GIS is linked to a row in an **attribute table** a structured table in which each row corresponds to one feature and each column, called a **field**, stores a specific type of descriptive information. The attribute table is what transforms a GIS from a simple digital map into an analytical tool: it enables you to query, classify, symbolise, and analyse features based on their characteristics rather than their position alone.

Fields are defined by their **data type**, which determines what kind of values they can store:

- **Text (String):** stores alphanumeric characters parcel IDs, street names, land use categories, owner names.
- **Integer:** stores whole numbers building floor count, land use code, population count.

- **Float (Double):** stores decimal numbers parcel area in square metres, elevation, percentage impervious cover.
- **Date:** stores date and time values survey date, permit issue date, last modification date.

Choosing the correct field type is important: storing numeric values as text prevents mathematical operations; storing large decimal values as integers causes rounding errors. Every table also has a system-generated **ObjectID** field a unique integer identifier assigned automatically to each feature by the GIS, used internally to manage records.

Fill in the blank: In a GIS attribute table, a field that stores decimal numbers such as parcel area or elevation uses the __________ data type.

Sample GIS Attribute Table: Land Parcel Data

The table below illustrates how different data types are structured within a GIS environment to support environmental planning and land use analysis.

Parcel_ID (Text)	Land_Use_Code (Integer)	Parcel_Area_HA (Float)	Survey_Date (Date
LAG-001-A	101	1.245	2023-05-12
LAG-002-B	205	0.890	2024-01-15
ABJ-015-C	101	15.422	2023-11-30

Parcel_ID (Text)	*Land_Use_Code (Integer)*	*Parcel_Area_HA (Float)*	*Survey_Date (Date)*
LAG-001-A	*101*	*1.245*	*2023-05-12*
LAG-002-B	*205*	*0.890*	*2024-01-15*
ABJ-015-C	*101*	*15.422*	*2023-11-30*

Short description: Diagram showing a GIS attribute table with labelled columns illustrating different field types: a text field for parcel ID, an integer field for land use code, a float field for area, and a date field for survey date.

Figure 2.4 GIS attribute table showing text, integer, float, and date field types

2.4.2 Joining and relating tables

One of the most powerful capabilities of the relational database model in GIS is the ability to connect spatial layers to external data tables. Two mechanisms support this: **table joins** and **table relates**.

A **table join** permanently appends the fields of an external table to the attribute table of a spatial layer, matching records using a common key field. For example, you might join a census population table (with Local Government Area codes and population figures) to a polygon layer of LGA boundaries, using the LGA code as the matching key. After the join, each polygon in the spatial layer carries both its original attributes and the population data from the census table, enabling you to map and analyse population distribution.

A **table relate** creates a dynamic link between tables without physically merging them. When you select a feature in the spatial layer, the GIS highlights the related records in the linked table. Relates are appropriate for one-to-many relationships for example, one land parcel linked to many planning application records where a join would duplicate feature rows.

Fill in the blank: A table __________ permanently appends the fields of an external table to a spatial layer using a common key field, while a table relate creates a dynamic link without merging the data.

2.4.3 Data classification and symbology

Symbology is the system of visual variables colour, size, shape, pattern, and transparency used to represent spatial data on a map. In GIS, symbology is driven by the attribute data in the layer's table: different values produce different visual representations, enabling the map reader to distinguish features by type, quantity, or rank.

Data classification is the process of grouping continuous or ordinal attribute values into a defined number of classes for display. Common classification methods include:

- **Equal interval:** divides the range of values into equal-width classes (e.g., 0–20, 21–40, 41–60). Best for uniformly distributed data without extreme outliers.
- **Quantile:** assigns an equal number of features to each class. Useful for comparing relative rank across features, but classes cover unequal value ranges.
- **Natural breaks (Jenks):** identifies class boundaries at natural gaps in the data distribution, minimising within-class variance. Widely used for choropleth maps.
- **Standard deviation:** classifies values by their distance from the mean, useful for highlighting above- and below-average patterns.

Choosing the appropriate classification method matters: different methods applied to the same dataset can produce dramatically different maps, conveying different spatial patterns and potentially supporting different planning conclusions. Always consider whether the classification method accurately represents the distribution of the data before publishing a map.

Fill in the blank: The __________ classification method assigns an equal number of features to each class, regardless of the value range of each class.

Pilot questions 2.4

1. Name four GIS attribute field types and give one example of the kind of data stored in each.
2. What is a table join in GIS and give one example of its use in a planning application.
3. What is the difference between a table join and a table relate?
4. Name two data classification methods and explain how each determines class boundaries.
5. *Fill in the blank: The __________ classification method assigns an equal number of features to each class.*

Series Summary

This Series has examined the spatial data models and database structures that underpin GIS. We began with the vector data model, describing its principles, the three geometry types of point, line, and polygon, and the role of topology in ensuring spatial data integrity. We then explored the raster data model explaining how continuous surfaces are encoded as regular grids of cells, how cell size determines spatial resolution, and how the vector and raster approaches compare in terms of their strengths and limitations. Following this, we examined spatial database structures, contrasting file-based formats such as the shapefile with modern geodatabase containers, and introducing the relational database concepts and SQL queries that underpin GIS data management. Finally, we explored attribute data and table management covering field types, table joins and relates, and the classification and symbology methods used to communicate spatial patterns through maps. By engaging with these topics, you should now be able to describe the principal spatial data models, select an appropriate database format, query GIS data using SQL, and apply classification methods to produce informative maps.

Glossary of Terms

- **Attribute table:** A structured table linked to a vector layer in which each row represents one feature and each column (field) stores a specific type of descriptive information about that feature.
- **Cell size:** The ground dimension represented by a single raster cell, expressed in the units of the coordinate reference system. Cell size determines the spatial resolution of a raster dataset.
- **Data type:** A classification that specifies what kind of values a field in an attribute table can store, such as text, integer, float, or date.
- **File Geodatabase:** An Esri spatial data container stored as a folder on disk, capable of holding multiple feature classes, raster datasets, and relationship tables in a single organised structure.
- **GeoJSON:** An open-standard, text-based spatial data format that stores both geometry and attribute data in a human-readable structure widely used in web mapping applications.
- **GeoPackage:** An open-standard spatial data format based on SQLite that stores both vector and raster datasets in a single portable file, widely supported by open-source GIS platforms.

- **Metadata:** Structured information describing the content, source, coordinate system, accuracy, date, and limitations of a spatial dataset, enabling users to assess its fitness for a given purpose.
- **NoData:** A special designation assigned to raster cells where data is absent, invalid, or outside the study boundary, instructing GIS software to exclude those cells from analysis.
- **Pixel:** A single cell in a raster dataset. Each pixel occupies a defined ground area and stores a single numeric value representing the characteristic of that location.
- **Primary key:** A field in a relational database table that uniquely identifies each record. In GIS, the primary key links the spatial feature to its attributes and enables table joins.
- **Raster data model:** A GIS data model that represents geographic space as a regular grid of equal-sized cells (pixels), each holding a single numeric value. Best suited to continuous surfaces such as elevation and temperature.
- **Shapefile:** An Esri file-based vector format consisting of at least three associated files (.shp, .dbf, .shx) that together store the geometry and attributes of a single spatial layer.
- **Spatial index:** A data structure that organises the spatial extent of features to enable GIS software to rapidly locate and retrieve features occupying a given area without scanning the entire dataset.
- **SQL (Structured Query Language):** The standard language for querying and managing relational databases. In GIS, SQL is used to select features based on attribute criteria.
- **Table join:** A GIS operation that appends the fields of an external table to the attribute table of a spatial layer by matching records using a common key field.
- **Table relate:** A dynamic link between two tables that allows the GIS to highlight related records when a feature is selected, without physically merging the tables. Suited to one-to-many relationships.
- **Topology:** A set of rules that defines the spatial relationships between vector features specifying how points, lines, and polygons must connect, share boundaries, and relate to one another to represent geographic reality correctly.
- **Vector data model:** A GIS data model that represents geographic features as discrete geometric objects points, lines, or polygons defined by coordinate pairs and linked to descriptive attribute tables.

Concept-Check Questions 2
Objective Questions

1. Define the vector data model and state two types of features it represents well. (Linked to SLO 2.1)
2. *Fill in the blank: The raster data model represents continuous surfaces as a regular grid of equal-sized __________. (Linked to SLO 2.2)*
3. Name two file-based GIS formats and state one advantage of each. (Linked to SLO 2.3)
4. What is the role of a primary key in a GIS relational database? (Linked to SLO 2.3)

Short-Answer Questions

5. Explain the difference between the vector and raster data models. For each model, give one example of a planning dataset that would typically use it and justify your choice. (Linked to SLOs 2.1 and 2.2)

6. Describe the role of topology in vector GIS and explain the consequences of topological errors in a road network used for route analysis. (Linked to SLO 2.1)

7. Compare a shapefile and a file geodatabase as spatial data formats, identifying two limitations of the shapefile that the geodatabase addresses. (Linked to SLO 2.3)
8. Explain what a table join is in GIS and describe a realistic planning scenario in which joining a census table to an LGA boundary layer would support a planning decision. (Linked to SLO 2.4)

Long-Answer Questions
9. Evaluate a scenario in which a planning department must choose between a raster Digital Elevation Model and a vector contour layer for a flood-risk mapping project. Discuss the suitability of each data model for the analysis tasks involved including slope calculation, inundation extent, and infrastructure intersection and justify a recommended approach. (Linked to SLOs 2.1 and 2.2)
10. Analyse the role of spatial database structures in supporting GIS-based urban planning in a Nigerian city context. Your answer should address the choice of data format, the use of SQL queries for attribute and spatial selection, and the importance of maintaining topologically correct data. (Linked to SLOs 2.1, 2.3, and 2.4)

Answers to Concept-Check Questions 2
Objective Questions
1. The vector data model represents features as discrete geometric objects points, lines, or polygons defined by coordinate pairs and linked to attribute tables. It represents well: land parcels (polygons) and road networks (lines).
2. Cells / pixels.
3. Shapefile advantage: universal compatibility across GIS platforms.
   GeoJSON advantage: text-based, human-readable, ideal for web mapping.
4. A primary key uniquely identifies each record in a table. In GIS, it links spatial features to their attribute records and enables table joins with external datasets.

Short-Answer Questions
5. Vector stores features as discrete objects (points, lines, polygons) defined by coordinates suited to cadastral data (land parcels) because boundaries are precise and legally defined. Raster stores space as a grid of cells each holding a value suited to satellite imagery or a Digital Elevation Model because these represent continuously varying surfaces.
6. Topology defines rules governing how vector features connect and relate. Topological errors in a road network such as gaps at junctions or overshoots at intersections break the connectivity of the network graph, causing routing algorithms to return incorrect paths or fail to find routes between connected locations.
7. Shapefile limitations addressed by the geodatabase: (1) field names restricted to 10 characters in shapefile vs. 64 in geodatabase; (2) 2 GB file size limit in shapefile vs. 1 TB in file geodatabase; (3) inability to enforce topological rules in shapefile, which the geodatabase supports natively.
8. A table join appends the fields of an external table to a spatial layer using a shared key field. Scenario: joining a National Population Commission census table (with LGA codes and population counts) to a GIS layer of LGA boundaries enables the planner to map population density by LGA, supporting decisions on service facility allocation.

Long-Answer Questions

9. Basic response: Identify that raster DEM supports slope calculation and inundation surface modelling; vector contours require conversion to a surface. Recommend raster DEM for analysis, with vector infrastructure overlaid for intersection analysis.

Value-added response: Discuss resolution choice (1 m vs 10 m DEM) relative to the precision required; explain how map algebra is used to calculate flow accumulation; address how vector road and building layers are intersected with the raster flood extent to identify infrastructure at risk; evaluate the cost of high-resolution DEM acquisition in the Nigerian context.

10. Basic response: Address shapefile vs. geodatabase choice; describe SQL for attribute queries; explain why topological errors invalidate analysis.

Value-added response: Discuss the GeoPackage as an open-standard alternative to proprietary geodatabase formats suitable for Nigerian local government agencies using QGIS; provide realistic SQL examples for Nigerian planning queries (land use zoning, development control); address challenges of data sharing between agencies using incompatible formats.

Answers to Pilot Questions 2

Part 2.1

1. The vector data model represents geographic features as discrete geometric objects defined by coordinate pairs and linked to attribute tables. It is well suited to features with defined boundaries: land parcels and road networks.
2. A point is defined by a single x,y coordinate pair and represents a location feature (e.g., a borehole). A line is an ordered sequence of vertices representing a linear feature (e.g., a road). A polygon is a closed line enclosing an area (e.g., a land parcel).
3. Scale determines representation. At national scale, a city is too small to show as a polygon and is mapped as a point; at a large local scale, the same city has a defined boundary and is mapped as a polygon.
4. Gaps.

Part 2.2

1. The raster data model represents space as a regular grid of equal-sized cells each holding a single value. It is well suited to: digital elevation models and satellite imagery.
2. Spatial resolution is determined by cell size the ground dimension of each cell. Smaller cell sizes capture greater spatial detail at the cost of larger file sizes and greater processing demand.
3. NoData.
4. Vector advantages: precise boundary representation; compact file sizes for discrete features. Raster advantages: natural representation of continuous surfaces; efficient surface analysis using map algebra.
5. Vector: a cadastral parcel layer for development control. Raster: a satellite image for land cover mapping.

Part 2.3

1. Shapefile advantage: universal compatibility. GeoJSON advantage: text-based and human-readable, suited to web mapping.

2. A primary key uniquely identifies each record in a table. In a GIS attribute table it links each feature to its attribute record and is used as the matching field for table joins.
3. Spatial indexing organises features by spatial extent so that queries can rapidly identify relevant features without scanning the entire dataset. It is important for large datasets because without indexing, spatial queries require a sequential full-table scan, which becomes prohibitively slow.
4. Example: 'Select all parcels that intersect the 100-year flood zone.' This enables the planner to identify properties at flood risk for development control decisions.

Part 2.4

1. Text: parcel ID. Integer: floor count. Float: parcel area in square metres. Date: permit issue date.
2. A table join appends the fields of an external table to a spatial layer using a common key field. Planning example: joining a census population table to an LGA boundary layer using the LGA code to map population density.
3. A join permanently appends external fields to the spatial layer's table. A relate creates a dynamic link and is appropriate for one-to-many relationships where a join would duplicate feature rows.
4. Equal interval: divides the value range into equal-width classes. Quantile: assigns an equal number of features to each class.
5. Quantile.

References and Attributions 2
Course content references

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de Smith, M. J., Goodchild, M. F., & Longley, P. A. (2023). Geospatial Analysis: A Comprehensive Guide to Principles, Techniques and Software Tools (6th ed.). The Winchelsea Press. Available at: www.spatialanalysisonline.com

Illustrations

Figure 2.1 The three vector geometry types: point, line, and polygon with attribute tables
AI-generated suggestion: "Generate a labelled diagram showing the three vector geometry types a point representing a water borehole, a line representing a road centreline, and a polygon representing a land parcel each connected by a line to a simplified attribute table showing one or two sample records."
Suggested OER search string: "vector GIS point line polygon geometry attribute table diagram OER."

Figure 2.2 The raster data model: a regular grid of cells each holding a single value

AI-generated suggestion: "Generate a diagram illustrating the raster data model as a regular grid of equal-sized cells, with elevation values shown inside each cell and the cell size dimension labelled on the side."
Suggested OER search string: "raster data model grid cells pixel elevation GIS diagram OER."

Figure 2.3 GIS spatial data formats: shapefile, GeoJSON, and geodatabase compared
AI-generated suggestion: "Generate a diagram comparing three GIS data storage formats side by side: the shapefile shown as a group of three associated files (.shp, .dbf, .shx), the GeoJSON shown as a text block, and the file geodatabase shown as an organised folder container, with one-line descriptions of the use of each."
Suggested OER search string: "GIS data formats shapefile geodatabase GeoJSON comparison diagram OER."

Figure 2.4 GIS attribute table showing text, integer, float, and date field types
AI-generated suggestion: "Generate a diagram showing a GIS attribute table with four labelled columns: a text column for parcel ID, an integer column for land use code, a float column for parcel area, and a date column for survey date, with three sample rows of realistic data."
Suggested OER search string: "GIS attribute table field types text integer float date OER."

Attributions
All AI prompts are intended for use with generative tools to create original illustrations. Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.

Course code: URP 316
Course title: Principles of GIS and AutoCAD
Course credit load: 2 Units

List of Series:
- Series 1: Fundamentals and Components of GIS
- **Series 2: Spatial Data Models and Database Structures**
- Series 3: GIS Operations, Editing and Accuracy Assessment
- Series 4: Integration of Remote Sensing, GPS and GIS
- Series 5: GIS Applications in Urban and Regional Planning

2 Spatial Data Models and Database Structures
Series outline
- **Part 1 (2.1): Vector Data Model**
  Sub-Part 2.1.1: Principles of the vector data model
  Sub-Part 2.1.2: Points, lines, and polygons
  Sub-Part 2.1.3: Topology in vector GIS
- **Part 2 (2.2): Raster Data Model**
  Sub-Part 2.2.1: Principles of the raster data model
  Sub-Part 2.2.2: Raster resolution, cell size, and data types

Sub-Part 2.2.3: Vector and raster compared

- **Part 3 (2.3): Spatial Database Structures**
  Sub-Part 2.3.1: File-based and geodatabase formats
  Sub-Part 2.3.2: Relational database concepts in GIS
  Sub-Part 2.3.3: Spatial indexing and query
- **Part 4 (2.4): Attribute Data and Table Management**
  Sub-Part 2.4.1: Attribute tables and field types
  Sub-Part 2.4.2: Joining and relating tables
  Sub-Part 2.4.3: Data classification and symbology

Introduction

Every map you see in a planning report, on your phone, or in a GIS application is underpinned by one of two fundamental ways of encoding geographic reality in digital form. Before GIS can analyse data, generate maps, or answer spatial questions, it must first represent the real world as structured digital information and the choice of how to do this profoundly affects what you can see, measure, and analyse. Understanding spatial data models is therefore not a technical detail to be memorised; it is the conceptual foundation upon which all GIS work rests.

The aim of this Series is to introduce you to the principal spatial data models used in GIS the Vector and Raster models the database structures through which spatial data is organised, and the principles of attribute data management and cartographic classification.

We shall commence this Series by examining the **Vector Data Model** describing its principles and the three fundamental geometry types of point, line, and polygon, and explaining the role of topology in ensuring spatial integrity. Next, we will explore the **Raster Data Model** covering how continuous surfaces are encoded as grids of cells, how resolution and cell size affect the level of detail captured, and how vector and raster approaches compare. Following that, we will examine **Spatial Database Structures** contrasting file-based formats such as the shapefile with modern geodatabase containers, and introducing the relational database concepts and SQL queries that power GIS data management. Finally, we will wrap up by exploring **Attribute Data and Table Management** covering field types, table joins and relates, and the classification and symbology techniques used to communicate spatial patterns through maps.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** describe the vector data model and identify the three fundamental geometry types and the role of topology,
- **SLO 2.2** explain the principles, resolution, and applications of the raster data model,
- **SLO 2.3** describe the principal spatial database structures and explain the relational database concepts used in GIS,
- **SLO 2.4** manage attribute data in a GIS, including creating and editing tables, performing joins, and applying data classification and symbology.

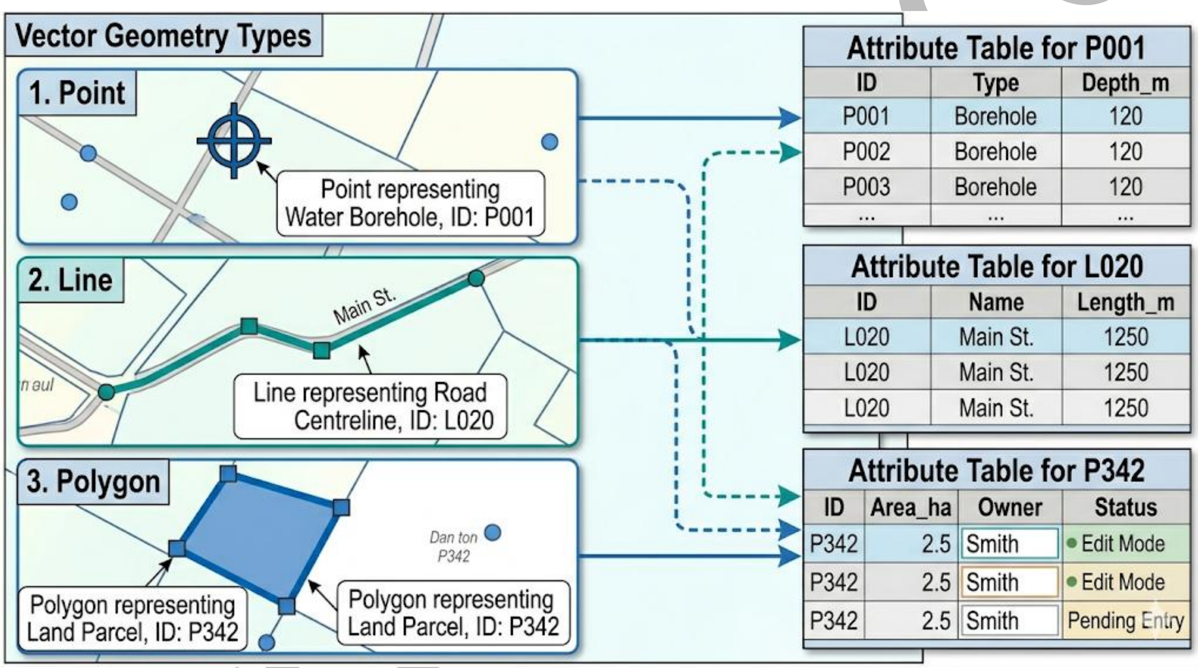
2.1 Vector Data Model

2.1.1 Principles of the vector data model

The **vector data model** represents geographic features as precisely defined geometric objects located in two-dimensional or three-dimensional space. Unlike approaches that approximate the world as a grid of equal-sized cells, the vector model encodes features as **discrete objects** each with a defined shape, a precise location, and a set of descriptive attributes stored in a linked table. This makes it ideally suited to representing features that have sharp, definable boundaries: a property parcel, a road centreline, a building footprint, an administrative boundary.

In the vector model, every feature is defined by its **coordinates** pairs of x and y values (or x, y, z for three-dimensional data) that fix positions in a defined coordinate reference system. The model is efficient because it stores only the coordinates that define the shape of a feature, not the empty space around it. A single road, for example, may be stored as a sequence of just a few dozen coordinate pairs rather than as thousands of cells.

Fill in the blank: The vector data model represents features as discrete __________ objects, each defined by coordinates and linked to descriptive attributes.



Short description: Diagram showing examples of the three vector geometry types: a point representing a borehole, a line representing a road, and a polygon representing a land parcel, each with an associated attribute table.

Figure 2.1 The three vector geometry types: point, line, and polygon with attribute tables

2.1.2 Points, lines, and polygons

All vector features belong to one of three fundamental geometry types: **points**, **lines** (also called polylines), and **polygons**. These three types are sufficient to represent any geographic phenomenon that has a definable location and boundary.

A point is defined by a single x,y coordinate pair. Points represent features whose area is too small to be mapped at a given scale, or whose location rather than extent is the primary attribute of interest. In urban and regional planning, points typically represent features such as boreholes, utility poles, school locations, or spot heights on a contour survey.

A line (or polyline) is defined by an ordered sequence of x,y coordinate pairs called **vertices**, connected by straight segments. Lines represent linear features such as roads, rivers, pipelines, electricity transmission lines, and cadastral boundaries. The accuracy of a line feature depends on the density of vertices: more vertices capture greater geometric complexity, but also increase file size.

A polygon is a closed line a sequence of vertices in which the first and last coordinates are identical, enclosing an area. Polygons represent features with measurable extent: land parcels, land use zones, administrative areas, building footprints, and conservation areas. Each polygon has both an interior (the area enclosed) and a boundary (the perimeter line), and may carry attributes describing the characteristics of the enclosed area.

Fill in the blank: In vector GIS, a polygon is a closed line whose first and last __________ are identical, enclosing a measurable area.

2.1.3 Topology in vector GIS

Topology is the set of rules that defines the spatial relationships between vector features specifying how points, lines, and polygons connect, share boundaries, and relate to one another. Topological rules do not define what features look like; they define how they must behave relative to each other in order to represent the real world correctly.

Common topological rules in GIS include: polygons must not overlap; polygon boundaries must not have gaps; lines must connect at nodes (not cross without connecting); and points must lie inside their designated polygon. When these rules are violated, the resulting errors overlapping parcels, gaps between administrative boundaries, disconnected roads produce incorrect analysis results and unreliable maps.

A key topological concept is the **node** a point where two or more line features meet or connect. In a road network, for example, nodes occur at junctions, dead ends, and intersections. Network analysis (finding the shortest route, modelling traffic flow, determining service areas) depends entirely on topologically correct node-arc relationships. A road network with topological errors will produce incorrect routing results regardless of the analytical method applied.

Fill in the blank: Topological rules ensure that polygon boundaries have no __________ and that adjacent polygons do not overlap.

Pilot questions 2.1

1. Define the vector data model and state two types of features it is well suited to represent.
2. What is the difference between a point, a line, and a polygon in vector GIS?
3. Why might the same geographic feature be represented as a point on one map and a polygon on another?
4. *Fill in the blank: Topological rules ensure that polygon boundaries have no __________ and that polygons do not overlap.*

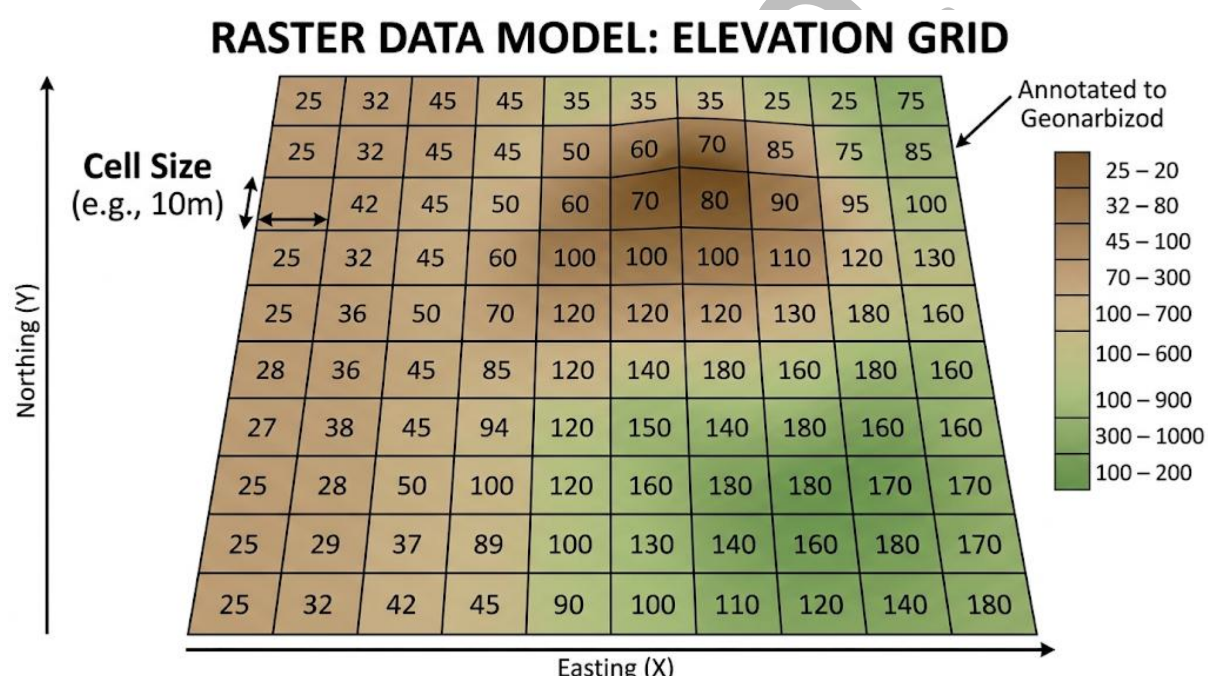
2.2 Raster Data Model

2.2.1 Principles of the raster data model

The **raster data model** represents geographic space as a regular grid of equal-sized cells, sometimes called **pixels**. Each cell occupies a defined area on the ground and holds a single numeric value representing the characteristic of that location an elevation, a temperature, a land cover category, or a spectral reflectance value. The raster model excels at representing **continuous surfaces**: phenomena that vary gradually across the landscape without sharp boundaries, such as elevation, slope, rainfall, soil moisture, and air temperature.

Where the vector model stores the precise coordinates of feature boundaries, the raster model stores the value at every location in a defined grid, regardless of whether the values change. This makes raster datasets well suited to surface analysis calculating slope and aspect from a digital elevation model, modelling flood inundation, identifying areas of high suitability using weighted overlay but less efficient for features with sharp, precisely defined boundaries.

Fill in the blank: The raster data model represents geographic space as a regular grid of equal-sized __________, each holding a single numeric value.



Short description: Diagram illustrating the raster data model as a regular grid of cells, showing how a continuous elevation surface is represented by cells of equal size each containing a single elevation value, with the cell size labelled.

Figure 2.2 The raster data model: a regular grid of cells each holding a single value

2.2.2 Raster resolution, cell size, and data types

The most important parameter of any raster dataset is its **spatial resolution**, defined by the **cell size** the ground dimension represented by a single cell, expressed in the units of the coordinate system (typically metres). A raster dataset with a cell size of 10 m means that each cell represents a 10 m × 10 m square on the ground. Smaller cell sizes produce finer resolution and capture greater spatial detail, but also create substantially larger files.

Resolution must be chosen to match the scale of the analysis. A digital elevation model (DEM) used for national-scale flood risk modelling might use 90 m cells; a DEM used to design drainage in an urban neighbourhood might require 1 m cells. Using a coarse resolution for fine-scale analysis introduces errors; using a fine resolution adds processing overhead without improving the result if the source data does not support it.

Raster datasets store values as different **data types**: integer values represent categorical data (land cover classes, administrative zones); floating-point values represent continuous measurements (elevation in metres, temperature in degrees Celsius). Cells where data is absent or outside the study boundary are assigned **NoData** values a special designation that tells the GIS to exclude those cells from calculations.

Fill in the blank: Raster cells where data is absent or invalid are assigned __________ values, which instruct GIS software to exclude them from analysis.

2.2.3 Vector and raster compared

Both the vector and raster models are valid representations of geographic reality. The choice between them depends on the nature of the features being mapped, the type of analysis required, and the available data.

Vector advantages include precise boundary representation, compact file sizes for discrete features, direct linkage to rich attribute tables, and suitability for network analysis and cadastral applications. **Vector limitations** include difficulty representing gradual spatial variation, and the complexity of topological editing when boundaries do not align.

Raster advantages include natural representation of continuous surfaces, simple data structure supporting efficient mathematical operations (map algebra), and compatibility with remotely sensed imagery. **Raster limitations** include blocky representation of sharp boundaries, large file sizes at fine resolution, and loss of attribute detail each cell stores only one value.

In planning practice, you will routinely work with both. A land use map and a parcel layer will be stored as vector data; a satellite image or an elevation model will be stored as raster. **Rasterisation** converts vector to raster; **vectorisation** converts raster to vector. Modern GIS platforms support both conversions and allow vector and raster layers to be combined in a single analysis.

Fill in the blank: Converting a vector layer to a grid of cells is called __________, while the reverse process extracting vector boundaries from a raster is called vectorisation.

Pilot questions 2.2

1. Define the raster data model and state two types of geographic phenomena it is well suited to represent.
2. What is spatial resolution in a raster dataset and how does cell size affect the level of detail captured?
3. *Fill in the blank: Raster cells where data is absent or invalid are represented using __________ values.*

4. State two advantages of vector data over raster data and two advantages of raster data over vector data.
5. Give one example of a planning application that would use vector data and one that would use raster data.

2.3 Spatial Database Structures

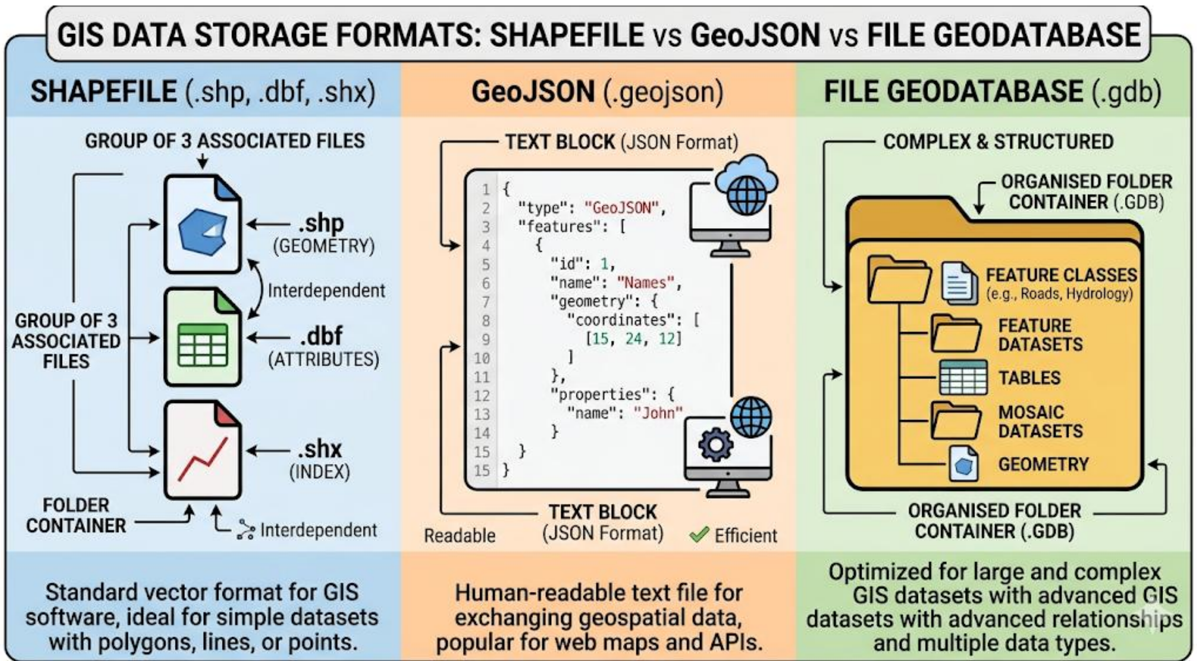
2.3.1 File-based and geodatabase formats

Before GIS can analyse spatial data, that data must be stored in a format that the software can read. Over the decades, a range of **spatial data formats** has been developed, broadly divided into **file-based formats** and **geodatabase formats**.

The most widely used file-based vector format is the **shapefile**, developed by Esri and now an industry standard supported by virtually every GIS platform. A shapefile is actually a collection of associated files at minimum a .shp (geometry), .dbf (attributes), and .shx (index) stored together in a folder. Despite its ubiquity, the shapefile has significant limitations: attribute field names are restricted to ten characters; the format cannot store more than 2 GB of data; and null values are handled inconsistently. The **GeoJSON** format stores both geometry and attributes in a plain-text structure, making it ideal for web mapping applications.

The **geodatabase** is a more sophisticated spatial data container. An Esri **File Geodatabase (.gdb)** stores multiple feature classes, raster datasets, and relationship tables in a single folder-based container, supports field names of up to 64 characters, handles large datasets, and enforces topological rules. The **GeoPackage (.gpkg)** is an open-standard alternative based on SQLite, supporting both vector and raster data and widely used with open-source GIS platforms such as QGIS.

Fill in the blank: A shapefile consists of at minimum three associated files: the .shp file storing __________, the .dbf file storing attributes, and the .shx file providing an index.



Short description: Diagram comparing three GIS data storage formats: the shapefile as a set of associated files, the GeoJSON as a text structure, and the geodatabase as an organised container, with brief notes on the use of each.

Figure 2.3 GIS spatial data formats: shapefile, GeoJSON, and geodatabase compared

2.3.2 Relational database concepts in GIS

Most GIS platforms organise attribute data using the principles of the **relational database model**. In a relational database, data is stored in **tables** organised as rows (records) and columns (fields). Each table represents a single theme, and tables are linked to one another through shared **key fields**.

The **primary key** is a field that uniquely identifies each record in a table for example, a parcel identification number in a land registry dataset. The **foreign key** is a matching field in a related table that links records between tables. When the primary key of one table matches the foreign key of another, the GIS can join the tables, combining attribute information from multiple sources into a single analytical dataset.

The **Structured Query Language (SQL)** is the standard language for querying and managing relational databases. In GIS, SQL queries are used to select features meeting defined attribute criteria for example, selecting all parcels within a flood zone, all roads classified as primary routes, or all buildings constructed before 1980. A simple SQL query takes the form:

```
SELECT * FROM parcels WHERE land_use = 'Residential' AND area > 500
```

This query retrieves all records from the parcels table where the land use field equals *'Residential'* and the area field exceeds 500 square metres.

Fill in the blank: In a relational database, the __________ key is a field that uniquely identifies each record within a table.

2.3.3 Spatial indexing and query

A **spatial index** is a data structure that organises the spatial extent of features in a dataset, enabling GIS software to rapidly identify which features occupy a given location or intersect a given area without having to examine every record in the dataset. Without spatial indexing, every spatial query would require a sequential scan of the entire dataset an approach that becomes prohibitively slow as datasets grow.

Common spatial indexing methods include the **R-tree** (which organises features by their bounding rectangles in a hierarchical structure) and the **quadtree** (which recursively divides the study area into quadrants). In practice, GIS users rarely need to manage spatial indexes directly most GIS platforms create and maintain them automatically but understanding their purpose helps you diagnose slow query performance in large datasets.

Spatial queries extend attribute queries by adding geometric criteria. A spatial query might ask: which parcels lie within 500 m of a flood-risk zone? Which road segments intersect a proposed development site? Which schools fall within a defined catchment area? These queries combine **attribute filters** (SQL-style conditions on field values) with **spatial predicates** (geometric relationships such as contains, intersects, within, and touches).

*Fill in the blank: A SQL query that retrieves all records from a parcel layer where the area exceeds 500 square metres would be written as SELECT * FROM parcels WHERE area __________ 500.*

Pilot questions 2.3

1. Name two file-based GIS vector formats and state one advantage of each.
2. What is a primary key in a relational database and what is its role in a GIS attribute table?
3. *Fill in the blank: A SQL query that retrieves all records from a parcel layer where the area exceeds 500 square metres would be written as SELECT * FROM parcels WHERE area __________ 500.*
4. What is spatial indexing and why is it important for large GIS datasets?
5. Give one example of a spatial query used in planning practice and state what it enables the planner to determine.

2.4 Attribute Data and Table Management

2.4.1 Attribute tables and field types

Every vector feature in a GIS is linked to a row in an **attribute table** a structured table in which each row corresponds to one feature and each column, called a **field**, stores a specific type of descriptive information. The attribute table is what transforms a GIS from a simple digital map into an analytical tool: it enables you to query, classify, symbolise, and analyse features based on their characteristics rather than their position alone.

Fields are defined by their **data type**, which determines what kind of values they can store:

- **Text (String):** stores alphanumeric characters parcel IDs, street names, land use categories, owner names.
- **Integer:** stores whole numbers building floor count, land use code, population count.

- **Float (Double):** stores decimal numbers parcel area in square metres, elevation, percentage impervious cover.
- **Date:** stores date and time values survey date, permit issue date, last modification date.

Choosing the correct field type is important: storing numeric values as text prevents mathematical operations; storing large decimal values as integers causes rounding errors. Every table also has a system-generated **ObjectID** field a unique integer identifier assigned automatically to each feature by the GIS, used internally to manage records.

Fill in the blank: In a GIS attribute table, a field that stores decimal numbers such as parcel area or elevation uses the __________ data type.

Sample GIS Attribute Table: Land Parcel Data

The table below illustrates how different data types are structured within a GIS environment to support environmental planning and land use analysis.

Parcel_ID (Text)	Land_Use_Code (Integer)	Parcel_Area_HA (Float)	Survey_Date (Date
LAG-001-A	101	1.245	2023-05-12
LAG-002-B	205	0.890	2024-01-15
ABJ-015-C	101	15.422	2023-11-30

Parcel_ID (Text)	*Land_Use_Code (Integer)*	*Parcel_Area_HA (Float)*	*Survey_Date (Date)*
LAG-001-A	*101*	*1.245*	*2023-05-12*
LAG-002-B	*205*	*0.890*	*2024-01-15*
ABJ-015-C	*101*	*15.422*	*2023-11-30*

Short description: Diagram showing a GIS attribute table with labelled columns illustrating different field types: a text field for parcel ID, an integer field for land use code, a float field for area, and a date field for survey date.

Figure 2.4 GIS attribute table showing text, integer, float, and date field types

2.4.2 Joining and relating tables

One of the most powerful capabilities of the relational database model in GIS is the ability to connect spatial layers to external data tables. Two mechanisms support this: **table joins** and **table relates**.

A **table join** permanently appends the fields of an external table to the attribute table of a spatial layer, matching records using a common key field. For example, you might join a census population table (with Local Government Area codes and population figures) to a polygon layer of LGA boundaries, using the LGA code as the matching key. After the join, each polygon in the spatial layer carries both its original attributes and the population data from the census table, enabling you to map and analyse population distribution.

A **table relate** creates a dynamic link between tables without physically merging them. When you select a feature in the spatial layer, the GIS highlights the related records in the linked table. Relates are appropriate for one-to-many relationships for example, one land parcel linked to many planning application records where a join would duplicate feature rows.

Fill in the blank: A table __________ permanently appends the fields of an external table to a spatial layer using a common key field, while a table relate creates a dynamic link without merging the data.

2.4.3 Data classification and symbology

Symbology is the system of visual variables colour, size, shape, pattern, and transparency used to represent spatial data on a map. In GIS, symbology is driven by the attribute data in the layer's table: different values produce different visual representations, enabling the map reader to distinguish features by type, quantity, or rank.

Data classification is the process of grouping continuous or ordinal attribute values into a defined number of classes for display. Common classification methods include:

- **Equal interval:** divides the range of values into equal-width classes (e.g., 0–20, 21–40, 41–60). Best for uniformly distributed data without extreme outliers.
- **Quantile:** assigns an equal number of features to each class. Useful for comparing relative rank across features, but classes cover unequal value ranges.
- **Natural breaks (Jenks):** identifies class boundaries at natural gaps in the data distribution, minimising within-class variance. Widely used for choropleth maps.
- **Standard deviation:** classifies values by their distance from the mean, useful for highlighting above- and below-average patterns.

Choosing the appropriate classification method matters: different methods applied to the same dataset can produce dramatically different maps, conveying different spatial patterns and potentially supporting different planning conclusions. Always consider whether the classification method accurately represents the distribution of the data before publishing a map.

Fill in the blank: The __________ classification method assigns an equal number of features to each class, regardless of the value range of each class.

Pilot questions 2.4

1. Name four GIS attribute field types and give one example of the kind of data stored in each.
2. What is a table join in GIS and give one example of its use in a planning application.
3. What is the difference between a table join and a table relate?
4. Name two data classification methods and explain how each determines class boundaries.
5. *Fill in the blank: The __________ classification method assigns an equal number of features to each class.*

Series Summary

This Series has examined the spatial data models and database structures that underpin GIS. We began with the vector data model, describing its principles, the three geometry types of point, line, and polygon, and the role of topology in ensuring spatial data integrity. We then explored the raster data model explaining how continuous surfaces are encoded as regular grids of cells, how cell size determines spatial resolution, and how the vector and raster approaches compare in terms of their strengths and limitations. Following this, we examined spatial database structures, contrasting file-based formats such as the shapefile with modern geodatabase containers, and introducing the relational database concepts and SQL queries that underpin GIS data management. Finally, we explored attribute data and table management covering field types, table joins and relates, and the classification and symbology methods used to communicate spatial patterns through maps. By engaging with these topics, you should now be able to describe the principal spatial data models, select an appropriate database format, query GIS data using SQL, and apply classification methods to produce informative maps.

Glossary of Terms

- **Attribute table:** A structured table linked to a vector layer in which each row represents one feature and each column (field) stores a specific type of descriptive information about that feature.
- **Cell size:** The ground dimension represented by a single raster cell, expressed in the units of the coordinate reference system. Cell size determines the spatial resolution of a raster dataset.
- **Data type:** A classification that specifies what kind of values a field in an attribute table can store, such as text, integer, float, or date.
- **File Geodatabase:** An Esri spatial data container stored as a folder on disk, capable of holding multiple feature classes, raster datasets, and relationship tables in a single organised structure.
- **GeoJSON:** An open-standard, text-based spatial data format that stores both geometry and attribute data in a human-readable structure widely used in web mapping applications.
- **GeoPackage:** An open-standard spatial data format based on SQLite that stores both vector and raster datasets in a single portable file, widely supported by open-source GIS platforms.

- **Metadata:** Structured information describing the content, source, coordinate system, accuracy, date, and limitations of a spatial dataset, enabling users to assess its fitness for a given purpose.
- **NoData:** A special designation assigned to raster cells where data is absent, invalid, or outside the study boundary, instructing GIS software to exclude those cells from analysis.
- **Pixel:** A single cell in a raster dataset. Each pixel occupies a defined ground area and stores a single numeric value representing the characteristic of that location.
- **Primary key:** A field in a relational database table that uniquely identifies each record. In GIS, the primary key links the spatial feature to its attributes and enables table joins.
- **Raster data model:** A GIS data model that represents geographic space as a regular grid of equal-sized cells (pixels), each holding a single numeric value. Best suited to continuous surfaces such as elevation and temperature.
- **Shapefile:** An Esri file-based vector format consisting of at least three associated files (.shp, .dbf, .shx) that together store the geometry and attributes of a single spatial layer.
- **Spatial index:** A data structure that organises the spatial extent of features to enable GIS software to rapidly locate and retrieve features occupying a given area without scanning the entire dataset.
- **SQL (Structured Query Language):** The standard language for querying and managing relational databases. In GIS, SQL is used to select features based on attribute criteria.
- **Table join:** A GIS operation that appends the fields of an external table to the attribute table of a spatial layer by matching records using a common key field.
- **Table relate:** A dynamic link between two tables that allows the GIS to highlight related records when a feature is selected, without physically merging the tables. Suited to one-to-many relationships.
- **Topology:** A set of rules that defines the spatial relationships between vector features specifying how points, lines, and polygons must connect, share boundaries, and relate to one another to represent geographic reality correctly.
- **Vector data model:** A GIS data model that represents geographic features as discrete geometric objects points, lines, or polygons defined by coordinate pairs and linked to descriptive attribute tables.

Concept-Check Questions 2

Objective Questions

1. Define the vector data model and state two types of features it represents well. (Linked to SLO 2.1)
2. *Fill in the blank: The raster data model represents continuous surfaces as a regular grid of equal-sized __________. (Linked to SLO 2.2)*
3. Name two file-based GIS formats and state one advantage of each. (Linked to SLO 2.3)
4. What is the role of a primary key in a GIS relational database? (Linked to SLO 2.3)

Short-Answer Questions

5. Explain the difference between the vector and raster data models. For each model, give one example of a planning dataset that would typically use it and justify your choice. (Linked to SLOs 2.1 and 2.2)
6. Describe the role of topology in vector GIS and explain the consequences of topological errors in a road network used for route analysis. (Linked to SLO 2.1)

7. Compare a shapefile and a file geodatabase as spatial data formats, identifying two limitations of the shapefile that the geodatabase addresses. (Linked to SLO 2.3)
8. Explain what a table join is in GIS and describe a realistic planning scenario in which joining a census table to an LGA boundary layer would support a planning decision. (Linked to SLO 2.4)

Long-Answer Questions
9. Evaluate a scenario in which a planning department must choose between a raster Digital Elevation Model and a vector contour layer for a flood-risk mapping project. Discuss the suitability of each data model for the analysis tasks involved including slope calculation, inundation extent, and infrastructure intersection and justify a recommended approach. (Linked to SLOs 2.1 and 2.2)
10. Analyse the role of spatial database structures in supporting GIS-based urban planning in a Nigerian city context. Your answer should address the choice of data format, the use of SQL queries for attribute and spatial selection, and the importance of maintaining topologically correct data. (Linked to SLOs 2.1, 2.3, and 2.4)

Answers to Concept-Check Questions 2
Objective Questions
1. The vector data model represents features as discrete geometric objects points, lines, or polygons defined by coordinate pairs and linked to attribute tables. It represents well: land parcels (polygons) and road networks (lines).
2. Cells / pixels.
3. Shapefile advantage: universal compatibility across GIS platforms.
   GeoJSON advantage: text-based, human-readable, ideal for web mapping.
4. A primary key uniquely identifies each record in a table. In GIS, it links spatial features to their attribute records and enables table joins with external datasets.

Short-Answer Questions
5. Vector stores features as discrete objects (points, lines, polygons) defined by coordinates suited to cadastral data (land parcels) because boundaries are precise and legally defined. Raster stores space as a grid of cells each holding a value suited to satellite imagery or a Digital Elevation Model because these represent continuously varying surfaces.
6. Topology defines rules governing how vector features connect and relate. Topological errors in a road network such as gaps at junctions or overshoots at intersections break the connectivity of the network graph, causing routing algorithms to return incorrect paths or fail to find routes between connected locations.
7. Shapefile limitations addressed by the geodatabase: (1) field names restricted to 10 characters in shapefile vs. 64 in geodatabase; (2) 2 GB file size limit in shapefile vs. 1 TB in file geodatabase; (3) inability to enforce topological rules in shapefile, which the geodatabase supports natively.
8. A table join appends the fields of an external table to a spatial layer using a shared key field. Scenario: joining a National Population Commission census table (with LGA codes and population counts) to a GIS layer of LGA boundaries enables the planner to map population density by LGA, supporting decisions on service facility allocation.

Long-Answer Questions

9. Basic response: Identify that raster DEM supports slope calculation and inundation surface modelling; vector contours require conversion to a surface. Recommend raster DEM for analysis, with vector infrastructure overlaid for intersection analysis.

Value-added response: Discuss resolution choice (1 m vs 10 m DEM) relative to the precision required; explain how map algebra is used to calculate flow accumulation; address how vector road and building layers are intersected with the raster flood extent to identify infrastructure at risk; evaluate the cost of high-resolution DEM acquisition in the Nigerian context.

10. Basic response: Address shapefile vs. geodatabase choice; describe SQL for attribute queries; explain why topological errors invalidate analysis.

Value-added response: Discuss the GeoPackage as an open-standard alternative to proprietary geodatabase formats suitable for Nigerian local government agencies using QGIS; provide realistic SQL examples for Nigerian planning queries (land use zoning, development control); address challenges of data sharing between agencies using incompatible formats.

Answers to Pilot Questions 2

Part 2.1

1. The vector data model represents geographic features as discrete geometric objects defined by coordinate pairs and linked to attribute tables. It is well suited to features with defined boundaries: land parcels and road networks.
2. A point is defined by a single x,y coordinate pair and represents a location feature (e.g., a borehole). A line is an ordered sequence of vertices representing a linear feature (e.g., a road). A polygon is a closed line enclosing an area (e.g., a land parcel).
3. Scale determines representation. At national scale, a city is too small to show as a polygon and is mapped as a point; at a large local scale, the same city has a defined boundary and is mapped as a polygon.
4. Gaps.

Part 2.2

1. The raster data model represents space as a regular grid of equal-sized cells each holding a single value. It is well suited to: digital elevation models and satellite imagery.
2. Spatial resolution is determined by cell size the ground dimension of each cell. Smaller cell sizes capture greater spatial detail at the cost of larger file sizes and greater processing demand.
3. NoData.
4. Vector advantages: precise boundary representation; compact file sizes for discrete features. Raster advantages: natural representation of continuous surfaces; efficient surface analysis using map algebra.
5. Vector: a cadastral parcel layer for development control. Raster: a satellite image for land cover mapping.

Part 2.3

1. Shapefile advantage: universal compatibility. GeoJSON advantage: text-based and human-readable, suited to web mapping.

2. A primary key uniquely identifies each record in a table. In a GIS attribute table it links each feature to its attribute record and is used as the matching field for table joins.
3. Spatial indexing organises features by spatial extent so that queries can rapidly identify relevant features without scanning the entire dataset. It is important for large datasets because without indexing, spatial queries require a sequential full-table scan, which becomes prohibitively slow.
4. Example: 'Select all parcels that intersect the 100-year flood zone.' This enables the planner to identify properties at flood risk for development control decisions.

Part 2.4

1. Text: parcel ID. Integer: floor count. Float: parcel area in square metres. Date: permit issue date.
2. A table join appends the fields of an external table to a spatial layer using a common key field. Planning example: joining a census population table to an LGA boundary layer using the LGA code to map population density.
3. A join permanently appends external fields to the spatial layer's table. A relate creates a dynamic link and is appropriate for one-to-many relationships where a join would duplicate feature rows.
4. Equal interval: divides the value range into equal-width classes. Quantile: assigns an equal number of features to each class.
5. Quantile.

References and Attributions 2
Course content references

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Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic Information Science and Systems (4th ed.). Hoboken, NJ: Wiley.
de Smith, M. J., Goodchild, M. F., & Longley, P. A. (2023). Geospatial Analysis: A Comprehensive Guide to Principles, Techniques and Software Tools (6th ed.). The Winchelsea Press. Available at: www.spatialanalysisonline.com

Illustrations

Figure 2.1 The three vector geometry types: point, line, and polygon with attribute tables
AI-generated suggestion: "Generate a labelled diagram showing the three vector geometry types a point representing a water borehole, a line representing a road centreline, and a polygon representing a land parcel each connected by a line to a simplified attribute table showing one or two sample records."
Suggested OER search string: "vector GIS point line polygon geometry attribute table diagram OER."

Figure 2.2 The raster data model: a regular grid of cells each holding a single value

AI-generated suggestion: "Generate a diagram illustrating the raster data model as a regular grid of equal-sized cells, with elevation values shown inside each cell and the cell size dimension labelled on the side."
Suggested OER search string: "raster data model grid cells pixel elevation GIS diagram OER."

Figure 2.3 GIS spatial data formats: shapefile, GeoJSON, and geodatabase compared
AI-generated suggestion: "Generate a diagram comparing three GIS data storage formats side by side: the shapefile shown as a group of three associated files (.shp, .dbf, .shx), the GeoJSON shown as a text block, and the file geodatabase shown as an organised folder container, with one-line descriptions of the use of each."
Suggested OER search string: "GIS data formats shapefile geodatabase GeoJSON comparison diagram OER."

Figure 2.4 GIS attribute table showing text, integer, float, and date field types
AI-generated suggestion: "Generate a diagram showing a GIS attribute table with four labelled columns: a text column for parcel ID, an integer column for land use code, a float column for parcel area, and a date column for survey date, with three sample rows of realistic data."
Suggested OER search string: "GIS attribute table field types text integer float date OER."

Attributions
All AI prompts are intended for use with generative tools to create original illustrations. Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.

Course code: URP 316

Course title: Principles of GIS and AutoCAD

Course credit load: 2 Units

List of Series:

- Series 1: Fundamentals and Components of GIS
- Series 2: Spatial Data Models and Database Structures
- **Series 3: GIS Operations, Editing and Analysis**
- Series 4: Integration of Remote Sensing, GPS and GIS
- Series 5: Traditional Urban Design in Analysis Cities

3 GIS Operations, Editing and Analysis

Series Outline

- **Part 1 (3.1):** Data Editing and Digitizing
    - **Sub-Part 3.1.1:** Creating and editing vector features

- **Sub-Part 3.1.2:** Digitizing from imagery and paper maps
- **Sub-Part 3.1.3:** Georeferencing and coordinate transformation
- **Part 2 (3.2):** Vector Analysis Operations
  - **Sub-Part 3.2.1:** Buffering and proximity analysis
  - **Sub-Part 3.2.2:** Overlay analysis
  - **Sub-Part 3.2.3:** Dissolve, clip, and other geoprocessing tools
- **Part 3 (3.3):** Raster Analysis Operations
  - **Sub-Part 3.3.1:** Surface analysis and digital elevation models
  - **Sub-Part 3.3.2:** Reclassification and map algebra
  - **Sub-Part 3.3.3:** Raster to vector conversion and integration
- **Part 4 (3.4):** Network Analysis and Spatial Statistics
  - **Sub-Part 3.4.1:** Network analysis: routing and service areas
  - **Sub-Part 3.4.2:** Spatial statistics and pattern analysis
  - **Sub-Part 3.4.3:** GIS analysis workflows in planning practice

Introduction

The real power of a Geographic Information System lies not simply in storing maps, but in the operations it makes possible editing, querying, measuring, overlaying, and modelling spatial data to answer planning questions. Once spatial data has been captured and organised, the planner's task becomes one of analysis: using GIS tools to extract meaning, identify patterns, and generate evidence for decisions. Mastery of GIS operations is therefore the bridge between data collection and planning action.

The aim of this Series is to introduce you to the principal GIS operations used in editing, geoprocessing, and spatial analysis, enabling you to prepare, manipulate, and analyse spatial data for planning applications.

We shall commence this Series by examining data editing and digitizing how vector features are created and edited, how on-screen digitizing from imagery and paper maps works, and how georeferencing aligns spatial data to a coordinate system. Next, we will explore vector analysis operations, covering buffering, overlay analysis, and geoprocessing tools such as dissolve and clip. Following that, we will examine raster analysis operations, including surface analysis derived from digital elevation models, reclassification, map algebra, and raster-to-vector conversion. Finally, we will conclude with network analysis and spatial statistics, demonstrating how GIS supports routing, service area delineation, pattern analysis, and the construction of structured analysis workflows for planning practice.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** create, edit, and georeference vector and raster spatial data in a GIS,

- **SLO 3.2** apply vector analysis operations including buffering, overlay, dissolve, and clip to answer spatial planning questions,
- **SLO 3.3** perform raster analysis operations including surface analysis, reclassification, and map algebra,
- **SLO 3.4** apply network analysis and spatial statistics tools and structure GIS analysis workflows for planning applications.

3.1 Data Editing and Digitizing

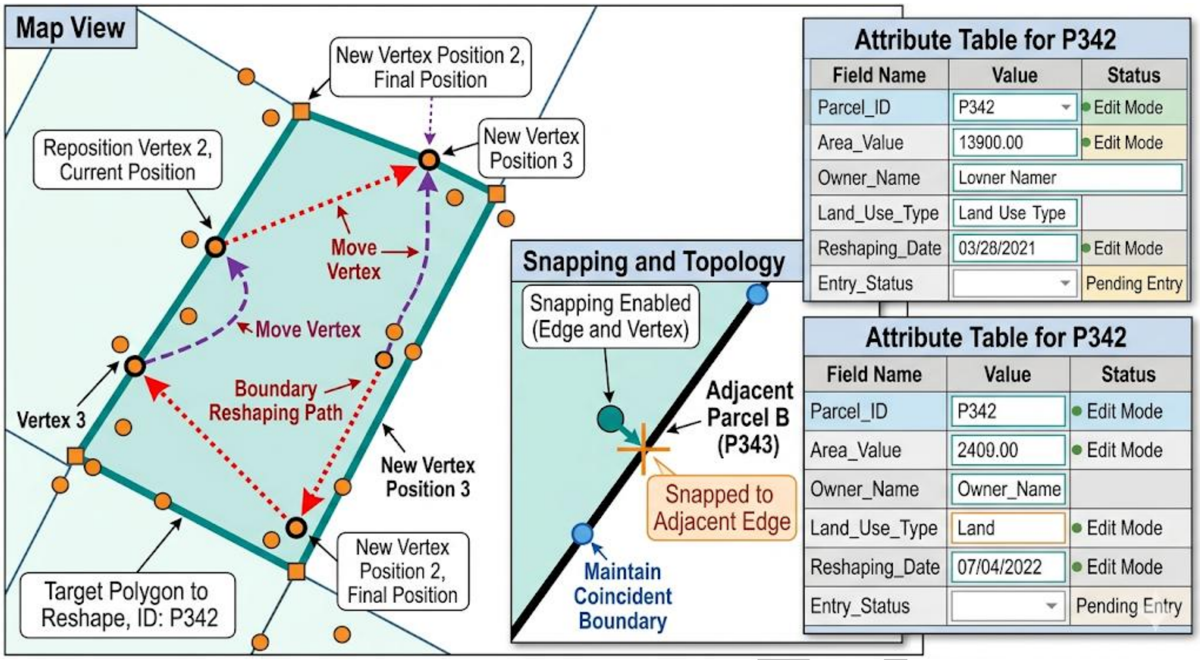
3.1.1 Creating and editing vector features

Before spatial data can be analysed, it must be correctly structured and free of errors. **Vector editing** is the process of creating, modifying, and maintaining the geometry and attributes of point, line, and polygon features in a GIS layer.

Key editing operations include:

- **Creating features:** New points, lines, or polygons are drawn interactively using the GIS editing toolbar. The geometry is defined by placing **vertices** coordinate nodes that define the shape of the feature.
- **Reshaping and moving:** Existing features can be reshaped by adding, deleting, or repositioning vertices. Features can also be moved to correct positional errors.
- **Splitting and merging:** A single feature can be split into two (e.g., dividing a land parcel) or two features merged into one (e.g., combining adjacent parcels under the same owner).
- **Snapping:** The **snapping** function automatically aligns newly digitised vertices to existing features ensuring that adjacent polygons share boundaries without gaps or overlaps, which is essential for maintaining **topological integrity**.
- **Attribute editing:** After geometry is created or corrected, the associated attribute table must be updated to record descriptive information such as land use class, road name, or parcel ID.

Fill in the blank: The snapping function in GIS aligns newly digitised vertices to existing features, preventing gaps and overlaps and maintaining __________ integrity.



Short description: Diagram illustrating a GIS editing session showing a polygon boundary being reshaped by repositioning vertices, with snapping enabled to adjacent parcels, and an attribute table open for data entry.

Figure 3.1 GIS vector editing: reshaping a polygon boundary with vertex editing and snapping

3.1.2 Digitizing from imagery and paper maps

Digitizing is the process of converting spatial features from an analogue or raster source into digital vector data. Two principal methods are used:

- **On-screen (heads-up) digitizing:** A georeferenced satellite image, aerial photograph, or scanned map is displayed in the GIS window. The operator traces features roads, buildings, land parcels, watercourses by clicking to place vertices directly on the screen. Accuracy depends on the resolution of the background image, the scale at which digitizing is performed, and the operator's care in placing vertices at feature boundaries.
- **Tablet digitizing:** A paper map is fixed to a digitising tablet. The operator traces features using a handheld cursor whose position is transmitted digitally to the GIS. This method is used when paper maps must be converted to digital format without first scanning.

Common digitizing errors that must be corrected during editing include:

- **Overshoots and undershoots:** Line features that extend beyond or fail to reach an intersection node.
- **Slivers:** Narrow, unintended gaps or overlapping polygons at boundaries between adjacent features, usually caused by inconsistent digitizing.
- **Duplicate features:** Features traced more than once, creating stacked geometries that inflate area and count measurements.

Fill in the blank: Narrow unintended gaps or overlapping slivers at polygon boundaries, caused by inconsistent digitizing, are a common __________ error in vector data.

3.1.3 Georeferencing and coordinate transformation

Georeferencing is the process of assigning geographic coordinates to a raster image such as a scanned topographic map, an aerial photograph, or a satellite image so that it aligns correctly with other spatial datasets in a defined coordinate system.

The georeferencing process involves:

- **Identifying ground control points (GCPs):** Well-defined locations visible in both the image and a reference dataset (such as road intersections, building corners, or benchmarks) are selected as **ground control points**
- **Assigning real-world coordinates:** The planimetric coordinates (Easting, Northing) of each GCP are entered from GPS measurements, existing maps, or a reference GIS layer.
- **Applying a transformation:** The GIS calculates a mathematical transformation typically a polynomial or affine transformation that warps the image to fit the reference coordinate system.
- **Assessing accuracy:** The quality of georeferencing is measured by the **Root Mean Square Error (RMSE)**, which quantifies the average positional discrepancy between the GCPs and their transformed positions. An RMSE below one pixel is generally considered acceptable.

Coordinate transformation extends this concept to vector datasets: converting the coordinates of an existing GIS layer from one coordinate reference system (CRS) to another for example, from the Minna datum to WGS84, or from Geographic coordinates (latitude/longitude) to UTM (metres). This is essential when combining datasets from different sources that use different coordinate systems.

Fill in the blank: The mathematical measure of average positional discrepancy after georeferencing is called the Root Mean Square __________ (RMSE).

Pilot questions 3.1

1. State two editing operations that can be performed on an existing vector feature in a GIS.
2. What is on-screen digitizing and what does its accuracy depend on?
3. What are ground control points and why are they needed for georeferencing?
4. *Fill in the blank: The mathematical measure of average positional discrepancy after georeferencing is called the root mean square __________.*

3.2 Vector Analysis Operations

3.2.1 Buffering and proximity analysis

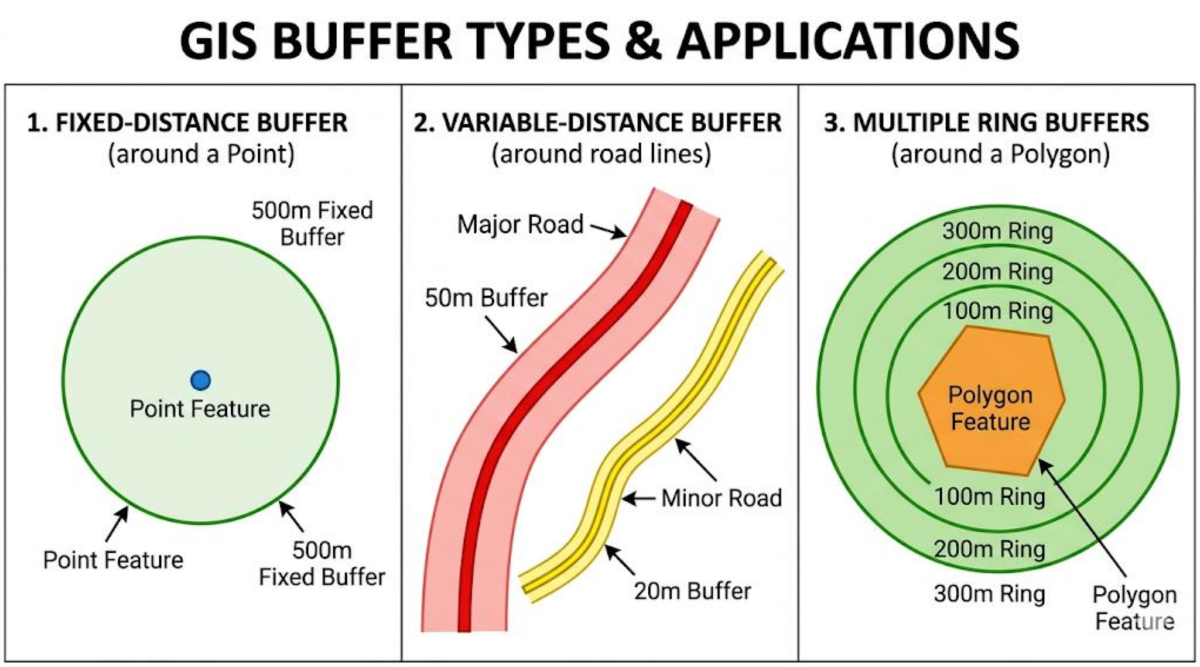
Buffering creates a new polygon layer representing all areas within a specified distance of input features points, lines, or polygons. It is one of the most widely used GIS operations in planning practice because proximity to features is a fundamental criterion in site selection, impact assessment, and zoning analysis.

Types of buffer include:

- **Fixed-distance buffer:** A uniform zone of the same width around all features for example, a 500-metre buffer around all primary schools to define a walking-catchment area.
- **Variable-distance buffer:** Different buffer widths applied to features based on an attribute value for example, wider noise impact zones around motorways than around local roads.
- **Multiple ring buffer:** Concentric zones at increasing distances from a feature for example, 100 m, 250 m, and 500 m rings around a proposed industrial facility to grade impact zones.

Planning applications of buffering include: delineating flood risk zones around watercourses; establishing development setback zones from high-voltage power lines; identifying properties within a proposed compulsory purchase area; and assessing access to public facilities within a walking distance threshold.

Fill in the blank: A buffer that applies different widths to features based on an attribute value such as wider zones around motorways than local roads is called a __________ buffer.



Short description: Diagram showing three buffer examples: a fixed-distance buffer around a point feature, a variable-distance buffer around road lines of different classes, and a multiple ring buffer around a polygon, each labelled.

Figure 3.2 Buffer types: fixed distance, variable distance, and multiple ring buffers

3.2.2 Overlay analysis

Overlay analysis combines two or more spatial layers to produce a new layer whose features and attributes are derived from the inputs. It is the GIS equivalent of placing transparent map sheets on top of each other to see how spatial patterns correspond. The principal overlay operations are:

- **Intersect:** Retains only the features and areas that fall within the spatial extent of both input layers. Used, for example, to identify parcels that are both within a flood zone and designated for residential development.
- **Union:** Combines all features from both input layers into a single output, preserving all geometry and attributes. Used to merge planning zones from two administrative datasets covering adjacent areas.
- **Erase (Difference):** Removes the area of one layer from another, leaving only the features that do not overlap. Used, for example, to exclude protected areas from a developable land dataset.
- **Identity:** Combines two layers but retains the full extent of the first (primary) layer, adding attributes from the second layer where they overlap.
- **Spatial join:** Transfers attributes from one layer to another based on spatial relationships (containment, proximity, intersection) rather than a shared field for example, assigning the ward name to each school point based on which ward polygon contains it.

Fill in the blank: The overlay operation that retains only features falling within the spatial extent of both input layers is called the __________ overlay.

3.2.3 Dissolve, clip, and other geoprocessing tools

Beyond buffering and overlay, GIS provides a range of geoprocessing tools for restructuring and extracting spatial data:

- **Dissolve:** Merges adjacent or overlapping features that share the same attribute value into a single feature. For example, dissolving land parcels by land use class produces a simplified land use map with one polygon per class.
- **Clip:** Extracts the portion of one layer that falls within the boundary of another (the clip layer). Used to trim a national road network dataset to the boundary of a study Local Government Area.
- **Merge:** Combines multiple layers of the same geometry type into a single layer for example, merging ward boundary files from all states into a national boundary dataset.
- **Select by attribute and Select by location:** Tools that extract a subset of features based on a database query (attribute) or spatial relationship (location) without altering the source layer.
- **Field Calculator:** Computes new attribute values from existing fields for example, calculating population density (persons per km²) from a population count field and an area field.

Fill in the blank: The geoprocessing tool that extracts the portion of one layer falling within the boundary of another is called the __________ tool.

Pilot questions 3.2

1. Define buffering in GIS and give one planning application example.
2. What is the difference between a union overlay and an intersect overlay?
3. *Fill in the blank: The geoprocessing tool that extracts the portion of one layer falling within the boundary of another is called the __________ tool.*
4. What does the dissolve tool do and give one example of its use in planning?
5. What is a spatial join and how does it differ from an attribute table join?

3.3 Raster Analysis Operations

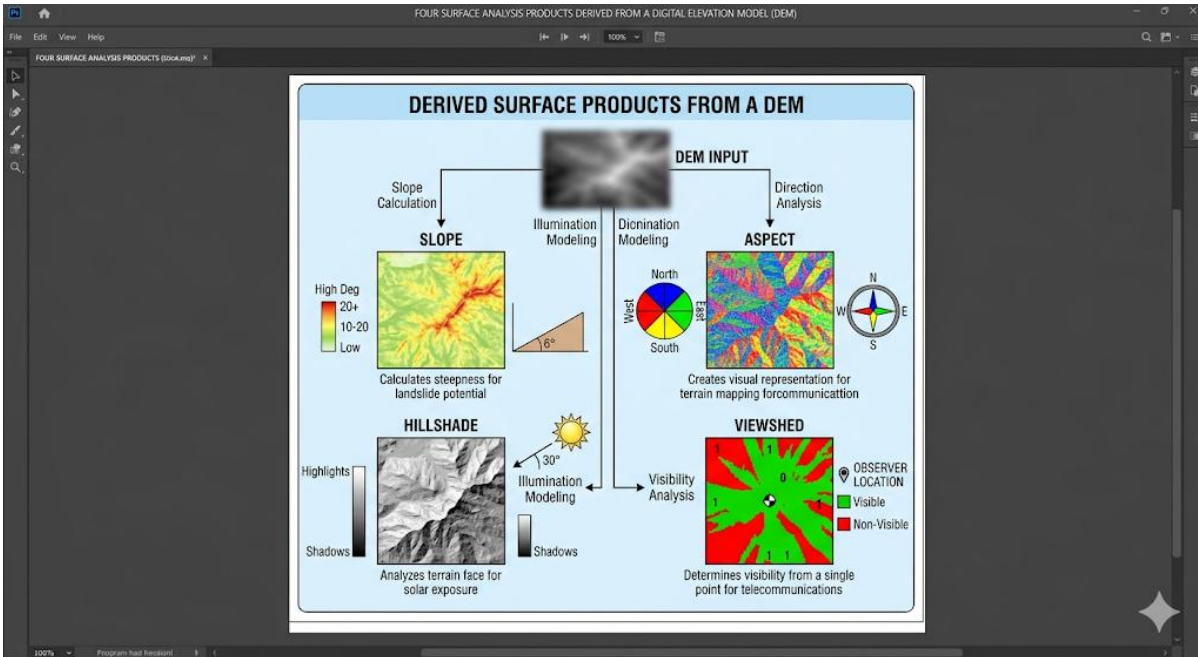
3.3.1 Surface analysis and digital elevation models

A **Digital Elevation Model (DEM)** is a raster dataset in which each cell stores the elevation of the land surface at that location, typically in metres above sea level. DEMs are fundamental inputs for surface analysis in planning, engineering, and environmental management.

Key surface analysis products derived from a DEM include:

- **Slope:** The rate of change of elevation between a cell and its neighbours, expressed in degrees or percent. Slope maps are used to identify land suitable for development, agriculture, or infrastructure, and to assess erosion risk.
- **Aspect:** The compass direction that a slope faces (north, south, east, west). Relevant for solar energy siting, agricultural planning, and ecological habitat assessment.
- **Hillshade:** A shaded relief representation of terrain created by simulating sunlight from a defined direction and elevation angle. Used as a base layer to improve the visual interpretation of terrain in map compositions.
- **Viewshed:** Identifies all areas visible from one or more observer points, given terrain obstruction. Used in telecommunications tower siting, scenic impact assessment, and security planning.
- **Flow direction and watershed delineation:** Determines the direction in which surface water flows from each cell and delineates catchment boundaries essential for flood risk mapping and drainage infrastructure planning.

Fill in the blank: A raster analysis that identifies all areas visible from a defined observer point, based on terrain obstruction, is called a __________ analysis.



Short description: Diagram showing four surface analysis products derived from a DEM: slope, aspect, hillshade, and a viewshed, each displayed as a small raster map with a brief label explaining the information it shows.

Figure 3.3 Surface analysis products derived from a DEM: slope, aspect, hillshade, and viewshed

3.3.2 Reclassification and map algebra

Reclassification reassigns the values of raster cells into a new set of categories, simplifying continuous data for suitability analysis. For example, a slope raster with values ranging from 0 to 60 degrees might be reclassified into three suitability classes:

- 0–8 degrees → Class 1 (Suitable for development)
- 8–20 degrees → Class 2 (Marginal)
- 20–60 degrees → Class 3 (Unsuitable)

Map algebra is the application of mathematical and logical operations to raster layers to produce new raster outputs. Two main types are used:

- **Conditional (Boolean) map algebra:** Applies a logical condition to assign cell values for example, assigning a value of 1 to all cells where slope is below 10 degrees AND land use is not forest, and 0 elsewhere.
- **Weighted overlay:** A multi-criteria analysis technique in which several reclassified raster layers are combined by assigning weights to each layer according to its relative importance. The resulting **suitability score** identifies optimal locations for a facility, development, or land use for example, finding the best location for a new primary school based on slope, accessibility, population density, and distance from existing schools.

Fill in the blank: A raster operation that applies a logical condition such as marking cells where slope is below 10 degrees is a form of __________ map algebra.

Step	Description
1. Define the objective	State the planning question e.g., 'Identify land suitable for a new health centre within Abuja Municipal Area Council.'
2. Select criteria layers	Choose raster inputs relevant to suitability slope, land use, distance from roads, distance from existing health centres, population density.
3. Reclassify each layer	Reclassify all inputs to a common suitability scale (e.g., 1 = Unsuitable to 5 = Highly Suitable).
4. Assign weights	Assign percentage weights to each layer based on expert judgement or stakeholder input e.g., population density 30%, distance from roads 25%, slope 20%, land use 15%, distance from existing facilities 10%.
5. Run weighted overlay	Multiply each reclassified layer by its weight and sum the products to produce a composite suitability score for every cell.
6. Interpret results	Identify cells or zones with the highest suitability scores as candidate sites. Verify against ground conditions and planning constraints.

Box 3.1 Weighted overlay suitability analysis: steps and example
Short description: A table summarising the six steps of a weighted overlay suitability analysis, with an example applied to locating a new health centre in Abuja.

3.3.3 Raster to vector conversion and integration

GIS analysis frequently requires moving data between raster and vector formats to combine the analytical strengths of each data model.

- **Raster to vector conversion (vectorisation):** Converts raster cells into vector features. Continuous raster zones (e.g., land cover classes from a classified satellite image) are converted to polygons. Raster lines (e.g., stream channels extracted from a DEM) are converted to polylines. Care is needed because vectorisation simplifies cell boundaries and some spatial detail is lost.
- **Vector to raster conversion (rasterisation):** Converts vector features into a raster grid. Polygon boundaries are approximated by cell edges; features smaller than the cell size may be lost. The choice of cell size is critical a cell size too large loses spatial detail, while one too small creates unnecessarily large files.
- **Raster-vector integration in analysis:** A typical planning workflow combines both formats for example, using vector road and settlement data for network analysis while using raster DEMs for terrain and flood analysis, then overlaying vector planning zones onto raster suitability maps to extract summary statistics by zone.

Fill in the blank: The process of converting raster land cover zones into polygon vector features is called __________, while the reverse process converting polygon features to a grid is called rasterisation.

Pilot questions 3.3

1. What is a Digital Elevation Model and name three surface analysis products that can be derived from it.
2. What is reclassification in raster GIS and give one example of its use in a suitability analysis.
3. *Fill in the blank: A raster operation that applies a logical condition to assign values to cells for example, marking cells where slope is below 10 degrees is a form of __________ map algebra.*
4. What is weighted overlay and for what type of planning problem is it used?
5. What information is lost when a vector layer is rasterised and how can this be minimised?

3.4 Network Analysis and Spatial Statistics

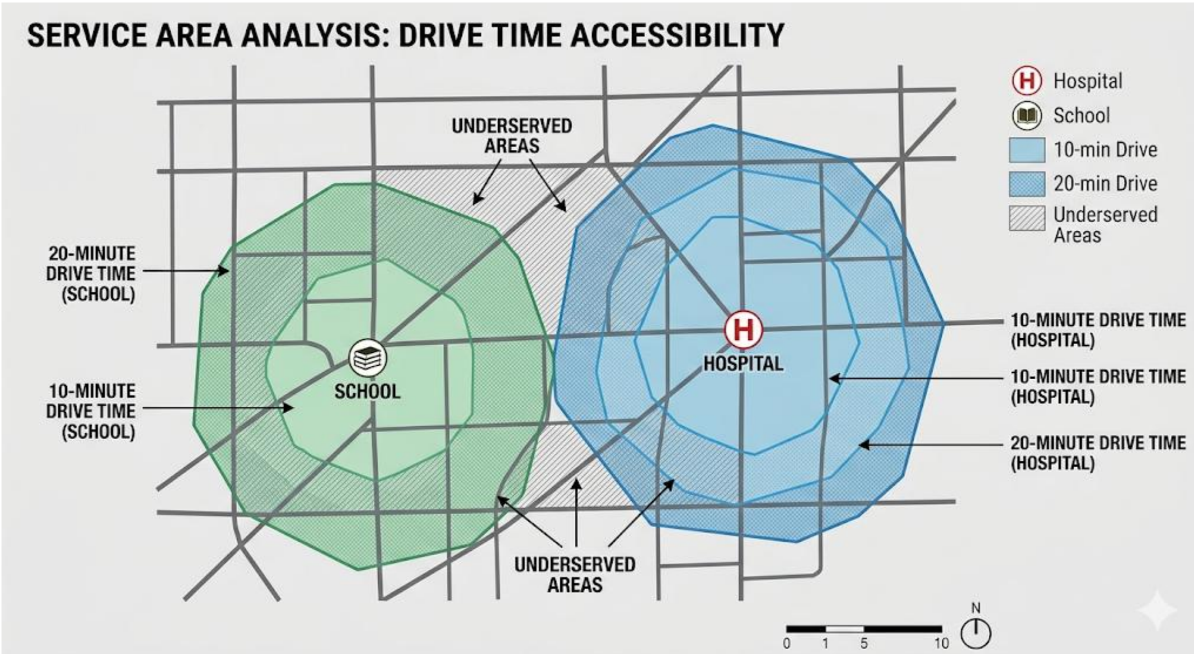
3.4.1 Network analysis: routing and service areas

Network analysis uses a topologically connected road or utility network dataset a **network dataset** to model movement, measure travel costs, and define service areas. Unlike simple straight-line distance measurements, network analysis respects real-world constraints: travel on roads, one-way streets, speed limits, and turn restrictions.

The principal network analysis operations are:

- **Shortest path (route) analysis:** Finds the optimal path between an origin and one or more destinations, minimising distance, time, or another cost attribute. Planning applications include emergency vehicle routing, school bus route optimisation, and utility maintenance scheduling.
- **Service area analysis:** Defines the area reachable from a facility within a specified travel cost for example, all areas within a 10-minute or 20-minute drive of a hospital. Service areas reveal which populations are well-served and which are underserved by essential facilities, directly informing facility location decisions and equity assessments.
- **Closest facility analysis:** For each demand point (e.g., an incident location or a residential area), identifies the nearest facility (e.g., fire station, market, or health centre) and calculates the travel time or distance to it.
- **Origin-destination (OD) cost matrix:** Calculates travel costs between all combinations of origins and destinations used in transportation planning, retail catchment analysis, and public transport accessibility assessment.

Fill in the blank: A network analysis that defines all areas reachable from a facility within a specified travel cost such as a 10-minute drive from a hospital is called a __________ analysis.



Short description: Diagram showing a road network with two service area polygons drawn around a hospital and a school, illustrating the area reachable within a 10-minute and 20-minute drive time, with underserved areas outside both service areas shaded.

Figure 3.4 Network service area analysis: drive-time catchments around a hospital and a school

3.4.2 Spatial statistics and pattern analysis

Spatial statistics quantify the distribution, pattern, and relationship of geographic features in a way that accounts for spatial proximity recognising that nearby things tend to be more similar than distant things (Tobler's First Law of Geography).

Key spatial statistical tools in planning GIS include:

- **Point density and kernel density estimation (KDE):** KDE produces a smooth continuous surface showing the concentration of point events such as crime incidents, traffic accidents, or market locations across an area. High-density zones are immediately visible without requiring manual count by area unit.
- **Nearest neighbour analysis:** Measures whether point features are clustered, randomly distributed, or regularly spaced, by comparing observed mean distances between features to what would be expected under random distribution.
- **Spatial autocorrelation (Moran's I):** Measures whether similar values of an attribute (e.g., household income, population density) tend to cluster together in space. A positive Moran's I value indicates clustering; a negative value indicates dispersion.
- **Hot spot analysis (Getis-Ord Gi*):** Identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots) within a dataset used in crime analysis, disease mapping, and infrastructure investment targeting.

Fill in the blank: A spatial statistical method that produces a smooth surface showing the concentration of point events across an area is called __________ density estimation.

3.4.3 GIS analysis workflows in planning practice

Professional GIS analysis in planning is not a single operation but a structured **workflow** a sequence of documented steps that converts raw spatial data into evidence-based planning outputs. A well-structured workflow is reproducible, auditable, and communicable to other planners and stakeholders.

A typical GIS analysis workflow in planning practice comprises the following stages:

- **1. Problem definition:** State the planning question clearly what decision must be made, what spatial information is needed, and what output is required?
- **2. Data inventory and assessment:** Identify available datasets, check their coordinate systems, currency, completeness, and accuracy. Obtain missing data through survey, digitizing, or secondary sources.
- **3. Data preparation:** Reproject datasets to a common coordinate system; clip to the study area; correct topology errors; join attribute tables as required.
- **4. Analysis:** Execute the planned sequence of GIS operations buffering, overlay, raster analysis, network analysis, or spatial statistics using the prepared data.
- **5. Validation and quality check:** Review outputs for spatial and attribute errors. Verify results against independent data where possible.
- **6. Output production:** Produce maps, tables, and summary statistics in formats appropriate for the audience printed maps for public exhibitions, web maps for broader sharing, tabular reports for committee papers.
- **7. Documentation:** Record all data sources, processing steps, software versions, and analytical decisions in a **metadata** record and processing log. Documentation enables results to be replicated, reviewed, and updated as new data becomes available.

Fill in the blank: Recording all data sources, processing steps, and analytical decisions in a processing log and metadata record is called __________, and ensures that a GIS analysis can be replicated and reviewed.

Pilot questions 3.4

1. What is shortest path analysis and give one planning application example.
2. What is kernel density estimation and what kind of planning problem can it help address?
3. State two spatial statistics that can be used to describe the distribution of point features.
4. Why is documentation an important stage of a GIS analysis workflow?
5. *Fill in the blank: Recording all data sources, processing steps, and analytical decisions in a processing log is called __________, and ensures GIS analysis can be replicated and reviewed.*

Series Summary

This Series has examined the principal GIS operations used in editing, geoprocessing, and spatial analysis. We began with data editing and digitizing, covering the creation and modification of vector features using vertex editing and snapping, on-screen digitizing from georeferenced imagery and scanned paper maps, and georeferencing the process of assigning coordinate references to raster images using ground control points, evaluated through the Root Mean Square Error.

We then explored vector analysis operations: buffering (fixed-distance, variable-distance, and multiple ring buffers) for proximity analysis; overlay operations (intersect, union, erase, identity, and spatial join) for combining spatial layers; and geoprocessing tools (dissolve, clip, merge, select by location, and field calculator) for restructuring and extracting data. Following this, we examined raster analysis operations, including surface analysis products derived from Digital Elevation Models (slope, aspect, hillshade, viewshed, and watershed), reclassification and map algebra for suitability analysis, weighted overlay as a multi-criteria decision tool, and raster-to-vector and vector-to-raster conversion for integrating both data models.

Finally, we addressed network analysis shortest path, service area, closest facility, and OD cost matrix and spatial statistics kernel density estimation, nearest neighbour analysis, spatial autocorrelation (Moran's I), and hot spot analysis (Getis-Ord Gi*). We concluded by outlining a seven-stage GIS analysis workflow applicable to planning practice, emphasising the importance of documentation and metadata for reproducibility. By engaging with all four parts, you should now be able to edit and georeference spatial data, apply vector and raster analysis operations, conduct network and statistical analysis, and structure a documented GIS workflow in accordance with the Series Learning Outcomes.

Glossary of Terms

- **Aspect:** The compass direction that a slope faces, derived from a Digital Elevation Model; used in solar energy siting, ecological habitat assessment, and agricultural planning.
- **Buffering:** A GIS operation that creates a polygon zone representing all areas within a specified distance of input point, line, or polygon features.
- **Clip:** A geoprocessing tool that extracts the portion of one spatial layer that falls within the boundary of another (the clip layer).
- **Conditional map algebra:** A raster operation that applies logical conditions (e.g., AND, OR, NOT) to assign output cell values based on whether cells meet specified criteria.
- **Coordinate transformation:** The mathematical conversion of spatial data from one coordinate reference system to another for example, from Minna datum to WGS84.
- **Digital Elevation Model (DEM):** A raster dataset in which each cell stores the elevation of the land surface at that location, typically in metres above sea level.
- **Digitizing:** The process of converting spatial features from an analogue or raster source into digital vector data by tracing features on-screen or on a digitising tablet.
- **Dissolve:** A geoprocessing tool that merges adjacent or overlapping features sharing the same attribute value into a single feature.

- **Georeferencing:** The process of assigning geographic coordinates to a raster image so that it aligns correctly with other spatial datasets in a defined coordinate reference system.
- **Ground control points (GCPs):** Well-defined locations identifiable in both a raster image and a reference dataset, used to calculate a georeferencing transformation.
- **Hot spot analysis (Getis-Ord Gi*):** A spatial statistical method that identifies statistically significant spatial clusters of high (hot spots) and low (cold spots) attribute values.
- **Intersect overlay:** An overlay operation that retains only the features and areas falling within the spatial extent of both input layers.
- **Kernel density estimation (KDE):** A spatial statistical method that produces a smooth continuous surface showing the concentration of point events across an area.
- **Map algebra:** The application of mathematical and logical operations to raster layers to produce new raster outputs, including conditional and weighted overlay operations.
- **Network analysis:** GIS analysis performed on a topologically connected network dataset (typically a road network) to model movement, calculate travel costs, and define service areas.
- **Reclassification:** A raster operation that reassigns existing cell values into a new set of categories, typically to simplify continuous data for suitability or multi-criteria analysis.
- **Root Mean Square Error (RMSE):** A measure of the average positional discrepancy between ground control points and their transformed positions after georeferencing; a lower RMSE indicates higher accuracy.
- **Service area analysis:** A network analysis operation that defines all areas reachable from a facility within a specified travel cost, such as a 10-minute drive time.
- **Snapping:** A GIS editing function that automatically aligns newly digitised vertices to existing features, preventing gaps and overlaps and maintaining topological integrity.
- **Spatial autocorrelation (Moran's I):** A spatial statistic measuring whether similar attribute values tend to cluster together in space (positive autocorrelation) or are dispersed (negative autocorrelation).
- **Topological integrity:** The maintenance of correct spatial relationships between GIS features such as shared boundaries without gaps or overlaps essential for accurate overlay and network analysis.
- **Union overlay:** An overlay operation that combines all features from both input layers into a single output, preserving all geometry and attributes from each.
- **Vectorisation:** The conversion of raster data into vector format for example, converting classified land cover raster cells into polygon features.
- **Viewshed:** A raster surface analysis product that identifies all areas visible from one or more observer points given terrain obstruction, derived from a Digital Elevation Model.
- **Weighted overlay:** A multi-criteria raster analysis technique in which reclassified layers are combined using assigned percentage weights to produce a composite suitability score.

Concept Check Questions 3

Objective Questions

1. State two editing operations that can be performed on a vector feature in GIS. (Linked to SLO 3.1)

2. Name three types of buffer and give a planning example of each. (Linked to SLO 3.2)

3. Fill in the blank: The raster analysis that identifies all areas visible from a defined observer point, based on terrain obstruction, is called a __________ analysis. (Linked to SLO 3.3)

4. State one planning application of network service area analysis. (Linked to SLO 3.4)

Short-Answer Questions

5. Distinguish between an intersect overlay and a union overlay, and give one planning example of each. (Linked to SLO 3.2)

6. Describe the process of georeferencing, including the role of ground control points and the meaning of RMSE. (Linked to SLO 3.1)

7. Explain what reclassification is in raster GIS and describe how it is used in a weighted overlay suitability analysis. (Linked to SLO 3.3)

8. What is spatial autocorrelation and why is it important in planning analysis? (Linked to SLO 3.4)

Long-Answer Questions

9. A planning agency must identify the most suitable locations for new primary schools within a rapidly growing peri-urban area of Abuja. Describe how you would use GIS including both vector and raster analysis operations to address this problem. (Linked to SLOs 3.2 and 3.3)

10. Explain why a structured, documented GIS analysis workflow is essential in planning practice. In your answer, describe each stage of the workflow and discuss the consequences of inadequate data preparation and documentation in a Nigerian planning context. (Linked to SLO 3.4)

Answers to Concept Check Questions 3

Objective Questions

1. Any two: move a feature, reshape a boundary by repositioning vertices, split a feature into two, merge two features into one, add or delete vertices.

2. Fixed-distance buffer: a uniform zone around all features e.g., a 500-metre buffer around all primary schools to define a walking catchment. Variable-distance buffer: different widths based on an attribute e.g., wider noise zones around motorways than local roads. Multiple ring buffer: concentric zones at increasing distances e.g., 100 m, 250 m, and 500 m rings around a proposed landfill to grade impact severity.

3. Viewshed.

4. Any one: identifying populations within a 10-minute drive of a hospital; determining which residential areas are within a 30-minute emergency response time from a fire station; assessing access to secondary schools by travel time.

Short-Answer Questions

5. An intersect overlay retains only features and areas that fall within the spatial extent of both input layers for example, identifying parcels that are both within a flood zone and zoned for residential use. A union overlay combines all features from both layers for example, merging planning zone datasets from two adjacent local government areas into a single seamless layer.

6. Georeferencing assigns geographic coordinates to a raster image (such as a scanned topographic map) so it aligns with other spatial data. Ground control points (GCPs) are well-defined locations identifiable in both the image and a reference dataset; the GIS calculates a transformation that moves image pixels to match the GCP coordinates. RMSE quantifies the average positional discrepancy between the GCPs and their transformed positions a low RMSE (ideally below one pixel) indicates a successful georeferencing result.

7. Reclassification reassigns raster cell values into simplified categories for example, converting a continuous slope raster into three classes (Suitable, Marginal, Unsuitable). In weighted overlay, each criterion layer is first reclassified to a common suitability scale (e.g., 1–5). The reclassified layers are then combined using percentage weights (reflecting each criterion's relative importance) to produce a composite suitability score identifying optimal sites.

8. Spatial autocorrelation measures whether similar attribute values tend to cluster together in space (positive) or are dispersed (negative). It is important in planning because many planning variables such as poverty, housing quality, and crime exhibit spatial clustering. Identifying these clusters informs targeted interventions, reveals equity disparities, and helps planners avoid drawing false conclusions from aggregate statistics that mask spatial variation.

Long-Answer Questions

9.

- **Basic response:** Vector analysis buffer existing schools to identify underserved areas; overlay with ward population data to identify high-demand zones; clip to developable land. Raster analysis reclassify slope and land use layers for suitability; run weighted overlay to produce a composite suitability surface; identify highest-scoring cells as candidate sites.
- **Value-added response:** Extend the analysis by adding network service area analysis to measure actual travel-time access (rather than straight-line distance) from residential areas to existing schools. Include a kernel density layer of school-age population to weight demand. Validate shortlisted sites against infrastructure capacity (water, electricity, road access) and land tenure data. Document each analytical step to ensure the workflow can be reviewed, replicated, and updated as new data becomes available.

10.

- **Basic response:** A structured workflow ensures that analysis is reproducible and that outputs can be reviewed and defended. The seven stages are: problem definition, data inventory, data preparation, analysis, validation, output production, and documentation. Skipping stages particularly data preparation and documentation leads to errors that may not be detected until decisions have already been made.
- **Value-added response:** In the Nigerian planning context, inadequate data preparation is particularly consequential because many available datasets are in different coordinate systems (Minna datum vs. WGS84), are incomplete, or are of uncertain currency. Failing to reproject and validate data before analysis can cause overlays to misalign by 50–100

metres enough to misidentify parcels, miscount affected populations, or misroute infrastructure. Inadequate documentation is equally costly: when staff change (a common occurrence in Nigerian agencies), undocumented workflows cannot be replicated or updated, wasting the investment in data collection. Structured, documented GIS workflows are therefore not bureaucratic overhead but essential professional practice.

Answers to Pilot Questions 3

Part 3.1

1. Any two: move, reshape, split, merge, add/delete vertices.
2. On-screen digitizing traces features on a georeferenced image; accuracy depends on image resolution, scale, and operator care.
3. Ground control points are locations identifiable in both image and reference data; they enable accurate transformation.
4. Error.

Part 3.2

1. Buffering creates zones around features (e.g., 300 m buffer around a road).
2. Union keeps all features/attributes; intersect keeps overlap only.
3. Clip.
4. Dissolve merges features with the same attribute (e.g., parcels by land use).
5. Spatial join links by location; table join links by shared field.

Part 3.3

1. DEM stores elevation; products include slope, aspect, hillshade, viewshed, watershed.
2. Reclassification groups raster values into categories (e.g., slope suitability).
3. Conditional.
4. Weighted overlay combines reclassified layers with weights for site selection.
5. Rasterising approximates boundaries; small features may be lost unless cell size is small.

Part 3.4

1. Shortest path finds optimal route (e.g., ambulance routing).
2. Kernel density maps event concentrations (e.g., crime hotspots, accident sites).
3. Any two: nearest neighbour index, Moran's I, Getis-Ord Gi*, kernel density.
4. Documentation records sources, steps, and decisions for replication and verification.
5. Documentation.

References and Attributions 3

Course Content References

- Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Hoboken, NJ: Wiley.
- Mitchell, A. (2005). *The Esri guide to GIS analysis, Volume 2: Spatial measurements and statistics.* Redlands, CA: Esri Press.
- QGIS Development Team. (2024). *QGIS user guide: Vector analysis and raster analysis chapters.* Retrieved from https://docs.qgis.org
- Esri. (2023). *ArcGIS Pro: Geoprocessing and network analysis documentation.* Retrieved from https://pro.arcgis.com

Illustrations

- *Figure 3.1* GIS vector editing: reshaping a polygon boundary with vertex editing and snapping.
  - AI-generated prompt: "Generate a diagram illustrating a GIS editing session showing a polygon boundary being reshaped by repositioning vertices, with snapping enabled to adjacent parcels and an attribute table open for data entry."
  - Suggested OER search string: "GIS vector editing vertex snapping polygon topology diagram OER."
- *Figure 3.2* Buffer types: fixed distance, variable distance, and multiple ring buffers.
  - AI-generated prompt: "Generate a diagram showing three buffer examples: a fixed-distance buffer around a point, a variable-distance buffer around road lines of different classes, and multiple ring buffers around a polygon, each labelled."
  - Suggested OER search string: "GIS buffer types fixed variable multiple ring buffer diagram OER."
- *Figure 3.3* Surface analysis products derived from a DEM: slope, aspect, hillshade, and viewshed.
  - AI-generated prompt: "Generate a diagram showing four surface analysis products derived from a digital elevation model: slope, aspect, hillshade, and viewshed, each as a small raster map with a label."
  - Suggested OER search string: "DEM surface analysis slope aspect hillshade viewshed raster diagram OER."
- *Box 3.1* Weighted overlay suitability analysis: steps and example.
  - AI-generated prompt: "Generate a table summarising the six steps of a weighted overlay suitability analysis for locating a new health centre, showing objective, criteria selection, reclassification, weighting, overlay, and result interpretation."
  - Suggested OER search string: "weighted overlay suitability analysis GIS multi-criteria steps diagram OER."
- *Figure 3.4* Network service area analysis: drive-time catchments around a hospital and a school.
  - AI-generated prompt: "Generate a diagram showing a road network with two service area polygons around a hospital and a school, illustrating areas reachable within 10-minute and 20-minute drive times, with underserved areas shaded."
  - Suggested OER search string: "GIS network service area drive time catchment hospital school diagram OER."

Attributions

- All AI prompts are intended for use with generative tools to create original illustrations.
- Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.

Course code: URP 316
Course title: Principles of GIS and AutoCAD
Course credit load: 2 Units

List of Series:

- Series 1: Fundamentals and Components of GIS
- Series 2: Spatial Data Models and Database Structures
- Series 3: GIS Operations, Editing and Accuracy Assessment
- **Series 4: Integration of Remote Sensing, GPS and GIS**
- Series 5: GIS Applications in Urban and Regional Planning

4 Integration of Remote Sensing, GPS and GIS

Series outline

- **Part 1 (4.1): Principles of Remote Sensing**
  Sub-Part 4.1.1: The electromagnetic spectrum and energy interactions
  Sub-Part 4.1.2: Satellite and aerial remote sensing platforms
  Sub-Part 4.1.3: Spatial, spectral, temporal, and radiometric resolution
- **Part 2 (4.2): Image Interpretation and Classification**
  Sub-Part 4.2.1: Visual image interpretation
  Sub-Part 4.2.2: Digital image classification
  Sub-Part 4.2.3: Accuracy assessment of classified imagery
- **Part 3 (4.3): GPS Technology and Field Data Collection**
  Sub-Part 4.3.1: GPS principles and components
  Sub-Part 4.3.2: GPS accuracy and error sources
  Sub-Part 4.3.3: Field data collection with GPS
- **Part 4 (4.4): Integrating Remote Sensing and GPS with GIS**
  Sub-Part 4.4.1: Importing and georeferencing remote sensing data in GIS
  Sub-Part 4.4.2: Integrating GPS field data with GIS
  Sub-Part 4.4.3: Combined workflows for planning applications

Introduction
Modern GIS does not work in isolation. The spatial data it analyses, displays, and communicates must come from somewhere and two of the most powerful sources of geographic data available to the contemporary planner are **remote sensing** and the **Global Positioning System (GPS)**. Remote sensing provides synoptic, regularly updated imagery of the earth's surface captured by satellite and airborne sensors. GPS provides precise, real-time geographic coordinates for features observed or measured in the field. Together, and integrated within a GIS, these technologies give the planner an unprecedented capacity to map, monitor, and analyse the built and natural environment at any scale.

The aim of this Series is to introduce you to the principles of remote sensing and GPS technology and to equip you to integrate imagery and field-collected data into a GIS for planning applications.

We shall commence this Series by examining the **Principles of Remote Sensing** describing the electromagnetic spectrum, the satellite and aerial platforms that carry remote sensing instruments, and the four types of resolution that determine the utility of imagery for a given planning task. Next, we will explore **Image Interpretation and Classification** covering the elements of visual interpretation, the methods of supervised and unsupervised digital classification, and the accuracy assessment techniques used to evaluate classification quality. Following that, we will examine **GPS Technology and Field Data Collection** explaining how the GPS system works, identifying the principal sources of positional error, and describing practical field data collection methods and equipment. Finally, we will bring these strands together by exploring **Integrating Remote Sensing and GPS with GIS** covering georeferencing, data import workflows, and combined multi-source analytical processes applicable to planning practice in Nigeria.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** describe the principles of remote sensing and explain the significance of spatial, spectral, temporal, and radiometric resolution,
- **SLO 4.2** apply the elements of visual interpretation and describe the methods of supervised and unsupervised digital image classification and accuracy assessment,
- **SLO 4.3** explain the principles of GPS, identify the sources of GPS error, and describe the methods used for field data collection,
- **SLO 4.4** integrate remote sensing imagery and GPS field data with GIS and apply combined workflows to planning problems.

4.1 Principles of Remote Sensing

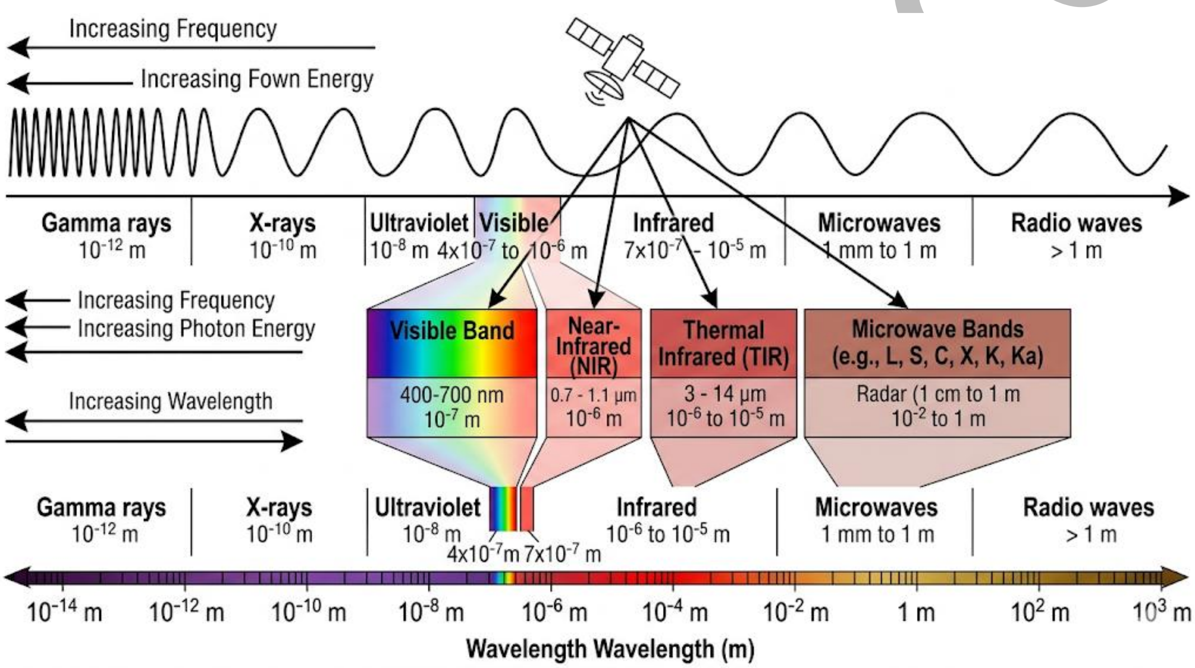
4.1.1 The electromagnetic spectrum and energy interactions

Remote sensing is the science of acquiring information about the earth's surface without direct physical contact, using sensors that detect and record **electromagnetic energy** reflected or emitted from surface features. Every material on the earth's surface vegetation, bare soil, water, urban fabric interacts with electromagnetic energy in a characteristic way, absorbing certain wavelengths and reflecting or emitting others. This characteristic pattern is called a **spectral signature**, and it is the basis for identifying and mapping surface features from remote sensing data.

The **electromagnetic spectrum** is the continuum of all electromagnetic radiation, ranging from very short wavelengths (gamma rays and X-rays) through visible light to very long wavelengths (microwave and radio waves). Remote sensing instruments operate across different portions of this spectrum. **Optical sensors** detect reflected solar radiation in the visible (0.4–0.7 μm) and near-infrared (0.7–1.3 μm) bands. **Thermal infrared sensors** detect emitted heat radiation (8–14 μm), enabling mapping of surface temperature and heat island effects in cities. **Radar sensors** transmit and receive microwave energy (1 mm–1 m), penetrating cloud cover and enabling all-weather, day-and-night imaging.

When electromagnetic energy encounters a surface, three interactions are possible: **reflection** (energy bounced back from the surface), **absorption** (energy retained by the surface, often converted to heat), and **transmission** (energy passing through the surface). The proportions of reflected, absorbed, and transmitted energy vary by wavelength and surface type, producing the distinctive spectral signatures that allow GIS analysts to distinguish vegetation from buildings, water from bare soil, and healthy crops from stressed ones.

Fill in the blank: Remote sensing detects __________ energy reflected or emitted from the earth's surface without direct physical contact with the features being mapped.



Short description: Diagram of the electromagnetic spectrum showing the principal wavelength bands from gamma rays to radio waves, with the portions used by optical, thermal infrared, and radar remote sensing highlighted.

Figure 4.1 The electromagnetic spectrum and the wavelength bands used in remote sensing

4.1.2 Satellite and aerial remote sensing platforms

Remote sensing instruments are carried on **platforms** vehicles or structures that position sensors above the earth's surface. The two principal platform categories are **satellite platforms** and **aerial platforms**.

Satellite platforms carry sensors in orbit, providing synoptic coverage of large areas. Key characteristics include **orbit type** (most earth observation satellites use sun-synchronous polar orbits, passing over the same location at the same local solar time), **swath width** (the strip of ground imaged in a single pass), and **revisit frequency** (the interval between successive images of the same location). Satellites widely used for land use and planning applications include Landsat 8/9 (30 m multispectral, free global archive), Sentinel-2 (10–20 m, free, 5-day revisit), and commercial platforms such as WorldView and Pléiades that provide sub-metre resolution imagery.

Aerial platforms carry sensors on aircraft or, increasingly, **Unmanned Aerial Vehicles (UAVs/drones)**. Aerial surveys provide much higher spatial resolution than satellite imagery, making them suitable for large-scale mapping of individual buildings and infrastructure. In Nigeria, the Office of the Surveyor-General of the Federation (OSGOF) and State Government agencies commission periodic aerial photography, though coverage and currency are inconsistent across states. UAV surveys have recently become accessible to planning agencies, enabling rapid, low-cost mapping of urban growth areas, informal settlements, and construction sites.

Fill in the blank: The interval between successive satellite images of the same location on the ground is called the satellite's __________ frequency.

4.1.3 Spatial, spectral, temporal, and radiometric resolution

Four types of resolution determine the suitability of a remote sensing dataset for a given planning application:

- **Spatial resolution:** the ground dimension represented by a single pixel, expressed in metres. High spatial resolution (sub-metre to 5 m) enables mapping of individual buildings, roads, and trees. Moderate resolution (10–30 m, e.g., Sentinel-2, Landsat) is suitable for land cover mapping and change detection at the neighbourhood or city scale. Coarse resolution (250 m–1 km, e.g., MODIS) is used for regional and national-scale monitoring.
- **Spectral resolution:** the number and width of spectral bands recorded by the sensor. A **multispectral** sensor records data in a small number of broad bands (typically 3–12), including visible, near-infrared, and shortwave infrared. A **hyperspectral** sensor records data in hundreds of narrow, contiguous bands, enabling detailed material identification. The number and position of spectral bands determines what surface types can be distinguished.
- **Temporal resolution:** the revisit frequency how often the satellite images the same location. High temporal resolution (daily to weekly) supports monitoring of rapid change, such as urban construction, flooding, or crop growth. Lower temporal resolution (monthly or longer) is adequate for slower processes such as land use change detection.
- **Radiometric resolution:** the sensitivity of the sensor the number of discrete levels used to record the intensity of reflected energy. An 8-bit sensor records 256 grey levels; a 16-bit sensor records 65,536 levels. Higher radiometric resolution enables finer discrimination of subtle differences in surface reflectance.

In planning practice, these four resolution types present trade-offs. Very high spatial resolution imagery typically has lower temporal resolution and higher cost. Choosing an appropriate dataset requires matching these resolution characteristics to the scale and purpose of the specific planning analysis.

Fill in the blank: The number of discrete grey levels used to record the intensity of reflected energy is determined by the __________ resolution of the sensor.

Pilot questions 4.1

1. Define remote sensing and explain the concept of spectral signature.
2. Name two satellite platforms that provide imagery useful for land use mapping in Nigeria.
3. What are the four types of resolution in remote sensing and what does each describe?
4. *Fill in the blank: A satellite's revisit frequency determines its __________ resolution, while the ground area covered by each pixel determines its spatial resolution.*

4.2 Image Interpretation and Classification

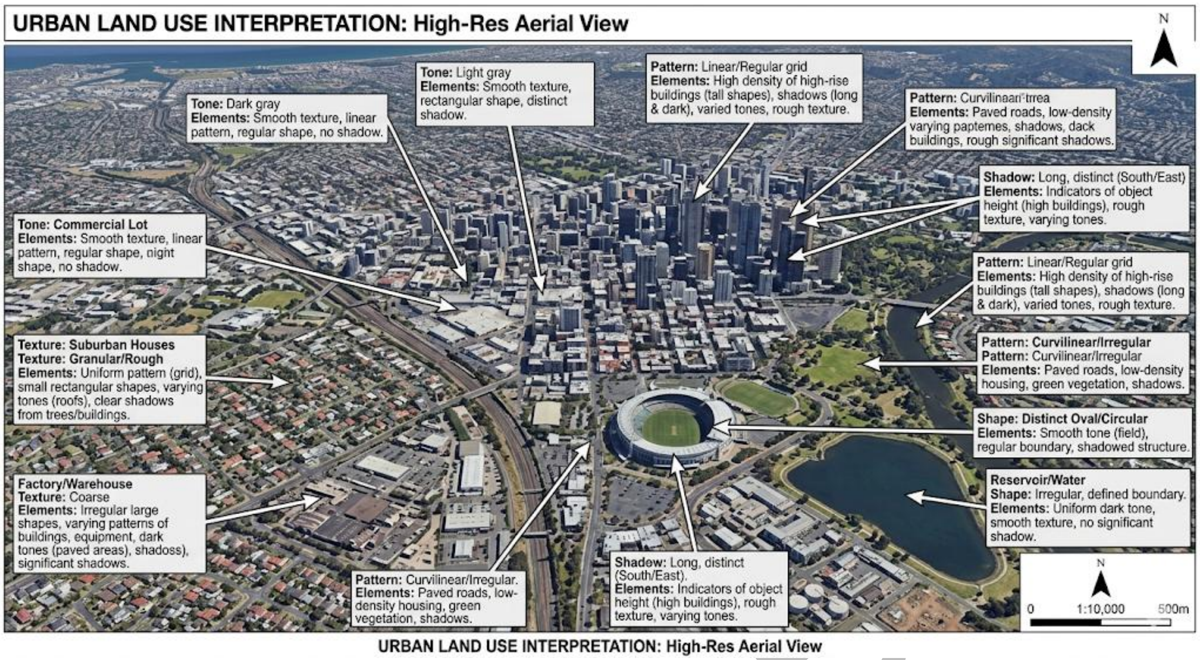
4.2.1 Visual image interpretation

Visual image interpretation is the process by which a trained analyst examines a remotely sensed image and identifies, delineates, and classifies features based on their visual characteristics. Although digital classification methods have largely supplanted manual interpretation for large-area mapping, visual interpretation skills remain essential for verifying digital results, interpreting ambiguous features, and producing detailed maps at large scales.

Seven primary **elements of image interpretation** are used to identify features:

- **Tone/colour:** the relative brightness or hue of features in the image. Light-toned surfaces reflect more energy; dark-toned surfaces absorb more. In a standard false colour composite, healthy vegetation appears bright red because of its high near-infrared reflectance.
- **Texture:** the frequency of tonal variation within an area. Rough surfaces (forest canopy, corrugated roofs) produce coarse texture; smooth surfaces (water, tarmac) produce fine texture.
- **Pattern:** the spatial arrangement of objects. Agricultural fields show regular geometric patterns; informal settlements show irregular patterns.
- **Shape:** the general form of a feature. Rectangular shapes indicate buildings; sinuous linear shapes indicate rivers.
- **Size:** the relative dimensions of a feature. Size provides context for identifying features a small rectangle may be a house; a large rectangle may be a factory or sports stadium.
- **Shadow:** the shadow cast by an object reveals its height and profile. Tall buildings cast long shadows in high-resolution imagery.
- **Association/site:** the relationship between a feature and its surroundings. A blue rectangle adjacent to a playing field and surrounded by buildings is likely a swimming pool.

Fill in the blank: The spatial arrangement of objects in a remotely sensed image for example, the regular geometry of agricultural fields is called the image interpretation element of __________.



Short description: A high-resolution satellite or aerial photograph of an urban area with annotations identifying different land use features using the elements of visual interpretation: tone, texture, pattern, shape, and shadow.

Plate 4.1 Visual image interpretation of an urban area: identifying features by tone, texture, pattern, shape, and shadow

4.2.2 Digital image classification

Digital image classification is the process of assigning every pixel in a remotely sensed image to one of a defined set of land cover categories, based on the spectral characteristics of that pixel. Classification is the principal method for producing land cover and land use maps from multispectral imagery.

Supervised classification requires the analyst to define **training areas** representative samples of each land cover class drawn on the image from known locations, often verified by field survey. The classification algorithm learns the spectral characteristics of each class from the training areas and uses these to classify the remaining pixels. Common supervised classifiers include the **Maximum Likelihood** classifier (assigns each pixel to the class whose spectral distribution it most probably belongs to) and **Support Vector Machine (SVM)** classifiers (draw optimal boundaries between classes in spectral feature space). Supervised classification requires prior knowledge of the classes present but produces well-defined, labelled outputs.

Unsupervised classification requires no prior knowledge of class characteristics. The algorithm groups pixels into clusters based on their spectral similarity using methods such as **K-means** or **ISODATA** and the analyst subsequently assigns meaningful land cover labels to each cluster. Unsupervised classification is useful as an exploratory tool when prior knowledge of the area is limited, but cluster labels must be interpreted carefully and may not correspond cleanly to planning-relevant categories.

Fill in the blank: In supervised classification, representative pixel samples used to define the spectral characteristics of each land cover class are called __________ areas.

4.2.3 Accuracy assessment of classified imagery

No digital classification is perfect. **Accuracy assessment** is the process of quantitatively evaluating the correspondence between the classified map and ground truth the actual land cover at sampled locations. Without accuracy assessment, a classified map has no stated reliability and cannot responsibly be used for planning decisions.

Accuracy assessment is conducted using an **error matrix** (also called a confusion matrix) a table that cross-tabulates the map classification against the reference (ground truth) classification for a sample of points. From the error matrix, several accuracy measures are derived:

- **Overall accuracy:** the proportion of correctly classified sample points across all classes.
- **Producer's accuracy:** the proportion of reference points in a class that were correctly mapped (measures omission error how often a class is missed).
- **User's accuracy:** the proportion of map points assigned to a class that are actually that class in the field (measures commission error how often a class is incorrectly included).
- **Kappa coefficient:** a statistical measure that accounts for agreement expected by chance. A Kappa of 1.0 represents perfect agreement; values above 0.80 are generally considered acceptable for planning applications.

Field verification visiting a sample of mapped locations to check the classification is the most reliable source of ground truth data. In Nigerian planning practice, combining GPS-collected field points with high-resolution imagery interpretation provides a practical and cost-effective accuracy assessment approach.

Fill in the blank: The statistical measure of classification accuracy that accounts for agreement expected by chance is called the __________ coefficient.

Pilot questions 4.2

1. Name five elements used in visual image interpretation and give one example of each.
2. What is the difference between supervised and unsupervised classification?
3. *Fill in the blank: The statistical measure of classification accuracy that accounts for agreement expected by chance is called the __________ coefficient.*
4. What is an error matrix and what accuracy measures can be derived from it?
5. Why should field verification be performed after a digital classification of remote sensing imagery?

4.3 GPS Technology and Field Data Collection

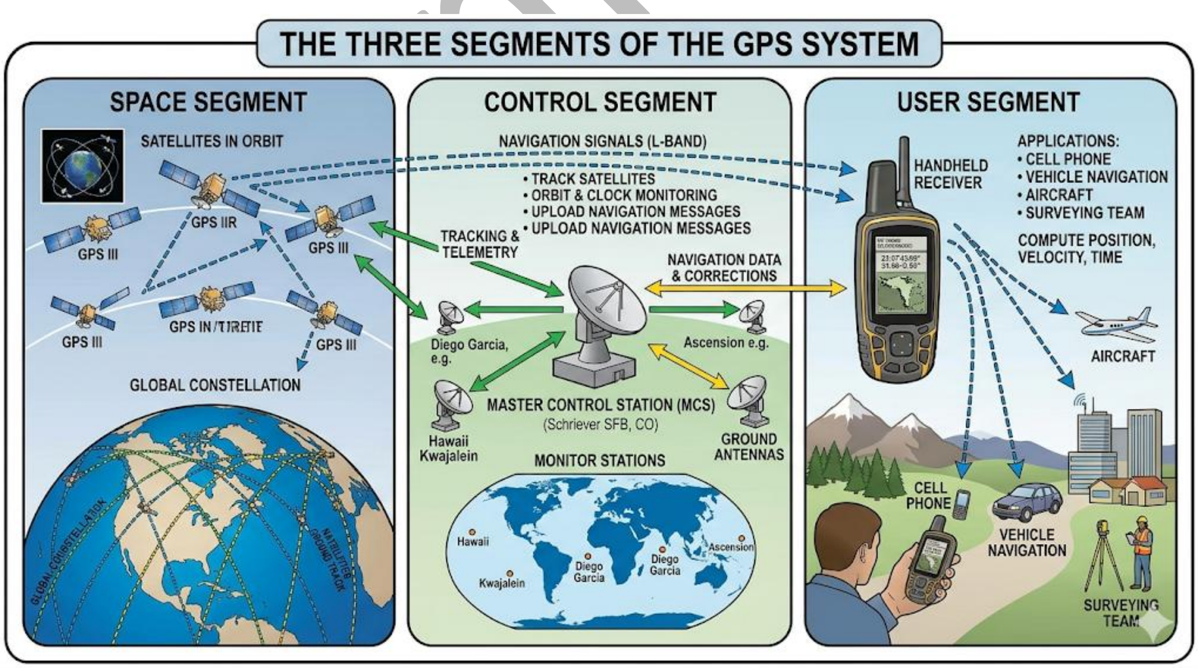
4.3.1 GPS principles and components

The **Global Positioning System (GPS)** is a satellite-based navigation system that enables a receiver anywhere on or near the earth's surface to determine its precise geographic position latitude, longitude, and elevation at any time and in any weather. GPS was developed and is operated by the United States Department of Defense, but its signals are freely available for civilian use worldwide. Equivalent systems operated by other states include Russia's GLONASS, the European Union's Galileo, and China's BeiDou; together, these systems are referred to as **Global Navigation Satellite Systems (GNSS)**.

The GPS system is organised into three **segments**:

- **Space segment:** a constellation of at least 24 operational satellites in medium earth orbit at approximately 20,200 km altitude, arranged in six orbital planes. Each satellite continuously broadcasts a timed radio signal on two frequencies (L1 and L2), carrying precise time information and orbital data (the ephemeris).
- **Control segment:** a network of ground stations that monitors satellite health, measures timing errors, and uploads corrected orbital and clock data to the satellites to maintain system accuracy. The Master Control Station is located at Schriever Air Force Base, Colorado.
- **User segment:** the receivers held or mounted by users. A GPS receiver determines its position by measuring the **pseudorange** the time taken for signals from multiple satellites to reach the receiver. By simultaneously measuring pseudoranges from a minimum of four satellites, the receiver can solve for its three-dimensional position and correct for clock error through a process called **trilateration**.

Fill in the blank: The GPS system calculates position by measuring the travel time of signals from a minimum of __________ satellites simultaneously, enabling the receiver to solve for latitude, longitude, elevation, and clock error.



Short description: Diagram showing the three segments of the GPS system the space segment of satellites in orbit, the control segment of ground stations, and the user segment of a handheld receiver with signal paths shown between them.

Figure 4.2 The three segments of the GPS system: space, control, and user

4.3.2 GPS accuracy and error sources

GPS positioning is subject to a range of error sources that reduce the accuracy of the computed position. Understanding these sources enables the field surveyor to anticipate, minimise, and correct errors in planning field data.

- **Satellite geometry (Dilution of Precision, DOP):** accuracy is maximised when satellites are spread widely across the sky. When satellites cluster together or when line of sight to satellites is blocked by buildings or trees, the **Dilution of Precision (DOP)** value increases, indicating reduced positional accuracy. A DOP value below 2 is considered excellent; values above 5 indicate degraded accuracy.
- **Atmospheric delays:** GPS signals are slowed as they pass through the **ionosphere** and **troposphere**, introducing timing errors. Dual-frequency receivers can correct for ionospheric delay; tropospheric correction models are applied by processing software.
- **Multipath errors:** GPS signals that reflect off buildings, vehicles, or terrain before reaching the receiver travel a longer path, introducing **multipath errors**. Multipath is particularly problematic in dense urban environments a significant consideration for field data collection in Nigerian cities.
- **Receiver clock errors:** low-cost receivers use less precise clocks than those aboard the satellites; the four-satellite solution corrects for this error.

Differential GPS (DGPS) and **Real-Time Kinematic (RTK) GPS** are correction techniques that substantially improve positional accuracy. DGPS uses a fixed reference receiver at a known location to compute corrections applied to the roving receiver's positions, reducing error from several metres to sub-metre. RTK GPS can achieve centimetre-level accuracy and is increasingly used for cadastral survey and infrastructure mapping in Nigeria.

Fill in the blank: GPS signals that reflect off buildings or other surfaces before reaching the receiver introduce __________ errors, which are particularly severe in dense urban environments.

4.3.3 Field data collection with GPS

GPS enables planners to collect precise geographic coordinates for features observed in the field, converting field observations into spatially referenced data that can be imported directly into GIS. Three fundamental feature types can be collected:

- **Point features:** a single coordinate pair recorded at the location of a discrete feature a borehole, a utility pole, a market stall, a heritage tree. Multiple readings averaged over time (**point averaging**) improve accuracy by reducing the effect of random errors.
- **Line features:** a sequence of coordinates recorded as the observer walks along a linear feature a road edge, a drainage channel, a property boundary. The density of recorded points determines the geometric accuracy of the resulting line.

- **Area features:** a closed sequence of coordinates recording the perimeter of an areal feature a market area, a public open space, an informal settlement boundary. The GIS closes the polygon by connecting the last point to the first.

Field data collection equipment ranges from dedicated **GNSS receivers** (handheld units such as the Garmin GPSMAP series or Trimble Juno) to **smartphones** running GPS field collection applications. In Nigeria, smartphone applications including Survey123 for ArcGIS, QField (for QGIS), and Fulcrum are widely used for participatory and rapid urban appraisal surveys. Attribute data photographs, land use observations, infrastructure condition ratings can be collected alongside geographic coordinates in structured digital forms.

Fill in the blank: GPS field data collected as the observer walks along a road edge or drainage channel, recording a sequence of coordinates, produces a __________ feature type in GIS.

Method	***Feature Type***	***Collection Procedure***	***GIS Geometry Produced***	***Planning Example***
Point	*Discrete, localized objects.*	*The user remains stationary at a specific location while the GPS receiver records a single set of coordinates.*	***Point*** *(0-dimensional).*	*Mapping the exact location of a specific* ***illegal dump site*** *or a* ***water sampling point****.*
Line	*Linear or path-based features.*	*The user moves along the feature while the GPS receiver records a series of connected coordinate points at set intervals.*	***Polyline*** *(1-dimensional).*	*Mapping the course of a* ***polluted stream*** *or the boundary of a* ***proposed access road****.*
Area	*Closed shapes or bounded regions.*	*The user walks the entire perimeter of the feature, and the GPS software automatically closes the loop between the start and end points.*	***Polygon*** *(2-dimensional).*	*Delineating the total area of a* ***deforested patch*** *or the extent of a* ***protected wetland****.*

GPS data collection methods: points, lines, and areas a summary of feature types, collection procedures, and GIS geometry outputs.

Pilot questions 4.3

1. Describe the three segments of the GPS system and explain the role of each.
2. What is Dilution of Precision and how does satellite geometry affect GPS accuracy?
3. *Fill in the blank: GPS errors caused by signals reflecting off buildings before reaching the receiver are called __________ errors.*

4. What is Differential GPS and how does it improve positioning accuracy?
5. State two smartphone applications used for GPS data collection in Nigerian planning fieldwork.

4.4 Integrating Remote Sensing and GPS with GIS

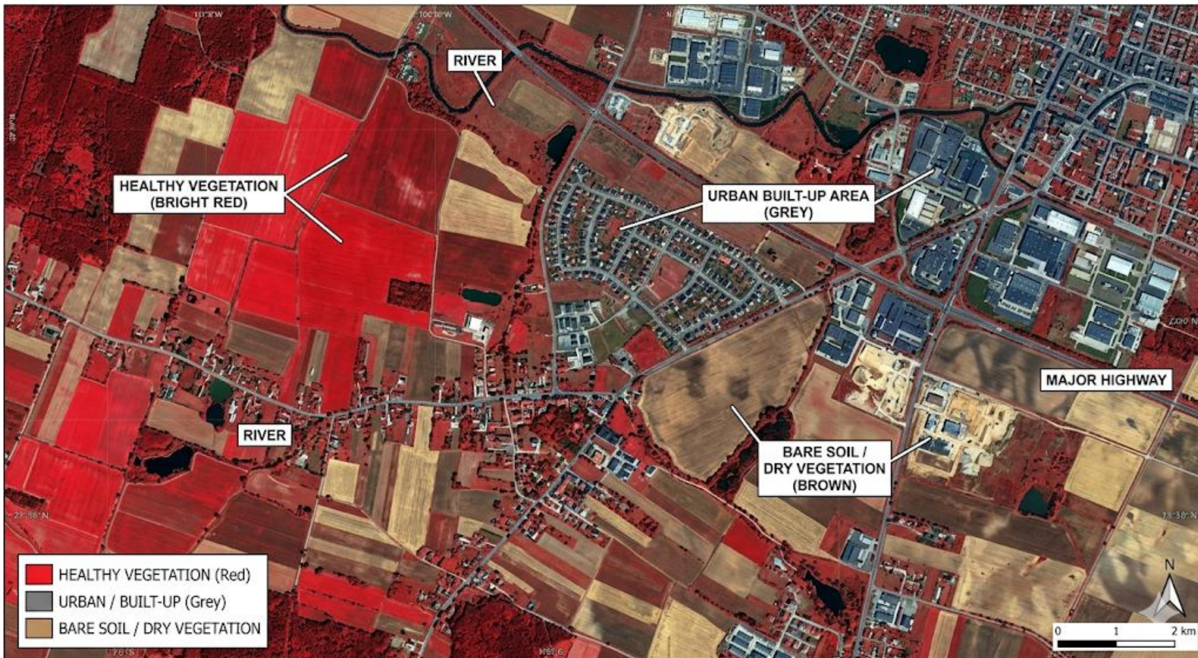
4.4.1 Importing and georeferencing remote sensing data in GIS

Before satellite or aerial imagery can be analysed in a GIS, it must be **georeferenced** assigned to a defined coordinate reference system so that every pixel occupies its correct location in geographic space. Most current satellite imagery distributed by agencies such as NASA, ESA, and USGS is supplied georeferenced in a standard coordinate system (commonly WGS84 geographic or a UTM projected system). However, historical aerial photographs, scanned paper maps, and imagery acquired from local sources in Nigeria may lack coordinate information and require manual georeferencing.

Georeferencing involves identifying a set of **Ground Control Points (GCPs)** locations visible in the image whose geographic coordinates are known. GCPs are selected to be well distributed across the image. The GIS uses the GCPs to compute a **geometric transformation** that warps and repositions the image to align with the coordinate system. The quality of georeferencing is assessed by the **Root Mean Square Error (RMSE)** a measure of the average displacement between the GCP positions and their transformed locations in the georeferenced image.

Before analysis, remote sensing imagery may also require **radiometric correction** (adjusting pixel values for sensor calibration, atmospheric scattering, and illumination effects) and **geometric correction** (removing distortions introduced by terrain relief or sensor orientation). These **preprocessing** steps are essential to ensure that pixel values accurately represent surface reflectance and that multi-date imagery can be accurately compared.

Fill in the blank: The quality of an image georeferencing operation is evaluated using the __________ Error, which measures the average displacement between ground control point positions and their transformed locations.



Short description: A multispectral satellite image displayed as a standard false colour composite in a GIS, with healthy vegetation appearing in bright red and urban areas appearing in grey and cyan tones.

Plate 4.2 Standard false colour composite of a peri-urban area showing vegetation in red and urban fabric in grey and cyan

4.4.2 Integrating GPS field data with GIS

GPS field data is typically exported in one of several standard formats for import into GIS:

- **GPX (GPS Exchange Format):** an XML-based format that stores waypoints (points), tracks (lines), and routes. Supported by most GPS receivers and smartphone applications. Imported into GIS as point or line vector layers.
- **CSV (Comma-Separated Values):** a simple table format in which each row contains a feature's coordinates and attributes as text. Imported into GIS by specifying the latitude and longitude columns, creating a point layer.
- **KML/KMZ (Keyhole Markup Language):** an XML-based format developed by Google, widely used by smartphone GPS applications. Supported by QGIS, ArcGIS, and Google Earth.

A critical step when integrating GPS data with existing GIS layers particularly legacy Nigerian cadastral and topographic data is **coordinate transformation**. GPS data is collected in **WGS84**, the global datum used by GPS satellites. Legacy Nigerian survey data may be referenced to the **Minna datum** (based on the Clarke 1880 ellipsoid), the standard for Nigerian mapping prior to the adoption of GPS. Combining WGS84 GPS data with Minna datum data without applying the correct transformation produces positional offsets that can exceed 100 m significant errors for cadastral or infrastructure mapping.

Fill in the blank: Legacy Nigerian cadastral data is referenced to the __________ datum, which must be transformed to WGS84 before it can be accurately combined with GPS field data.

4.4.3 Combined workflows for planning applications

The greatest analytical power of remote sensing and GPS is realised when their outputs are integrated within a GIS and combined with other spatial data layers. The following workflow illustrates an integrated approach to **land use change detection** a common planning application in Nigerian cities experiencing rapid urban growth:

1. **Image acquisition and preprocessing:** obtain multispectral satellite imagery for two dates (e.g., Landsat 8 for 2015 and Sentinel-2 for 2024). Apply atmospheric correction to both images to produce surface reflectance values. Georeference both images to the same UTM coordinate system.
2. **Classification:** perform supervised classification of both images, using training areas drawn from field-verified GPS points and high-resolution imagery. Define a land cover schema appropriate for Nigerian urban contexts: built-up area, vegetation, water, bare soil, agricultural land.
3. **Accuracy assessment:** collect GPS-georeferenced field verification points distributed stratified randomly across the study area. Construct an error matrix and compute overall accuracy and Kappa coefficient for each classified image.
4. **Change detection:** compare the two classified images pixel by pixel (post-classification comparison) or compute spectral change indices directly from the imagery (e.g., Normalised Difference Vegetation Index NDVI change). Map the locations and extents of land cover transitions.
5. **GIS integration and analysis:** overlay the change detection map with existing planning layers zoning maps, development permit records, infrastructure layers to identify where urban growth has occurred within and outside designated development zones, informing enforcement and planning review decisions.

Fill in the blank: The NDVI Normalised Difference __________ Index is a spectral index calculated from near-infrared and red bands used to assess vegetation cover and health from satellite imagery.

Pilot questions 4.4

1. What preprocessing operations may be applied to satellite imagery before it is used for analysis in GIS?
2. In what formats is GPS field data typically exported for import into GIS and what GIS geometry type does each produce?
3. Describe the steps of an integrated remote sensing and GIS workflow for mapping land use change.
4. What coordinate transformation is required when combining GPS data with legacy Nigerian cadastral data?
5. *Fill in the blank: The NDVI is calculated from the __________ and red spectral bands and is used to assess vegetation cover from satellite imagery.*

Series Summary

This Series has examined the integration of remote sensing, GPS, and GIS as a coordinated spatial data infrastructure for planning. We began with the principles of remote sensing, covering the electromagnetic spectrum and the interactions of energy with surface features, the satellite and aerial platforms that carry remote sensing sensors, and the four resolution types spatial, spectral, temporal, and radiometric that determine the utility of imagery for a given planning application. We then explored image interpretation and classification, describing the seven elements of visual interpretation, the distinction between supervised and unsupervised digital classification methods, and the accuracy assessment procedures including the error matrix and Kappa coefficient used to evaluate classification quality. Following this, we examined GPS technology and field data collection, explaining the three GPS system segments, the principal sources of positional error including multipath and atmospheric delay, and the practical methods for collecting point, line, and area features in the field using GPS receivers and smartphone applications. Finally, we explored the integration of remote sensing and GPS data within a GIS, covering georeferencing, coordinate transformation between WGS84 and the Nigerian Minna datum, GPS data import formats, and a combined land use change detection workflow applicable to rapidly urbanising Nigerian cities. By engaging with these topics, you should now be able to describe the principal remote sensing platforms and resolution types, apply image interpretation and classification concepts, collect and import GPS field data, and implement integrated remote sensing and GPS workflows for planning applications.

Glossary of Terms

- **Accuracy assessment:** A process that quantitatively evaluates a classified map against ground truth data using an error matrix, from which measures such as overall accuracy, producer's and user's accuracy, and the Kappa coefficient are derived.
- **Atmospheric correction:** A preprocessing operation that adjusts remote sensing pixel values to remove the effects of atmospheric scattering and absorption, producing surface reflectance values comparable across dates and sensors.
- **Differential GPS (DGPS):** A GPS accuracy improvement technique that uses a fixed reference receiver at a known location to compute corrections applied to a roving receiver's positions, reducing error from metres to sub-metre accuracy.
- **Dilution of Precision (DOP):** A numerical indicator of GPS positional accuracy based on the geometric arrangement of satellites in the sky. Low DOP values indicate good satellite geometry and high positional accuracy.
- **Electromagnetic spectrum:** The continuum of all electromagnetic radiation, ranging from gamma rays and X-rays at short wavelengths through visible light to microwave and radio waves at long wavelengths.
- **Error matrix:** A table that cross-tabulates the classification assigned by a map against the reference (ground truth) classification for a sample of locations, used to compute accuracy statistics.
- **Georeferencing:** The process of assigning a defined coordinate reference system to a spatial dataset particularly remotely sensed imagery by identifying ground control points whose geographic coordinates are known.
- **Ground Control Point (GCP):** A clearly identifiable location visible in a remotely sensed image whose geographic coordinates are known, used to georeferencing the image to a coordinate reference system.

- **GNSS (Global Navigation Satellite System):** A collective term for satellite-based positioning systems, including the US GPS, Russian GLONASS, European Galileo, and Chinese BeiDou systems.
- **Hyperspectral sensor:** A remote sensing instrument that records data in hundreds of narrow, contiguous spectral bands, enabling detailed identification and mapping of surface materials.
- **Kappa coefficient:** A statistical measure of classification accuracy that accounts for agreement expected by chance. Values above 0.80 are generally considered acceptable for planning applications.
- **Minna datum:** The geodetic datum historically used for Nigerian topographic and cadastral mapping, based on the Clarke 1880 ellipsoid. Must be transformed to WGS84 before combination with GPS data.
- **Multispectral sensor:** A remote sensing instrument that records data in a small number of broad spectral bands, typically including visible, near-infrared, and shortwave infrared wavelengths.
- **Multipath error:** A GPS positioning error caused by satellite signals reflecting off buildings, vehicles, or terrain before reaching the receiver, resulting in longer apparent signal travel times.
- **NDVI (Normalised Difference Vegetation Index):** A spectral index calculated from near-infrared and red reflectance values used to assess the density and health of vegetation cover from satellite imagery.
- **Remote sensing:** The science of acquiring information about the earth's surface without direct physical contact, using sensors mounted on satellite or aerial platforms that detect and record electromagnetic energy.
- **Spectral signature:** The characteristic pattern of electromagnetic energy reflected or emitted by a surface type across different wavelengths, enabling remote sensing sensors to distinguish between vegetation, water, urban fabric, and other land cover types.
- **Supervised classification:** A digital image classification method in which the analyst defines training areas for each land cover class; the algorithm uses the spectral characteristics of these areas to classify the remaining image pixels.
- **Trilateration:** The mathematical process used by GPS receivers to determine their three-dimensional position by measuring signal travel times from at least four satellites simultaneously.
- **Unsupervised classification:** A digital image classification method in which the algorithm groups pixels into spectral clusters without prior class definitions; the analyst subsequently assigns land cover labels to each cluster.

Concept-Check Questions 4
Objective Questions

1. Define remote sensing and explain the concept of spectral signature. (Linked to SLO 4.1)
2. *Fill in the blank: The __________ coefficient is a statistical accuracy measure that accounts for agreement expected by chance in a classified remote sensing image. (Linked to SLO 4.2)*
3. Name the three segments of the GPS system and state the role of each. (Linked to SLO 4.3)

4. What coordinate transformation is required before GPS data (WGS84) can be combined with legacy Nigerian cadastral data (Minna datum)? (Linked to SLO 4.4)

Short-Answer Questions

5. Explain the four types of resolution in remote sensing and, for each, give one example of how it affects the choice of imagery for a planning application in Nigeria. (Linked to SLO 4.1)

6. Distinguish between supervised and unsupervised digital image classification, explaining the role of training areas in supervised classification and describing when unsupervised classification might be preferred. (Linked to SLO 4.2)

7. Describe three sources of GPS positioning error and explain one technique that can be used to reduce each. (Linked to SLO 4.3)

8. Explain the purpose of georeferencing and describe the role of Ground Control Points and RMSE in evaluating georeferencing quality. (Linked to SLO 4.4)

Long-Answer Questions

9. Evaluate how remote sensing imagery and GPS field data can be combined within a GIS to support a land use change detection study in a rapidly urbanising Nigerian city. Your answer should address image acquisition and preprocessing, classification method selection, accuracy assessment, and the use of GIS overlay analysis to inform planning decisions. (Linked to SLOs 4.1, 4.2, and 4.4)

10. Analyse the challenges of GPS field data collection in a dense Nigerian urban environment, explaining the principal sources of error, the accuracy requirements for different planning applications (cadastral mapping vs. land use survey), and the methods available to improve positional accuracy. (Linked to SLO 4.3)

Answers to Concept-Check Questions 4
Objective Questions

1. Remote sensing collects earth data without contact; spectral signature is the reflectance pattern that distinguishes surfaces.
2. **Kappa.**
3. Space: satellites send signals. Control: ground stations monitor and correct. User: receivers calculate position.
4. GPS data in WGS84 must be transformed to Minna datum (or vice versa) using Nigeria's shift parameters.

Short-Answer Questions

5. Spatial resolution defines feature size (sub-metre for buildings, 30 m for city land cover). Spectral resolution distinguishes cover types (e.g., vegetation needs near-infrared). Temporal resolution shows data currency (construction needs frequent revisits). Radiometric resolution captures tonal detail (16-bit finer than 8-bit).

6. Supervised classification uses training samples; unsupervised groups pixels into clusters later labeled. Unsupervised is useful with little prior land cover knowledge.

7. DOP errors reduced by low-DOP times; multipath by avoiding tall structures or using choke-ring antennas; atmospheric delays corrected with dual-frequency receivers or models.

8. Georeferencing matches image points to known coordinates. RMSE measures average error; low RMSE (<1 pixel) means good accuracy.

Long-Answer Questions

9. Basic response: Describe the five-step workflow acquisition, classification, accuracy assessment, change detection, GIS overlay identifying appropriate satellite sources (Landsat, Sentinel-2) and classification methods.

Value-added response: Discuss the selection of training areas from GPS field points and high-resolution imagery; address the challenges of classifying the spectrally heterogeneous Nigerian urban environment (mixed materials, informal construction); evaluate post-classification comparison vs. spectral change indices (NDVI change); discuss how change maps are overlaid with zoning boundaries to identify unauthorised development for enforcement action.

10. Basic response: Identify multipath, atmospheric delay, and DOP as key error sources; describe DGPS or RTK as accuracy improvement methods.

Value-added response: Evaluate the differential accuracy requirements: cadastral boundary survey requires sub-10 cm accuracy achievable only with RTK GPS; land use field survey for classification training areas requires 1–5 m accuracy achievable with a quality GNSS receiver with point averaging; rapid urban appraisal with smartphone GPS may tolerate 5–10 m error. Discuss the specific challenges of dense Nigerian urban fabric high-rise buildings in Lagos, narrow market streets on DOP and multipath, and practical mitigation strategies for low-resource planning teams.

Answers to Pilot Questions 4

Part 4.1

1. Remote sensing collects earth surface data without contact; spectral signature is the reflectance pattern that identifies surfaces.
2. Landsat 8/9 (30 m, free), Sentinel-2 (10–20 m, free, 5-day revisit).
3. Spatial: pixel size. Spectral: bands. Temporal: revisit. Radiometric: sensor sensitivity.
4. Temporal.

Part 4.2

1. Visual cues: tone/colour, texture, pattern, shape, size, shadow, association.
2. Supervised uses training samples; unsupervised clusters pixels later labeled.
3. Kappa.
4. Error matrix compares map vs. ground truth; measures include overall, producer's, user's accuracy, and Kappa.
5. Digital classification relies on spectral values; field verification provides ground truth and accuracy check.

Part 4.3

1. Space: satellites send signals. Control: ground stations monitor/correct. User: receivers compute position.
2. DOP measures satellite geometry; wide spread = low DOP/high accuracy, clustering = high DOP/low accuracy.
3. Multipath.
4. DGPS uses a fixed base to correct rover, improving accuracy to sub-metre.
5. Survey123, QField (also Fulcrum, KoBoToolbox, ODK).

Part 4.4

1. Preprocessing: radiometric correction, geometric correction, georeferencing, pan-sharpening.

2. GPX → points/lines; CSV → points; KML/KMZ → points/lines/polygons.
3. Steps: acquire/correct imagery, classify, assess accuracy, compare dates, overlay change map with zoning/infrastructure.
4. GPS data (WGS84) must be transformed to Minna datum using Nigeria's shift parameters.
5. Near-infrared.

References and Attributions 4

Course content references

Campbell, J. B., & Wynne, R. H. (2011). Introduction to Remote Sensing (5th ed.). New York: Guilford Press.
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Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic Information Science and Systems (4th ed.). Hoboken, NJ: Wiley.
Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). Remote Sensing and Image Interpretation (7th ed.). Hoboken, NJ: Wiley.

Illustrations

Figure 4.1 The electromagnetic spectrum and the wavelength bands used in remote sensing
AI-generated suggestion: "Generate a labelled diagram of the electromagnetic spectrum from gamma rays to radio waves, highlighting the visible, near-infrared, thermal infrared, and microwave bands used in remote sensing, with wavelength values labelled on the horizontal axis."
Suggested OER search string: "electromagnetic spectrum remote sensing wavelength bands diagram OER."

Plate 4.1 Visual image interpretation of an urban area: identifying features by tone, texture, pattern, shape, and shadow
AI-generated suggestion: "Generate an annotated aerial photograph of a mixed urban area with labels identifying features using the seven elements of visual interpretation: tone, texture, pattern, shape, size, shadow, and association."
Suggested OER search string: "visual image interpretation elements urban aerial photograph annotated OER."

Figure 4.2 The three segments of the GPS system: space, control, and user
AI-generated suggestion: "Generate a diagram showing the three GPS system segments satellites in orbit, ground control stations, and a handheld user receiver with signal transmission arrows between the space segment and the user segment."
Suggested OER search string: "GPS system segments space control user diagram OER."

Box 4.1 GPS data collection methods: points, lines, and areas
AI-generated suggestion: "Generate a summary box table comparing three GPS field data collection methods point, line, and area showing for each: the feature type, the collection procedure, the GIS geometry produced, and a planning example."
Suggested OER search string: "GPS field data collection point line area GIS planning OER."

Plate 4.2 Standard false colour composite of a peri-urban area showing vegetation in red and urban fabric in grey and cyan
AI-generated suggestion: "Generate a labelled false colour composite satellite image of a peri-urban area, with healthy vegetation displayed in bright red, urban built-up areas in grey, and bare soil or dry vegetation in brown or tan tones."
Suggested OER search string: "false colour composite satellite image urban vegetation land cover OER."

Attributions
All AI prompts are intended for use with generative tools to create original illustrations. Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.

Course code: URP 316

Course title: Principles of GIS and AutoCAD

Course credit load: 2 Units

List of Series:

- Series 1: Fundamentals and Components of GIS
- Series 2: Spatial Data Models and Database Structures
- Series 3: GIS Operations, Editing and Analysis
- Series 4: Integration of Remote Sensing, GPS and GIS
- **Series 5: Applications of GIS and AutoCAD in Planning**

5 Applications of GIS and AutoCAD in Planning

Series Outline

- **Part 1 (5.1):** GIS Applications in Urban and Regional Planning
  - **Sub-Part 5.1.1:** Land use planning and environmental assessment
  - **Sub-Part 5.1.2:** Infrastructure planning and facility management
  - **Sub-Part 5.1.3:** Disaster risk reduction and climate adaptation
- **Part 2 (5.2):** GIS for Development Control and Land Administration
  - **Sub-Part 5.2.1:** Development control and planning applications
  - **Sub-Part 5.2.2:** Cadastral mapping and land registration
  - **Sub-Part 5.2.3:** GIS for public participation and plan communication
- **Part 3 (5.3):** Introduction to AutoCAD for Planners
  - **Sub-Part 5.3.1:** AutoCAD interface and drawing environment

- **Sub-Part 5.3.2:** Drawing and editing in AutoCAD
- **Sub-Part 5.3.3:** Layers, annotation, and plotting in AutoCAD
- **Part 4 (5.4):** Integrating AutoCAD and GIS in Planning Practice
  - **Sub-Part 5.4.1:** Data exchange between AutoCAD and GIS
  - **Sub-Part 5.4.2:** Using AutoCAD data in GIS workflows
  - **Sub-Part 5.4.3:** Integrated workflows for planning output production

Introduction

This final Series brings together the technical foundations of the course by applying them to real planning problems. Throughout the preceding Series, you have built knowledge of GIS data models, spatial analysis operations, and remote sensing integration. Here, you will see how those capabilities translate into practical planning tasks from producing land use maps and processing development applications to drawing layout plans in AutoCAD and exchanging data between the two platforms.

The aim of this Series is to describe the principal planning applications of GIS, introduce the AutoCAD drawing environment and its core tools, and explain how AutoCAD and GIS are integrated in planning workflows to produce maps, plans, and spatial analyses.

We shall commence this Series by examining GIS applications in urban and regional planning land use mapping and environmental assessment, infrastructure and facility management, and disaster risk reduction. Next, we will explore GIS in development control and land administration, covering planning application management, cadastral mapping, and digital public participation. Following that, we will introduce AutoCAD for planners the interface, drawing commands, editing tools, and the layer, annotation, and plotting system. Finally, we will address the integration of AutoCAD and GIS, covering data exchange formats, the use of AutoCAD data in GIS workflows, and the construction of integrated workflows for planning output production.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** describe the principal applications of GIS in urban and regional planning in Nigeria,
- **SLO 5.2** explain how GIS supports development control, cadastral mapping, and land administration in Nigerian planning practice,
- **SLO 5.3** use the AutoCAD drawing environment to create, edit, and annotate plan drawings,
- **SLO 5.4** exchange data between AutoCAD and GIS and apply integrated workflows for planning output production.

5.1 GIS Applications in Urban and Regional Planning

5.1.1 Land use planning and environmental assessment

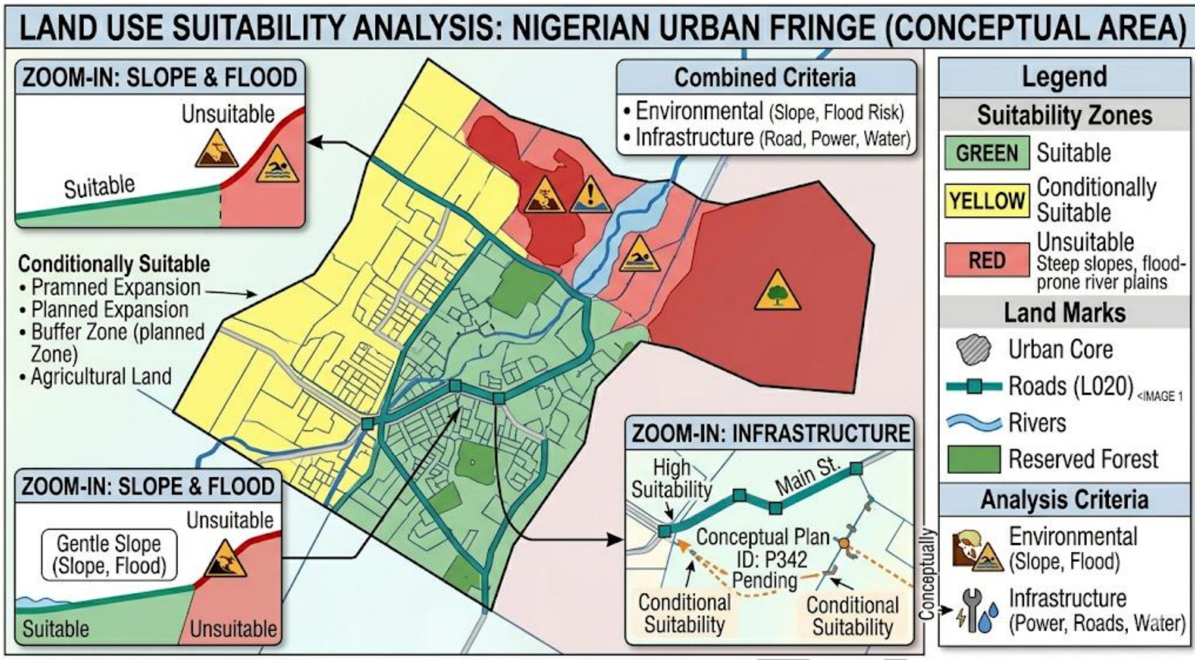
Land use planning is one of the most fundamental functions of urban and regional planning, and GIS has become its primary technical tool. A **land use GIS** integrates cadastral boundaries, zoning maps, satellite imagery, and socioeconomic data to support every stage of the land use planning cycle.

Key GIS applications in land use planning include:

- **Land use mapping and change detection:** GIS is used to produce current land use maps by digitising field survey data or classifying satellite imagery. Overlaying maps from different dates allows planners to detect and measure land use change identifying areas of urban encroachment on agricultural land, deforestation, or loss of open space.
- **Suitability analysis:** By combining layers representing slope, flood risk, soil type, infrastructure access, and existing land use, planners use **weighted overlay** to identify land most suitable for residential, industrial, or agricultural development guiding the allocation of land uses in structure plans and local development plans.
- **Environmental constraints mapping:** GIS overlays protected areas, flood plains, erosion-prone slopes, and ecological corridors to define the environmental framework within which development decisions must be made.

Environmental Impact Assessment (EIA) in Nigeria, regulated by the National Environmental Standards and Regulations Enforcement Agency (**NESREA**), increasingly requires GIS-based spatial analysis to map proposed project footprints against environmental sensitivity layers, model potential pollution dispersal, and assess habitat disruption.

Fill in the blank: The national agency responsible for environmental standards in Nigeria, which requires GIS-based environmental assessment for major developments, is known as __________.



Short description: Map showing a GIS-based land use suitability analysis for a Nigerian urban fringe area, with a legend showing areas classified as suitable, conditionally suitable, and unsuitable for development based on combined environmental criteria.

Plate 5.1 GIS land use suitability analysis for an urban fringe area: suitable, conditional, and unsuitable zones

5.1.2 Infrastructure planning and facility management

GIS provides planners and engineers with the tools to map, manage, and optimise physical infrastructure networks and public service facilities across a city or region.

- **Road network management:** A GIS road layer stores each road segment as a feature with attributes including road class, surface type, carriageway width, condition rating, and speed limit. Network analysis tools use these attributes to model traffic flow, optimise maintenance scheduling, identify structural deficiencies, and plan new alignments.
- **Utility infrastructure:** Water supply mains, sewers, electricity distribution lines, and telecommunications cables can all be mapped in GIS as **utility network datasets**. When a fault occurs, GIS allows engineers to trace the network, identify affected customers, and dispatch repair teams efficiently.
- **Facility location and service area analysis:** Network service area analysis defines the population reachable from a school, hospital, market, or fire station within a defined travel time. This directly informs decisions on where to build new facilities to maximise coverage and reduce underservice.
- **Asset management:** GIS-based asset management systems track the location, condition, and maintenance history of public infrastructure reducing reactive maintenance costs and extending asset lifespans.

Fill in the blank: A GIS __________ network dataset stores the topology, attributes, and travel costs of road or utility connections, enabling network analysis such as routing and service area delineation.

5.1.3 Disaster risk reduction and climate adaptation

Nigerian cities face growing exposure to floods, erosion, drought, and extreme heat risks that are intensifying with climate change and rapid urbanisation. GIS is an essential tool for understanding, mapping, and reducing these risks.

- **Flood risk mapping:** Digital Elevation Models (DEMs) and hydrological GIS tools are used to delineate flood plains, model inundation extents under different rainfall scenarios, and identify buildings, roads, and populations within risk zones. Flood risk maps directly inform development plan policies, building setback requirements, and infrastructure investment priorities.
- **Erosion hazard assessment:** GIS-based erosion models combine slope, soil erodibility, vegetation cover, and rainfall intensity data to identify land at high risk of gully erosion a major hazard in south-eastern Nigeria and guide land use restrictions and reforestation programmes.
- **Vulnerability mapping:** Overlaying hazard maps with population density, housing quality, infrastructure access, and socioeconomic data produces **vulnerability indices** that identify the communities most at risk and least able to cope essential for targeting disaster risk reduction interventions equitably.
- **Emergency response planning:** GIS supports the pre-positioning of relief resources, the planning of evacuation routes, and the real-time coordination of emergency operations using live spatial data feeds from GPS-equipped response teams.

Fill in the blank: GIS-based __________ maps identify communities most exposed to hazards and least able to cope, combining hazard exposure data with socioeconomic indicators to guide targeted risk reduction interventions.

Pilot questions 5.1

1. State two uses of GIS in land use planning and one use in environmental assessment.

2. How is GIS used in road network management and what attributes would a road segment layer typically contain?

3. What is flood risk mapping in GIS and how is it used in development plan preparation?

4. Fill in the blank: The national agency responsible for environmental standards in Nigeria, which requires GIS-based environmental assessment for major developments, is known as __________.

5.2 GIS for Development Control and Land Administration

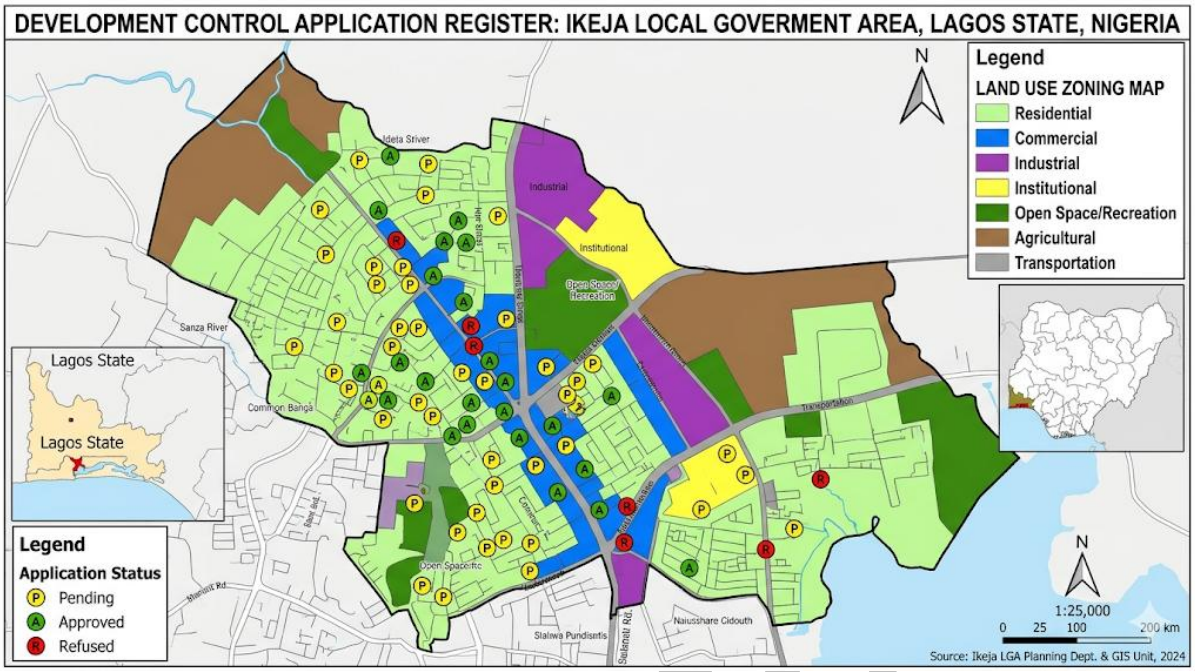
5.2.1 Development control and planning applications

Development control is the statutory function by which planning authorities regulate land use change, building activity, and subdivision in accordance with approved development plans. GIS transforms this function from a paper-based filing system into a spatially referenced, queryable database.

GIS supports development control in the following ways:

- **Application register and tracking:** Each planning application is recorded as a point or polygon in a GIS layer, with attributes storing the application reference number, applicant, proposed use, date received, and decision status (pending, approved, refused, appealed). Officers can instantly query how many applications are pending in a given ward, or whether a site has a history of refused applications.
- **Compliance checking against zoning plans:** By overlaying an application's proposed footprint against the zoning map, GIS allows officers to check automatically whether a proposed use is permitted, conditional, or prohibited in the zone reducing the risk of inconsistent decisions.
- **Development monitoring:** Approved developments can be tracked through construction to completion. Satellite imagery or drone photography updated periodically is compared against approved plans to detect unauthorised development or deviations from approval conditions.
- **Enforcement mapping:** Enforcement notices and stop-work orders are spatially referenced, enabling the planning authority to monitor compliance and prioritise enforcement action geographically.

Fill in the blank: GIS supports development control by storing each planning application as a spatially referenced feature linked to an attribute database of application status, proposed use, and __________ history.



Short description: Map showing a GIS development control application register for a Nigerian local government area, with planning application points symbolised by status (pending, approved, refused), overlaid on a land use zoning map.

Plate 5.2 GIS development control register: planning application locations by status overlaid on land use zoning

5.2.2 Cadastral mapping and land registration

Cadastral GIS is the spatial management of land parcels their boundaries, ownership, tenure, valuation, and legal status. In Nigeria, land administration is governed by the **Land Use Act of 1978**, which vests all land in the state governor and requires that rights of occupancy be registered as **Certificates of Occupancy (C of O)**. GIS is transforming the previously manual, paper-based land registry into a digital, spatially integrated system.

A cadastral GIS parcel layer typically contains the following attributes:

- Parcel identifier (plot number, block, survey plan reference)
- Registered owner name and contact details
- Certificate of Occupancy number and date of issue
- Land use class (residential, commercial, industrial, agricultural)
- Plot area (square metres) and parcel perimeter
- Assessed value and ground rent status
- Encumbrances (mortgages, easements, court orders)

GIS-based cadastral systems improve transparency and reduce land disputes by making parcel boundaries and ownership records searchable and verifiable. They also support land valuation, property taxation, and infrastructure planning by enabling spatial queries such as: How many unregistered parcels are in this LGA? Which plots have C of O but have not paid ground rent?

Fill in the blank: In Nigeria, land administration is governed by the Land Use Act of __________, which vests all land in the state governor and requires rights of occupancy to be registered as Certificates of Occupancy.

5.2.3 GIS for public participation and plan communication

Public participation is a statutory requirement in Nigerian planning legislation and an ethical cornerstone of inclusive planning practice. GIS enhances the quality and accessibility of participation in several ways:

- **Web GIS for plan display:** Development plans, zoning maps, and planning proposals can be published as interactive web maps using platforms such as ArcGIS Online or QGIS Cloud, allowing community members to view proposals, zoom to their neighbourhood, and understand the spatial implications of planning decisions without attending a public meeting.
- **Participatory GIS (PGIS):** Community members contribute spatial knowledge marking problem locations, identifying valued resources, or sketching preferred development options directly onto maps or digital platforms. This **participatory mapping** captures local knowledge that is often absent from official datasets and helps planners design solutions that reflect community priorities.
- **Printed map-based consultation:** Where internet access is limited, GIS-produced printed maps at A0 or A1 size are displayed at public exhibitions, enabling communities to annotate proposals using overlays, sticky notes, or marked transparencies a particularly relevant approach in many Nigerian peri-urban and rural contexts.

Fill in the blank: The approach in which community members contribute spatial knowledge by marking features and priorities directly onto maps or digital platforms is called participatory __________ or PGIS.

Pilot questions 5.2

1. State three ways in which GIS supports the development control function of a planning authority.
2. What is cadastral GIS and what attributes would a parcel layer typically contain?
3. *Fill in the blank: Certificates of Occupancy in Nigerian states are registered under the Land Use Act of __________, which vests all land in the state governor.*
4. How can GIS be used to support public participation in planning and what are the limitations of web-based participation tools in the Nigerian context?
5. What is participatory mapping and how does it contribute to the planning GIS?

5.3 Introduction to AutoCAD for Planners

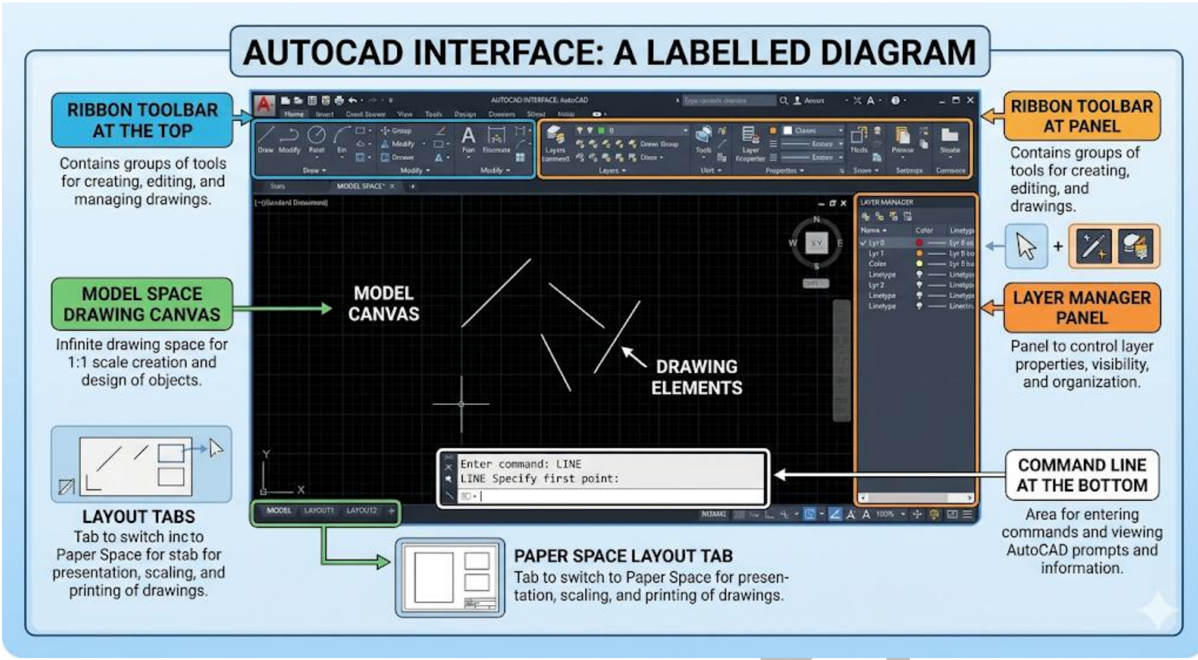
5.3.1 AutoCAD interface and drawing environment

AutoCAD (Computer-Aided Design and Drafting) is the industry-standard software for producing precise technical drawings. In planning practice, AutoCAD is used to draw layout plans, subdivision designs, infrastructure alignments, and site plans with exact dimensions and standard annotation. Unlike GIS, which positions features in geographic coordinate space and links them to attribute databases, AutoCAD is a **drafting environment** focused on geometric precision, line quality, and print-ready output.

The key elements of the AutoCAD interface are:

- **Model Space:** The main drawing canvas where geometry is created at full (1:1) scale. All drawing and editing takes place in Model Space. The coordinate system in Model Space uses X (Easting), Y (Northing), and Z (elevation) values and for geographically referenced drawings, real-world UTM coordinates can be assigned so that AutoCAD drawings align with GIS data.
- **Paper Space (Layout tabs):** A virtual sheet of paper on which one or more **viewports** display views of the Model Space drawing at defined print scales (e.g., 1:500, 1:1000, 1:2500). Title blocks, north arrows, scale bars, and legends are drawn in Paper Space. Separate layout tabs can produce different sheets from a single drawing file.
- **Command line:** The AutoCAD command line at the bottom of the screen is the primary interface for entering drawing commands, specifying coordinates, and selecting options. Experienced operators type commands directly rather than using the ribbon toolbar, making the command line the fastest way to work.
- **Ribbon toolbar:** Organises drawing, editing, annotation, and layer management tools into tabbed panels for users who prefer a graphical interface.
- **Layer Manager:** Controls the layer structure of the drawing see Sub-Part 5.3.3.

Fill in the blank: In AutoCAD, all geometry is drawn at full scale in __________ Space, while print layouts, viewports, and title blocks are set up in Paper Space.



Short description: Diagram of the AutoCAD interface showing the Model Space drawing canvas, command line, ribbon toolbar, layer manager, and Paper Space layout tab, with each element labelled.

Figure 5.1 The AutoCAD interface: Model Space, command line, ribbon, layer manager, and Paper Space

5.3.2 Drawing and editing in AutoCAD

AutoCAD provides a comprehensive set of drawing commands that create precise geometric objects:

- **LINE:** Draws straight line segments between specified coordinate points. Used for road centre lines, property boundaries, and grid lines.
- **PLINE (Polyline):** Draws connected sequences of lines and arcs as a single object. Used for road kerb lines, plot boundaries, and contour lines essential because polylines can be assigned width and can be converted to GIS features.
- **CIRCLE and ARC:** Draw circular and curved geometry for roundabouts, cul-de-sacs, curved road alignments, and site features.
- **RECTANGLE and POLYGON:** Draw regular closed shapes for building footprints, plot boundaries, and block layouts.
- **HATCH:** Fills a closed area with a pattern or solid fill to represent surface materials, land use zones, or section cuts in plans.

Precision drawing in AutoCAD relies on several tools:

- **Object Snap (OSNAP):** Snaps the cursor to precise geometric points on existing objects endpoints, midpoints, intersections, centres, and perpendicular points. OSNAP is essential for ensuring that features join correctly without gaps.

- **Coordinate input:** Coordinates can be entered as absolute values (X,Y from the drawing origin), relative values (@ΔX,ΔY from the last point), or polar values (@distance<angle) for efficient accurate drawing.
- **TRIM and EXTEND:** Trim cuts an object at a boundary; Extend stretches an object to reach a boundary both essential for clean intersections in road and plot layout drawings.
- **OFFSET:** Creates a copy of a line, polyline, or curve at a specified perpendicular distance used to draw parallel kerb lines, setback lines, and road reserve boundaries.
- **FILLET and CHAMFER:** Create smooth curved corners (fillet) or angled corners (chamfer) at intersections used for road junctions and building corners.

Fill in the blank: The AutoCAD snapping tool that snaps the cursor to precise geometric points on existing objects such as endpoints and intersections is called Object __________ (OSNAP).

5.3.3 Layers, annotation, and plotting in AutoCAD

Layers in AutoCAD organise drawing content by category, function, or discipline analogous to GIS layers but serving primarily drafting and plot management purposes. Each AutoCAD layer has the following properties:

- **Name:** A descriptive name identifying the content e.g., ROAD-CENTRELINE, PLOT-BOUNDARY, BUILDING-FOOTPRINT, CONTOUR.
- **Colour:** Controls the display colour in Model Space and, when plotting, determines the pen weight used if a colour-to-pen weight plotting style (CTB) is applied.
- **Linetype:** Defines the line pattern Continuous (solid), Dashed, Dotted, or Centre to distinguish different feature types visually.
- **Lineweight:** The plotted thickness of lines on that layer, set directly or controlled by colour. Heavier lineweights are used for primary roads and building outlines; finer lineweights for contours and grid lines.
- **Visibility and freeze:** Layers can be turned on or off (visible/invisible) or frozen (excluded from regeneration) to manage complex drawings and produce plots that show only relevant information.

Layer Name	Content	Colour	Linetype
BOUNDARY	Survey/site boundary	Red	Continuous
ROAD-CENTRELINE	Road centre lines	Yellow	Centre
ROAD-KERB	Kerb/carriageway edge	White	Continuous
PLOT-BOUNDARY	Land parcel boundaries	Cyan	Continuous
BUILDING-FOOTPRINT	Building outlines	Green	Continuous
CONTOUR	Topographic contours	Brown	Continuous

TEXT-ANNOTATION	Labels and dimensions	White	Continuous
TITLEBLOCK	Title block (Paper Space)	White	Continuous

Box 5.1 AutoCAD layer conventions for planning drawings: standard layer names and their uses
Short description: A table showing recommended AutoCAD layer names, content descriptions, display colours, and linetypes for planning drawings, following standard practice in Nigerian planning offices.

Annotation in AutoCAD adds text and dimensions to the drawing. **TEXT** and **MTEXT** commands place labels; **DIMENSION** commands (linear, aligned, angular, radius) add measured dimensions with automatic leaders and extension lines. **Plotting** (printing) is set up in Paper Space: the scale of each viewport is defined, a **plotting style table (CTB)** maps layer colours to pen weights, and the sheet is printed to a physical plotter or exported as a PDF.

Fill in the blank: A __________ style table (CTB) maps AutoCAD layer colours to pen weights during plotting, controlling the thickness of each line type on the printed plan.

Pilot questions 5.3

1. What is the difference between AutoCAD and GIS in terms of their primary function?

2. Name four AutoCAD drawing commands and state the type of geometry each creates.

3. Fill in the blank: The AutoCAD snapping tool that snaps the cursor to precise geometric points on existing objects such as endpoints and intersections is called __________.

4. What is the purpose of layers in AutoCAD and what properties does each layer have?

5. What is the difference between Model Space and Paper Space in AutoCAD and when is each used?

5.4 Integrating AutoCAD and GIS in Planning Practice

5.4.1 Data exchange between AutoCAD and GIS

In planning offices, AutoCAD and GIS are complementary tools that handle different stages of the planning workflow. AutoCAD excels at precise geometric drafting; GIS excels at spatial analysis and attribute management. Effective practice requires smooth data exchange between the two platforms.

The principal data exchange formats are:

- **DXF (Drawing Exchange Format):** An open, text-based format developed by Autodesk for exchanging AutoCAD drawings between software packages. DXF files preserve layer names, geometry types, and text annotation, and are directly importable into QGIS and ArcGIS as vector layers. DXF is the standard format for transferring AutoCAD drawing data into GIS.
- **DWG:** AutoCAD's proprietary binary drawing format. Modern GIS platforms can read DWG files directly, but DXF is preferred for interoperability and long-term archiving.
- **Shapefile and GeoPackage:** The standard GIS vector formats, which can be exported from GIS and imported into AutoCAD (with limitations) using translation tools. These

formats carry coordinate reference system information and attribute tables that AutoCAD DXF/DWG do not natively support.

- **GeoTIFF and PDF:** Georeferenced raster images (GeoTIFF) or georeferenced PDFs exported from GIS can be inserted into AutoCAD as background references for example, inserting a GIS-produced land use or constraint map as a reference layer while drafting a layout plan.

Fill in the blank: The open, text-based format used to exchange AutoCAD drawing geometry and layer data with GIS software is called __________ (Drawing Exchange Format).

Step	*Process*	*Description*
1. Design	***AutoCAD (DWG)***	*Initial engineering or site plans are created in the native AutoCAD format (.dwg).*
2. Export	***DWG to DXF***	*The drawing is saved or exported as a Drawing Exchange Format (.dxf) to ensure file compatibility during transfer.*
3. Import	***GIS Integration***	*The DXF file is imported into a GIS environment (e.g., ArcGIS or QGIS) and converted into vector layers (points, lines, or polygons).*
4. Analysis	***GIS Processing***	*Spatial analysis is performed, such as proximity buffering or environmental sensitivity mapping, adding attribute data to the vectors.*
5. Feedback	***GIS to AutoCAD***	*The analyzed layers are exported back to AutoCAD (often via DXF or DWG plugins) to inform the final technical plan production.*

Short description: Diagram showing the data exchange workflow between AutoCAD and GIS: AutoCAD DWG drawing exported as DXF, imported into GIS as vector layers, analysed in GIS, and results exported back to AutoCAD for plan production.

Figure 5.2 Data exchange workflow between AutoCAD and GIS

5.4.2 Using AutoCAD data in GIS workflows

When AutoCAD drawing files are brought into GIS for spatial analysis, several preparatory steps are required to ensure the data is usable:

- **Coordinate system assignment:** AutoCAD drawings may be in local or arbitrary coordinate systems. Before use in GIS, the drawing must be assigned the correct

Coordinate Reference System (CRS) typically UTM Zone 32N (EPSG:32632) for most of Nigeria by georeferencing control points or entering the known origin coordinates.

- **Layer separation and cleaning:** AutoCAD files typically contain many layers, not all of which are needed for a given GIS analysis. Unwanted layers should be excluded during import. Geometry must be checked for errors: duplicate lines, unclosed polygons, and self-intersecting features must be corrected before topological analysis can proceed.
- **Geometry type conversion:** AutoCAD LINE and PLINE entities import into GIS as line features. Closed polylines representing plot boundaries or building footprints must be converted to polygon features using GIS tools before area calculations or overlay analysis can be performed.
- **Attribute addition:** AutoCAD features carry no attribute data beyond their layer name and block properties. After import, attributes such as land use class, plot area, and ownership must be added manually or joined from an external table.

Fill in the blank: When AutoCAD data is imported into GIS, closed polylines representing building footprints must be converted from line features to __________ features before area calculations or overlay analysis can be performed.

5.4.3 Integrated workflows for planning output production

In professional planning practice, AutoCAD and GIS work together across the planning cycle. A typical integrated workflow for preparing a **local development plan** follows these stages:

- **1. Basemap preparation in GIS:** Assemble and process the spatial datasets needed cadastral boundaries, road network, topographic contours, land use, utility infrastructure, and aerial imagery. Reproject all datasets to UTM Zone 32N. Conduct spatial analysis (suitability analysis, flood risk mapping, service area analysis) to identify constraints and opportunities.
- **2. Export reference layers from GIS to AutoCAD:** Export key GIS layers (cadastral parcels, road centre lines, administrative boundaries, constraint zones) as DXF or shapefile. Import into AutoCAD, assigning each to a named layer.
- **3. Design and draft in AutoCAD:** Using the GIS reference layers as a base, draft the proposed layout road alignments, plot subdivisions, open space, facilities as precise AutoCAD polylines and polygons. Use OSNAP and coordinate input for accuracy. Apply layer conventions for different feature types.
- **4. Export AutoCAD design back to GIS:** Export the completed design as DXF. Import into GIS, assign the CRS, convert closed polylines to polygons, and add attribute data (proposed land use, plot area, density). Run spatial analysis on the design calculate population capacity, check facility service areas, verify flood risk compliance.
- **5. Produce final planning outputs:** Map plates and technical plans are finalised in AutoCAD Paper Space at the required scales. GIS-produced thematic maps (land use, constraints, phasing) are exported as PDFs or GeoTIFFs for insertion as insets. The final

document set statutory plan, technical appendices, and digital GIS and AutoCAD files is assembled and archived.

Fill in the blank: In an integrated AutoCAD-GIS workflow, the final step of assembling statutory plans, technical appendices, and digital GIS and AutoCAD files for submission and archiving is called __________ output production.

Pilot questions 5.4

1. What is DXF format and why is it used for data exchange between AutoCAD and GIS?
2. What checks must be performed on AutoCAD data before it is used for spatial analysis in GIS?
3. Describe the integrated AutoCAD and GIS workflow for preparing a local development plan.
4. Why is it important to establish data exchange protocols between the drawing office and the GIS unit before a project begins?
5. *Fill in the blank: The open, text-based format used to exchange AutoCAD geometry and layer data with GIS software is called __________ (Drawing Exchange Format).*

Series Summary

This final Series has applied the technical foundations of GIS and AutoCAD to planning practice. We began by examining GIS applications in urban and regional planning: land use mapping, change detection, suitability analysis, and environmental constraints mapping, including the GIS-based environmental assessment requirements of NESREA; infrastructure planning and utility network management; and disaster risk reduction through flood risk mapping, erosion hazard assessment, vulnerability mapping, and emergency response planning.

We then explored GIS in development control and land administration, covering GIS-based application registers and compliance checking against zoning plans; cadastral GIS and the attributes of a parcel layer within the framework of the Land Use Act 1978 and Certificates of Occupancy; and digital public participation through web GIS platforms and participatory mapping (PGIS). Next, we introduced AutoCAD for planners the Model Space and Paper Space drawing environment, the command line, and the ribbon toolbar; drawing commands (LINE, PLINE, CIRCLE, RECTANGLE, HATCH); precision tools (OSNAP, TRIM, OFFSET, FILLET); and the layer, annotation, and plotting system, including standard layer conventions for planning drawings and the use of CTB plotting style tables.

We concluded with the integration of AutoCAD and GIS using DXF and DWG formats, the preparatory steps needed for AutoCAD data in GIS workflows such as CRS assignment, layer cleaning, geometry conversion, and attribute addition, and a five-stage workflow that begins with GIS basemap analysis, moves through AutoCAD drafting, and returns to GIS for verification before final output. By completing this Series and course, you are now able to describe GIS planning applications, explain its role in development control and land administration, work effectively in AutoCAD, and apply integrated AutoCAD–GIS workflows to produce professional planning outputs in line with all four Learning Outcomes.

Glossary of Terms

- **AutoCAD:** A commercial computer-aided design and drafting software used in planning practice to produce precise technical drawings including layout plans, subdivision designs, and infrastructure alignments.
- **Cadastral GIS:** A GIS-based system for managing land parcel boundaries, ownership records, tenure status, and land use classification, forming the spatial foundation of land administration.
- **Certificate of Occupancy (C of O):** A legal document issued under the Nigerian Land Use Act 1978 that records an individual's right of occupancy over a parcel of land in a state.
- **CTB (Colour-dependent plot style table):** An AutoCAD file that maps layer colours to pen weights during plotting, controlling the printed line thickness of each layer type on the final plan.
- **Development control:** The statutory function of a planning authority to regulate land use change, building activity, and subdivision in accordance with approved development plans and zoning regulations.
- **DXF (Drawing Exchange Format):** An open, text-based file format for exchanging AutoCAD drawing geometry and layer data with other software including GIS platforms.
- **DWG:** AutoCAD's proprietary binary drawing file format, containing full drawing geometry, layers, and annotation.
- **Flood risk mapping:** The use of GIS and Digital Elevation Models to delineate flood plains, model inundation extents, and identify assets and populations within flood risk zones.
- **Land Use Act 1978:** Nigerian federal legislation that vests all land in each state in the state governor, requiring that rights of occupancy be registered as Certificates of Occupancy.
- **Layer (AutoCAD):** An organisational unit in an AutoCAD drawing that groups features by category, with properties including name, colour, linetype, and lineweight.
- **Model Space:** The main drawing canvas in AutoCAD where geometry is created at full (1:1) scale.
- **NESREA:** The National Environmental Standards and Regulations Enforcement Agency the Nigerian federal body responsible for enforcing environmental standards, including requirements for GIS-based environmental impact assessment.
- **Object Snap (OSNAP):** An AutoCAD drawing aid that snaps the cursor to precise geometric points on existing objects such as endpoints, midpoints, intersections, and centres ensuring accurate feature connection.
- **Paper Space:** A virtual sheet in AutoCAD used to set up print layouts containing viewports displaying Model Space content at defined scales, alongside title blocks and legends.
- **Participatory GIS (PGIS):** An approach to planning and GIS in which community members contribute local spatial knowledge by marking features, resources, and priorities directly onto maps or digital platforms.

- **Polyline (PLINE):** An AutoCAD drawing object consisting of connected line and arc segments treated as a single entity; essential for representing plot boundaries and road kerb lines that will be converted to GIS polygon features.
- **Suitability analysis:** A GIS technique typically using weighted overlay that combines multiple spatial criteria layers to identify land best suited for a proposed use such as development, conservation, or agriculture.
- **Utility network dataset:** A GIS layer representing the topology, attributes, and connectivity of utility infrastructure such as water mains, sewers, and electricity distribution lines, enabling network tracing and fault management.
- **Viewport:** A window in AutoCAD Paper Space that displays a defined view of the Model Space drawing at a specified print scale.
- **Vulnerability index:** A composite spatial measure combining hazard exposure (e.g., flood risk zone) with socioeconomic sensitivity indicators (e.g., poverty rate, housing quality) to identify communities most at risk from a hazard.

Concept Check Questions 5

Objective Questions

1. **Land use planning:** produce/update land use maps; detect land use change.
   Environmental assessment: overlay project footprint with sensitivity layers.
2. Maintain spatial application register; check proposals against zoning maps; track approved developments for compliance.
3. **OSNAP (Object Snap).**
4. **DXF (Drawing Exchange Format).**
   Check: assign correct Coordinate Reference System before analysis.

Short-Answer Questions

5. GIS models flood plains and inundation zones; maps guide restrictions, floor levels, setbacks, and infrastructure upgrades in Nigerian local plans.

6. **Cadastral GIS:** manages parcels with attributes like ID, owner, C of O, land use, area, value, rent status. Improves search, dispute detection, taxation, and accessibility compared to paper records.

7. **Layers in AutoCAD:** organize content with name, colour, linetype, lineweight, visibility. Structured layers ensure consistent drawings, selective plotting, and easier GIS transfer.

8. **Workflow:**
   - Stage 1 (GIS): basemap prep, analysis.
   - Stage 2: export/import to AutoCAD.
   - Stage 3 (AutoCAD): layout drafting.
   - Stage 4 (GIS): import design, assign CRS, verify.
   - Stage 5: final plans with both.
     GIS analysis: Stages 1 & 4; AutoCAD drafting: Stage 3.

Long-Answer Questions

9. **Development control GIS system:**
    - Data: zoning maps, parcels, roads, boundaries.
    - Software: QGIS/ArcGIS with geodatabase.
    - Workflow: applications logged in GIS, checked against zoning, decisions recorded, approvals monitored with imagery.
    - Nigerian context: digitize legacy records, train staff, phased rollout with web portal for submissions.

10. **Integration strengths:** AutoCAD = precise drafting; GIS = analysis/attributes; DXF enables exchange.
Limitations: CRS issues, geometry errors, staff training gaps, weak infrastructure.
Improvements: standard layer naming, DXF/GIS protocols, cross-training, shared folders, adopt GIS tools that read DWG/DXF directly.

Answers to Pilot Questions 5

Part 5.1

1. Land use planning: produce/update maps; detect change; suitability analysis; map constraints.
   Environmental assessment: overlay project footprints with sensitivity layers.
2. Road network GIS stores attributes (class, surface, width, condition, speed). Used for traffic modelling, maintenance scheduling, and alignment planning.
3. Flood risk mapping: DEM + hydrological analysis to delineate plains, model inundation. In plans: define restricted zones, set floor levels, identify flood-proofing needs.
4. **NESREA.**

Part 5.2

1. Maintain spatial application register; check proposals against zoning; monitor approvals via imagery; reference enforcement notices.
2. Cadastral GIS: manages parcels with attributes—ID, owner, C of O, land use, area, value, rent status, encumbrances.
3. **1978.**
4. GIS publishes zoning maps online, supports participatory mapping. Limitations: poor internet access, low digital literacy, need for printed alternatives.
5. Participatory mapping: communities mark features/resources/hazards. Adds local knowledge, improves accuracy and relevance of plans.

Part 5.3

1. AutoCAD: precise drafting, local coordinates, no attributes. GIS: geographic coordinates, linked attributes, spatial analysis.
2. Examples: LINE, PLINE, CIRCLE, ARC, RECTANGLE, POLYGON, HATCH.
3. **OSNAP (Object Snap).**
4. Layers: organize content with name, colour, linetype, lineweight, visibility.

5. Model Space: full-scale drawing. Paper Space: layouts with scaled viewports, title blocks, legends.

Part 5.4

1. **DXF (Drawing Exchange Format):** open format for AutoCAD–GIS exchange, preserves layers and geometry.
2. Checks: assign CRS; remove duplicates; fix unclosed/self-intersecting polygons; convert polylines to polygons; add attributes.
3. Workflow:
    - (1) GIS basemap + analysis
    - (2) Export GIS layers to AutoCAD
    - (3) Draft layout in AutoCAD
    - (4) Export to GIS, assign CRS, verify geometry/attributes
    - (5) Final plans in AutoCAD with GIS insets
4. Data exchange protocols: standard layer naming, agreed formats, documented CRS, defined handover checks.
5. **DXF.**

References and Attributions 5

Course Content References

- Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Hoboken, NJ: Wiley.
- Autodesk. (2024). *AutoCAD 2024 user guide.* Retrieved from https://help.autodesk.com/view/ACD/2024/ENU/
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- Federal Republic of Nigeria. (1978). *Land Use Act, Cap. L5, Laws of the Federation of Nigeria.* Abuja: Federal Government Press.
- NESREA. (2011). *National Environmental Impact Assessment Procedures.* Abuja: National Environmental Standards and Regulations Enforcement Agency.

Illustrations

- *Plate 5.1* GIS land use suitability analysis for an urban fringe area: suitable, conditional, and unsuitable zones.
    - AI-generated prompt: "Generate a GIS map showing a land use suitability analysis for a Nigerian urban fringe area, with zones classified as suitable (green), conditionally suitable (yellow), and unsuitable (red) based on combined environmental and infrastructure criteria, with a legend."
    - Suggested OER search string: "GIS land use suitability analysis urban fringe map Nigeria OER."
- *Plate 5.2* GIS development control register: planning application locations by status overlaid on land use zoning.

- AI-generated prompt: "Generate a GIS map showing a development control application register for a Nigerian local government area, with planning application points symbolised by status (pending yellow, approved green, refused red), overlaid on a land use zoning map with a legend."
- Suggested OER search string: "GIS development control planning applications zoning map Nigeria OER."

- *Figure 5.1* The AutoCAD interface: Model Space, command line, ribbon, layer manager, and Paper Space.
  - AI-generated prompt: "Generate a labelled diagram of the AutoCAD interface showing the Model Space drawing canvas, command line at the bottom, ribbon toolbar at the top, layer manager panel, and a Paper Space layout tab, with each element clearly labelled."
  - Suggested OER search string: "AutoCAD interface diagram Model Space Paper Space command line ribbon layer manager OER."
- *Box 5.1* AutoCAD layer conventions for planning drawings: standard layer names and their uses.
  - AI-generated prompt: "Generate a table showing standard AutoCAD layer naming conventions for planning drawings, listing layer names (BOUNDARY, ROAD-CENTRELINE, PLOT-BOUNDARY, BUILDING-FOOTPRINT, CONTOUR, TEXT-ANNOTATION), content descriptions, display colours, and linetypes."
  - Suggested OER search string: "AutoCAD layer naming conventions planning drawings standards table OER."
- *Figure 5.2* Data exchange workflow between AutoCAD and GIS.
  - AI-generated prompt: "Generate a workflow diagram showing data exchange between AutoCAD and GIS: AutoCAD DWG file exported as DXF, imported into GIS as vector layers, analysed in GIS, and results exported back to AutoCAD for plan production, with arrows showing each step."
  - Suggested OER search string: "AutoCAD GIS data exchange workflow DXF DWG shapefile integration diagram OER."

Attributions

- All AI prompts are intended for use with generative tools to create original illustrations.
- Suggested search strings are provided to locate open educational resources (OER) for non-commercial academic use.