Ministry of Higher Education and Scientific Research

Ferhat Abbas University - Setif 1
Faculty of Natural and Life Sciences
Department of Biotechnology

وزارة التعليم العالي و البحث العلمي
جامعة فرحات عباس- سطيف 1
كلية علوم الطبيعة و الحياة
قسم البيوتكنولوجيا

Bachelor's degree in ecology and the environment

3rd Year

Remote Sensing and GIS

Course Elements

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Academic Year: 2025/2026

Remote Sensing and GIS

Pedagogical syllabus

Semester: 6

Core Teaching Unit 2 (UEF 3.2.2): Mapping

Subject 1: Remote Sensing and GIS

Credits: 4

Coefficient: 2

Educational Objectives: The knowledge acquired in this module will enable the student to become familiar with new remote sensing and GIS techniques.

Recommended Prerequisites: Knowledge of the ecological factors governing species distribution is required (bioclimatic, phytogeographical, oro-topographic factors, etc.).

Chapter I. Basics of Remote Sensing

1. Introduction

1.1. Definitions of Remote Sensing

1.2. Electromagnetic Radiation

1.3. The Electromagnetic Spectrum

1.4. Interactions with the Atmosphere

1.5. Passive and Active Sensing

1.6. Image Characteristics

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2.1. Types of Orbits

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Chapter 1

Basics of Remote Sensing

1. Introduction to Remote Sensing

1.1. Introduction

Remote sensing is a scientific technique used to collect information about objects or areas from a distance, typically using satellites, aircraft, or unmanned aerial vehicles (UAVs). Unlike traditional field measurements, remote sensing does not require direct physical contact with the observed object. Instead, it relies on the detection and measurement of electromagnetic radiation (EMR) reflected or emitted from the Earth's surface.

This technology has become essential in many fields such as environmental monitoring, agriculture, geology, urban planning, and disaster management. For example, satellite imagery allows scientists to monitor deforestation in tropical regions, track climate change, and assess natural disasters like floods and wildfires.

Remote sensing systems consist of three main components: a radiation source (usually the Sun), a sensor to detect the energy, and a platform to carry the sensor.

1. 2. Basic Principles of Remote Sensing

The fundamental principle of remote sensing is based on the interaction between electromagnetic radiation and matter. When radiation reaches the Earth's surface, it interacts with different materials in various ways depending on their physical and chemical properties.

These interactions can be classified into three main types: reflection, absorption, and transmission.

Table 1: Interaction of EMR with Matter

Interaction Type	Description	Effect on EMR	Key Applications
Reflection	Incident energy rebounds from the surface of the material without altering its wavelength.	Changes direction (angle of reflection equals angle of incidence).	**Optical remote sensing**, **laser scanning**.
Absorption	The material takes in the electromagnetic energy, converting it into other forms (usually heat or chemical energy).	Diminishes the intensity of the transmitted or reflected wave.	**Spectroscopy**, **thermal mapping**, **atmospheric science**.

These interactions create unique spectral signatures for different materials, allowing scientists to identify them from satellite images.

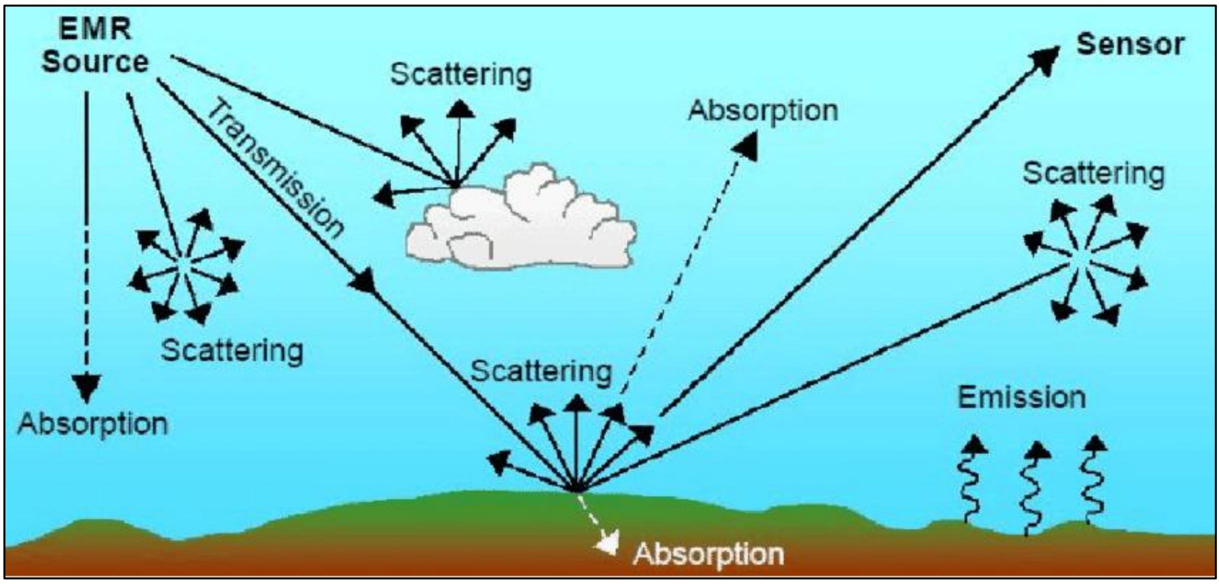


Figure 1. Interaction of Electromagnetic Radiation with the Earth's Surface

1.3. Electromagnetic Spectrum

The electromagnetic spectrum represents the range of all types of electromagnetic radiation, ordered by wavelength or frequency. Remote sensing mainly uses visible light, infrared, and microwave regions.

Each region of the spectrum provides different types of information. For instance, visible light allows us to see images similar to human vision, while infrared can detect heat and vegetation health.

Table 2: Main Regions of the Electromagnetic Spectrum

Type of radiation	Wavelength (m)	Frequency (Hz)
Radio	10^{3}	10^{4}
Microwave	10^{-2}	10^{8}
Infrared	10^{-5}	10^{12}
Visible	0.5×10^{-6}	10^{15}
Ultraviolet	10^{-8}	10^{16}
X-ray	10^{-10}	10^{18}
Gamma ray	10^{-12}	10^{20}

1.4. Remote Sensing Platforms

Remote sensing platforms are the carriers of sensors. They can be classified into three main categories: ground-based, airborne, and spaceborne platforms.

Ground-based platforms are used for close-range observations and calibration. Airborne platforms include aircraft and drones, which provide high-resolution data over smaller areas. Spaceborne platforms, such as satellites, offer large-scale and repeated coverage of the Earth's surface.

Table 3: Types of Platforms

Platform Type	Characteristics	Example
Ground-based	High accuracy, limited area	Field spectrometers
Airborne	Flexible, high resolution	Drones (UAVs)
Spaceborne	Large coverage, periodic data	Satellites

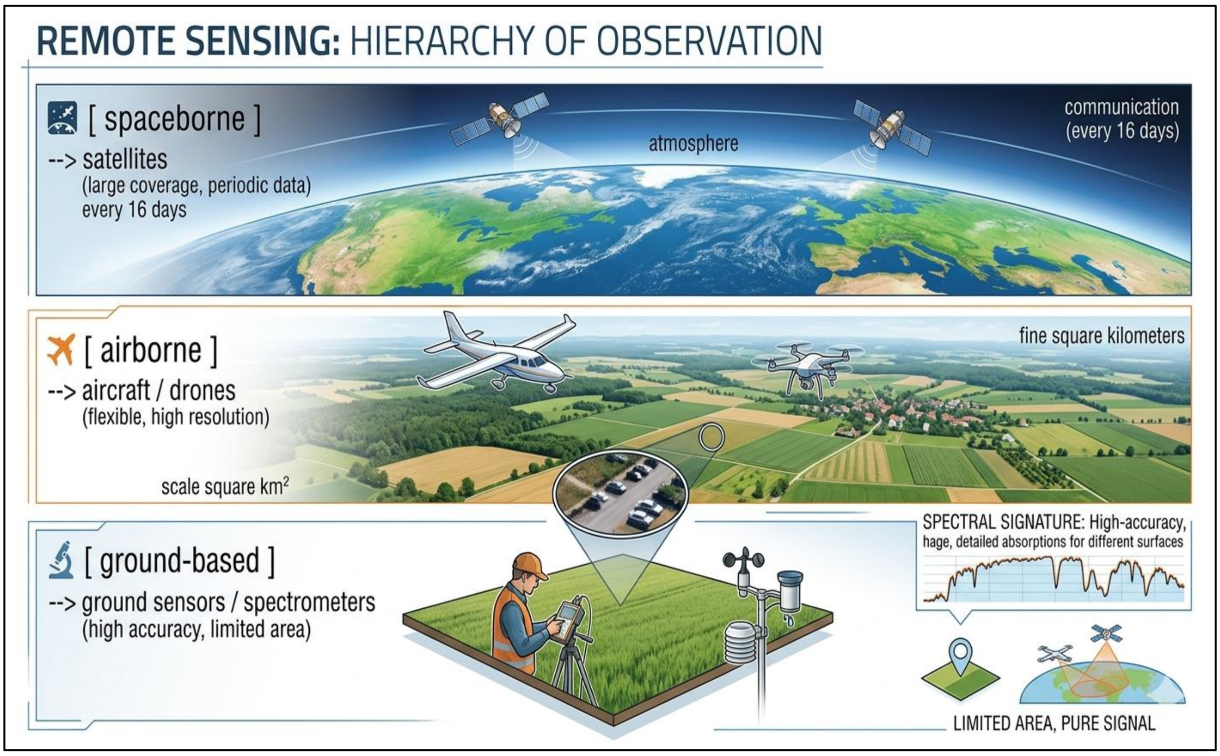


Figure 2: Remote Sensing Platforms

1. 5. Types of Sensors

Sensors are devices that detect electromagnetic radiation and convert it into digital data. They are broadly classified into passive and active sensors.

Passive sensors rely on natural sources of energy, such as sunlight, while active sensors generate their own energy and measure the reflected signal.

Table 4: Passive vs Active Sensors

Feature	Passive Sensors	Active Sensors
Energy Source	Sun (reflected light, emitted heat)	Internal system (self-generated pulse)
Weather Dependency	Blocked by clouds, fog, and darkness	Penetrates clouds, light rain, and darkness
Key Examples	Optical cameras, multispectral scanners	Radar (SAR), LiDAR, laser altimeters
Primary Output	Color imagery, chemical compositions	3D structural data, surface roughness

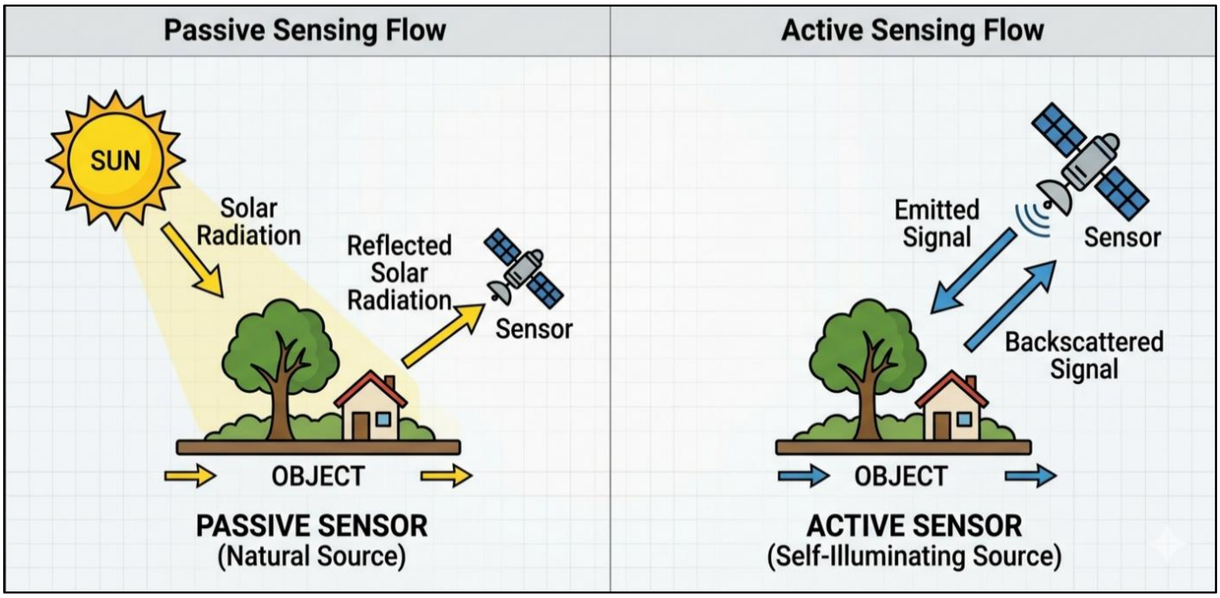


Figure 3: Passive vs Active Sensing

1. 6. Resolution in Remote Sensing

Resolution is a critical concept in remote sensing and determines the quality and usefulness of the data. There are four main types of resolution: spatial, spectral, temporal, and radiometric.

Spatial resolution refers to the size of the smallest object that can be detected. Spectral resolution indicates the ability to distinguish different wavelengths. Temporal resolution describes how often data is acquired, and radiometric resolution refers to the sensitivity of the sensor.

Table 5: Types of Resolution

Resolution Type	What It Measures	Higher Resolution Means...	Typical Application
Spatial	Pixel ground size	Smaller pixels, sharper image details	Urban planning, mapping roads
Spectral	Number/width of color bands	More bands, better chemical/material ID	Identifying crop stress, mineral types
Temporal	Revisit frequency	Shorter wait time between images	Disaster tracking, crop growth cycles
Radiometric	Bit depth (greyscale levels)	Better contrast, more shades of color	Distinguishing water from wet mud

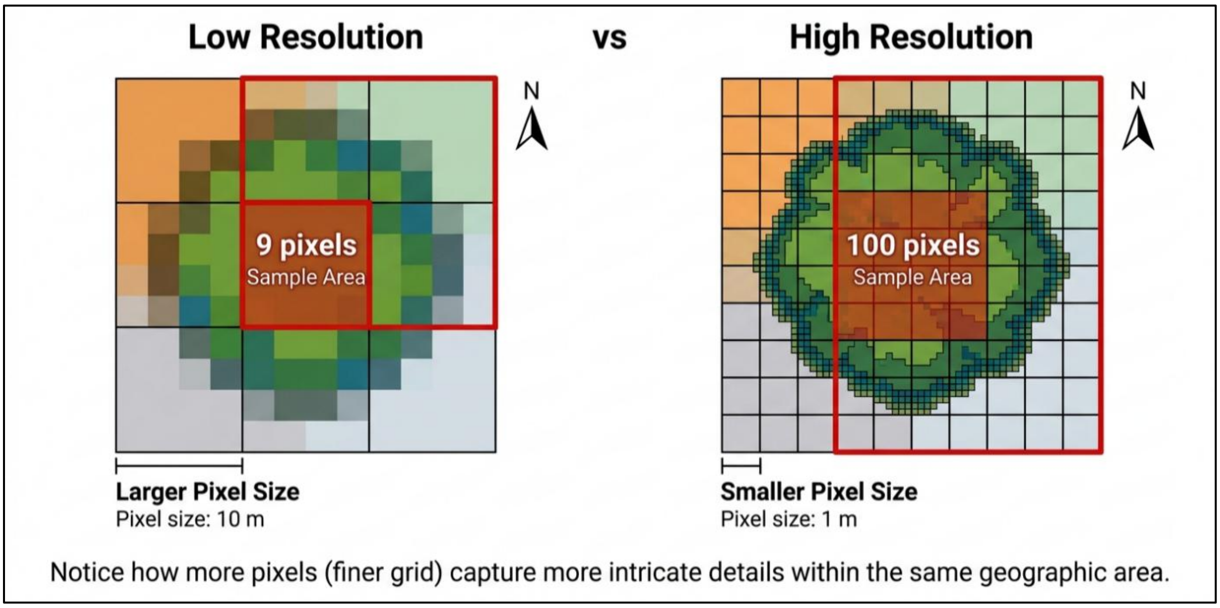


Figure 4: Spatial Resolution Comparison

1.7. Applications of Remote Sensing

Remote sensing has a wide range of applications across different disciplines. In agriculture, it helps monitor crop health and estimate yields. In environmental science, it is used to detect deforestation and pollution. Urban planners use it to analyze land use and expansion, while disaster management teams rely on it for rapid assessment of floods, earthquakes, and fires.

Table 6: Applications

Field	**Primary Platform**	**Sensor Configuration**	**Ideal Resolution**
Agriculture	Airborne Drones / Satellites	Passive Multispectral	High Spectral / High Temporal
Environment	Spaceborne Satellites	Active LiDAR & Optical	High Temporal / Medium Spatial
Urban Planning	Airborne & High-Res Satellites	High-Resolution Optical	High Spatial / Low Temporal
Disaster Mgmt.	Spaceborne Satellites	Active Radar & Thermal	High Temporal / High Radiometric

1. 8. Advantages and Limitations

Remote sensing fundamentally transforms how we study Earth by providing unmatched capabilities alongside complex technical challenges. On the positive side, its primary advantage is the ability to acquire massive, continuous spatial coverage over vast geographical regions in a single scan. This bird's-eye view allows scientists to establish repetitive observations over time, capturing rapid environmental changes like glacier melt or urban sprawl as they happen. Furthermore, it grants safe, unrestricted access to remote or dangerous territories, including active volcanic craters, conflict zones, and dense, impenetrable rainforests, completely eliminating risks to human field crews. Financially, it offers a highly cost-effective mapping alternative, reducing the immense time and budget required for manual ground surveys.However, these extensive benefits are directly paired with demanding technical limitations that require careful management. Optical sensors suffer from high sensitivity to atmospheric conditions, meaning clouds, heavy fog, and thick smoke can entirely block surface visualization and corrupt data collections. Additionally, modern sensors generate a massive volume of complex data, creating storage and processing bottlenecks that require expensive, high-performance computing architecture. Transforming these raw, multi-band digital numbers into accurate, actionable maps demands highly specialized engineering knowledge in physics, orbital mechanics, and advanced geostatistics. Finally, the initial financial barrier remains exceptionally high, given the immense costs involved in manufacturing, launching, and maintaining advanced satellite instruments.

2. Sensors (Capteurs)

Sensors are fundamental components in remote sensing systems. They are responsible for detecting electromagnetic radiation and converting it into digital signals that can be analyzed. The quality and type of data obtained depend largely on the characteristics of the sensor, including its resolution and the platform on which it is mounted.

Sensors can be designed for different purposes, such as capturing visible images, detecting thermal variations, or measuring surface roughness using radar systems. Understanding how sensors operate is essential for interpreting remote sensing data correctly.

2.1 Types of Orbits

Satellites follow specific paths around the Earth called orbits. The type of orbit determines the coverage area, revisit time, and application of the satellite.

There are two main types of orbits used in remote sensing: geostationary and polar (sun-synchronous).

Table 7: Types of Satellite Orbits

Feature	**Geostationary Orbit (GEO)**	**Polar / Sun-Synchronous Orbit (SSO)**
Altitude	Extremely High (~36,000 km)	Low Earth Orbit (500 – 1,000 km)
Coverage Area	Fixed hemisphere (cannot see the poles)	Complete global coverage over multiple days
Revisit Time	Continuous, uninterrupted live feed	Periodic (revisits a spot every few days/weeks)
Spatial Resolution	Generally lower (due to immense distance)	Very high (close proximity to the ground)
Primary Use	Weather forecasting, satellite TV, communication	Environmental monitoring, mapping, military

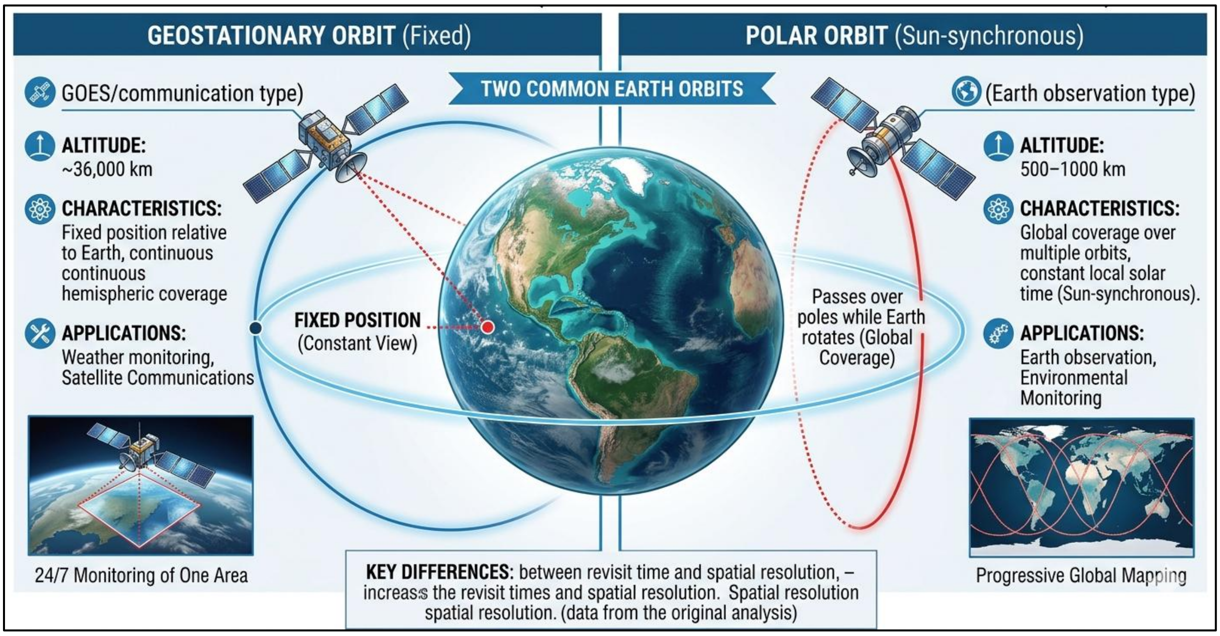


Figure 5: Satellite Orbits

2.2 Types of Satellites

Remote sensing satellites are designed depending on their mission objectives. Some focus on environmental monitoring, while others are used for communication or military purposes.

Earth observation satellites are the most relevant for remote sensing applications.

Satellite orbits are carefully designed trajectories that determine exactly how a spacecraft observes our planet, directly shaping the nature and utility of the collected data. Geostationary orbits are positioned at an immense altitude of approximately 36,000 kilometers directly above the Earth's equator. At this specific distance, the satellite's orbital speed perfectly matches the rotation of the Earth, allowing it to remain permanently fixed over one geographic location. This stationary viewpoint delivers continuous, real-time monitoring of an entire hemisphere, making it indispensable for tracking fast-moving weather patterns, predicting severe storms, and maintaining uninterrupted global telecommunication networks. However, because of this extreme distance, geostationary sensors struggle to capture fine ground details and completely lose visibility near the North and South poles due to the Earth's curvature.

In stark contrast, polar and sun-synchronous orbits operate at much lower altitudes, typically ranging between 500 and 1,000 kilometers above the surface. These satellites travel longitudinally from pole to pole while the Earth slowly rotates beneath them, allowing the instruments to systematically sweep across the entire globe over a period of several days. Because they fly significantly closer to the ground, polar-orbiting satellites achieve a much higher spatial resolution, capturing sharp details such as individual roads, fields, and buildings. Furthermore, their sun-synchronous design ensures they cross the equator at the exact same local solar time on every single pass, maintaining a constant angle of sunlight and uniform shadows across images. This predictable illumination makes polar orbits the absolute gold standard for scientific Earth observation, enabling researchers to reliably compare environmental changes over months, years, or decades.

2.3 Spectral Resolution

Spectral resolution refers to the ability of a sensor to distinguish between different wavelengths of electromagnetic radiation. A sensor with high spectral resolution can capture data in many narrow wavelength bands.

Spectral resolution defines a sensor's ability to divide reflected light into highly precise wavelength intervals, acting as a remote chemical analysis laboratory. Unlike the human eye, which only perceives three broad color channels (Red, Green, and Blue), advanced multispectral and hyperspectral sensors capture electromagnetic energy across dozens or hundreds of narrow bands, including the invisible infrared spectrum. This fine slicing allows scientists to record a unique "spectral signature" for every material based on its distinct molecular and physical properties. Consequently, high spectral resolution makes it possible to distinguish between objects that appear identical to the naked eye—enabling researchers to identify specific tree species, measure crop water stress, calculate toxic algae concentrations in lakes, and map precise mineral compositions across bare soils,

Table 8: Spectral Resolution

Spectral Level	**Number & Width of Bands**	**Conceptual Visual Grid**	**Technology Example**	**Primary Data Application**
Low	Few broad bands	|———|———|———|	Standard RGB digital cameras	Basic visual photography, land vs water mapping
Medium	Several distinct bands	|—|—|—|—|—|	Multispectral sensors (Landsat 9, Sentinel-2)	Monitoring regional deforestation, tracking vegetation health
High	Many narrow, continuous bands	|-|-|-|-|-|-|-|-|-|-|-|-|-|	Hyperspectral sensors (EnMAP, PRISMA, EMIT)	Identifying specific soil minerals, detecting

				early crop diseases

2.4 Radiometric Resolution

Radiometric resolution describes the ability of a sensor to detect small differences in energy (brightness). It is usually expressed in bits.

A higher radiometric resolution means the sensor can detect more subtle differences in intensity.

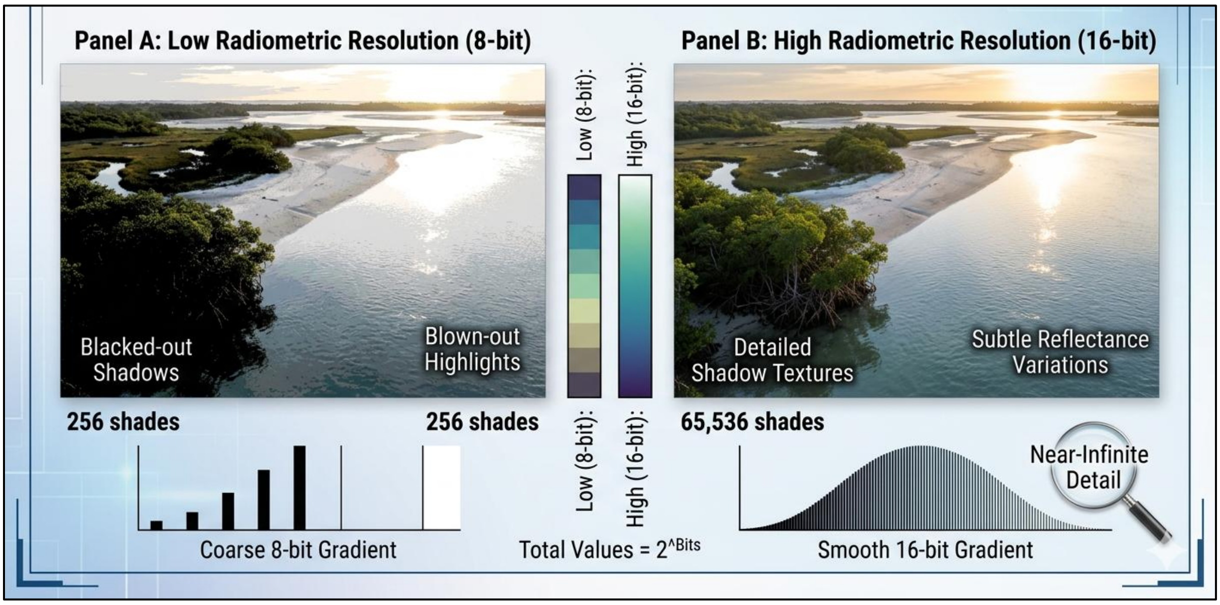


Figure 6. Radiometric Resolution

2.5 Temporal Resolution

Temporal resolution refers to how often a satellite revisits the same location on Earth. It is crucial for monitoring changes over time.

High temporal resolution is important for applications such as weather forecasting and disaster monitoring.

Temporal resolution refers to the frequency with which a satellite sensor captures imagery of the exact same geographical location on Earth. Often called the "revisit time," this interval depends heavily on the satellite's orbital characteristics, swath width, and whether it operates as part of a multi-satellite constellation. High temporal resolution means the sensor revisits an area very frequently—ranging from every few hours to a few days—which generates a rapid stream of data. This constant coverage is absolutely critical for tracking dynamic, fast-moving phenomena such as developing weather systems, spreading wildfires, and unfolding natural disasters. Conversely, low temporal resolution involves longer gaps of weeks or months, which is sufficient for mapping stable features like geology or long-term urban sprawl but useless for real-time monitoring. In remote sensing, a classic trade-off exists where high temporal frequency often requires sacrificing high spatial detail. Furthermore, cloud cover can frequently obstruct optical sensors, meaning a high revisit rate is technically necessary just to guarantee a few clear, usable images over time. Ultimately, managing this high-frequency data demands massive storage and robust processing pipelines to turn rapid observations into actionable environmental insights.

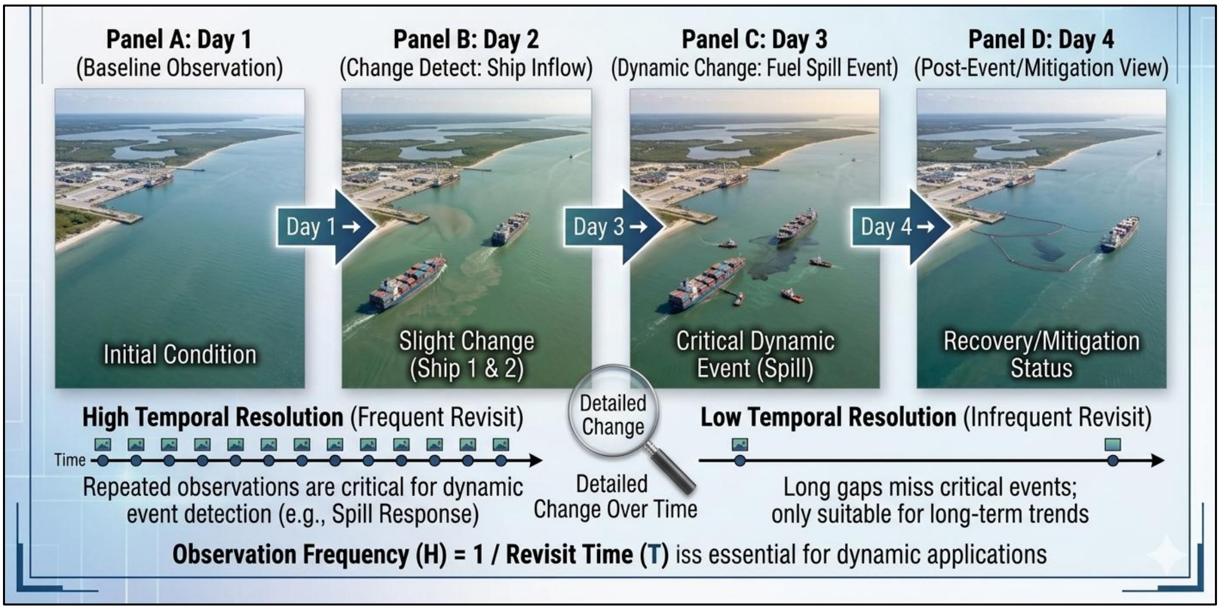


Figure 7: Temporal Resolution

2.6 Photography

Aerial photography is one of the earliest forms of remote sensing. It involves capturing images using cameras mounted on aircraft or drones. There are two main types of aerial photographs: vertical and oblique.

Vertical photographs are taken from directly above and are used for mapping.

Oblique photographs are taken at an angle and provide a more realistic perspective.

2.7 Earth Observation

Earth observation refers to the collection of information about the Earth's surface using remote sensing technologies. It includes monitoring natural and human activities. This field is essential for sustainable development, climate studies, and resource management, examples include:

- **Climate Change and Environmental Monitoring**
- **Glacier and Ice Sheet Melting:** Satellites track the rate of polar ice melt and rising sea levels over decades.

- **Deforestation Tracking:** High-resolution imaging monitors the loss of rainforests in real-time, such as in the Amazon, helping to detect illegal logging.
- **Atmospheric Composition:** Sensors measure greenhouse gas concentrations (like CO_2 and methane) and track air quality index (AQI) changes globally.
- **Agriculture and Food Security**
- **Crop Health Assessment:** By measuring the Normalized Difference Vegetation Index (NDVI), satellites can assess crop vigor, detect drought stress, and predict food yields.
- **Soil Moisture Mapping:** Microwave remote sensing helps optimize irrigation by mapping water content in the upper soil layers.
- **Disaster Management and Response**
- **Flood Mapping:** Radar imaging penetrates cloud cover during severe storms to map the exact extent of flooded areas, guiding rescue operations.
- **Wildfire Detection:** Thermal sensors spot active fire fronts and track smoke plumes to assist firefighting efforts and post-fire scar assessment.
- **Earthquake and Volcanic Activity:** Interferometric Synthetic Aperture Radar (InSAR) measures millimeter-scale ground deformation before and after seismic events.
- **Water Resource Management**
- **Surface Water Dynamics:** Monitoring the shrinking or expanding boundaries of vital reservoirs, lakes, and rivers (such as monitoring dams and watersheds).
- **Water Quality Assessment:** Optical sensors detect chlorophyll-a concentration, suspended sediments, and harmful algal blooms in coastal and inland waters.
- **Urban Planning and Infrastructure**
- **Urban Heat Islands:** Thermal infrared sensors map how concrete and asphalt retain heat in cities compared to surrounding rural areas.
- **Land Use and Land Cover (LULC) Mapping:** Categorizing the Earth's surface into forest, agricultural, urban, or wetland zones to manage sustainable expansion.

2.8 Data Processing

Raw remote sensing data must be processed before it can be used. This involves several steps, including correction, enhancement, and analysis. The goal is to transform raw data into meaningful information.

Main Steps:

- Data acquisition
- Preprocessing (correction)
- Image enhancement
- Classification
- Interpretation

Table 9: Data Processing Steps

Step	**Technical Purpose**	**Actionable Actions Taken**	**Final Output / Result**
Preprocessing	Remove distortions	Corrects for atmospheric haze, sensor noise, and orbital tilts.	Clean, geometrically accurate raw imagery.
Enhancement	Improve visibility	Adjusts image contrast, sharpens edges, and applies color stretches.	Visually optimized data ready for human or machine interpretation.
Classification	Identify features	Groups pixels into thematic classes using machine learning or thresholding.	An categorized map (e.g., separating water, forest, and urban areas).
Analysis	Extract information	Runs mathematical models, calculates indices (like NDVI), and tracks changes.	Actionable environmental metrics, statistics, and decision-making reports.

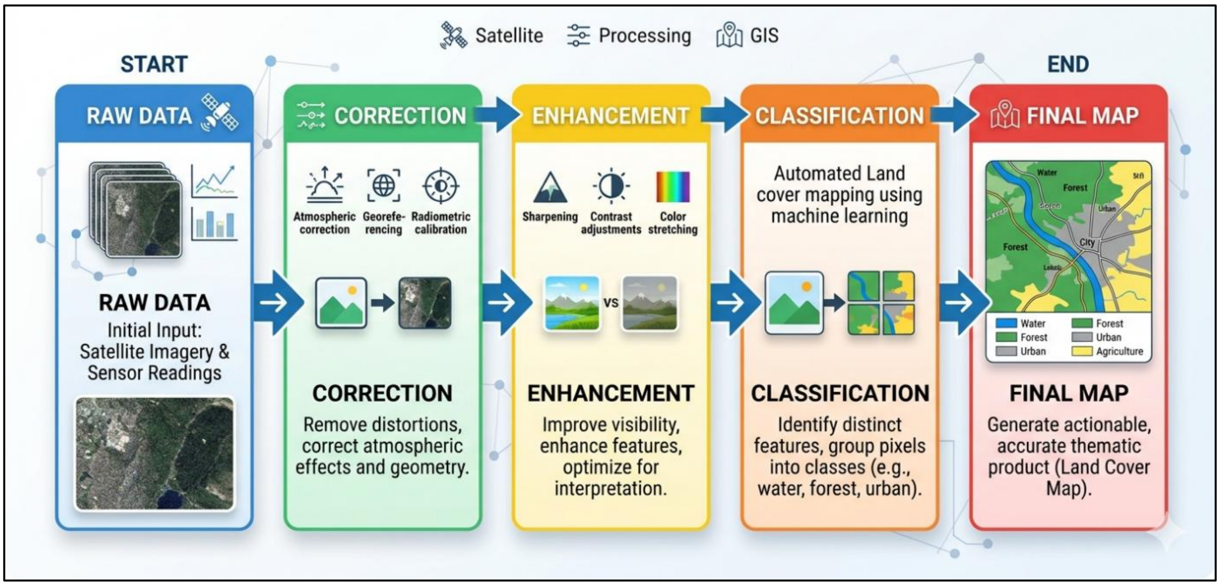


Figure 8: Data Processing Workflow

3. Image Analysis

Image analysis is a fundamental step in remote sensing that transforms raw satellite or aerial images into meaningful information. It involves extracting, interpreting, and classifying features present in an image.

This process can be performed using two main approaches: visual interpretation (human-based analysis) and digital image processing (computer-based techniques). Both methods are complementary and widely used depending on the application.

3.1 Visual Interpretation

Visual interpretation is the manual analysis of images by a human expert. It relies on the analyst's ability to recognize patterns, shapes, colors, and textures in an image.

This method is particularly useful when expert knowledge is required, such as identifying land use types or geological structures. The interpretation is based on several key elements.

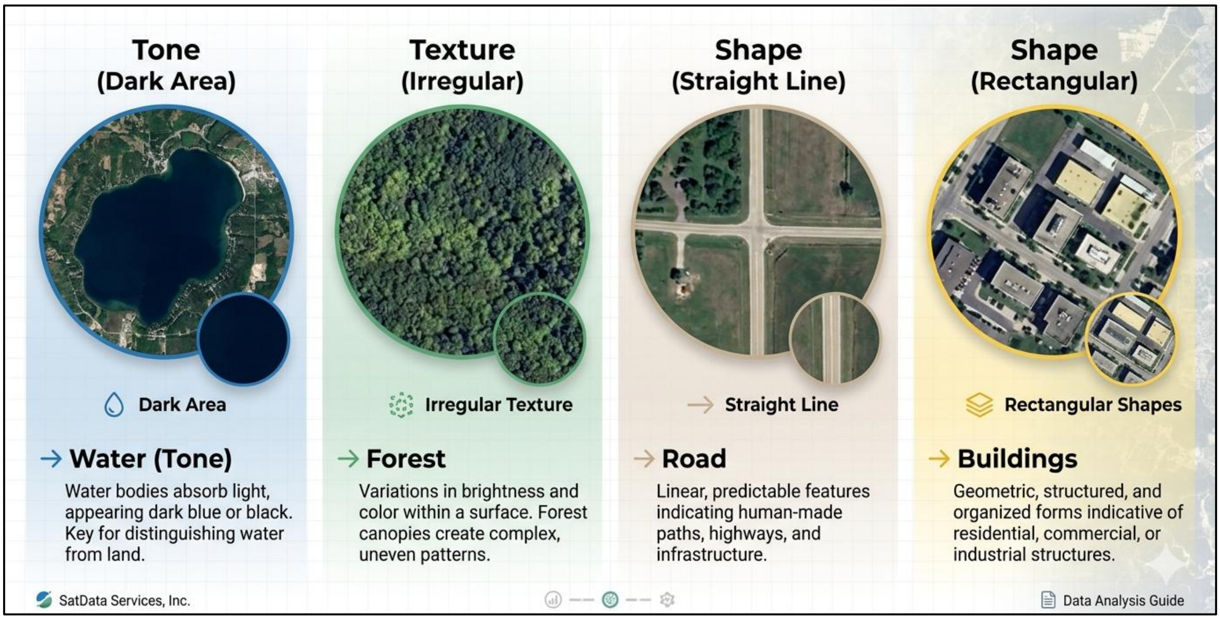


Figure 9: Visual interpretation

For example, a trained analyst can distinguish between urban and rural areas by observing texture and pattern. Urban areas usually show a complex pattern with sharp edges, while rural areas appear smoother and more homogeneous. Although visual interpretation is powerful, it can be subjective and time-consuming, especially for large datasets.

3.2 Image Processing

Image processing refers to the use of computer algorithms to enhance and analyze remote sensing images. It allows for faster, more objective, and reproducible results compared to manual interpretation.

The processing workflow generally includes several steps, starting from raw data correction to advanced analysis.

For instance, satellite images may contain distortions due to sensor movement or atmospheric conditions. Image processing corrects these issues, making the data more accurate and usable.

Enhancement techniques such as contrast stretching make features like vegetation or water bodies more visible, improving interpretation and classification.

3.3 Classification

Classification is the process of grouping pixels in an image into meaningful categories, such as water, vegetation, urban areas, or bare soil. It is one of the most important steps in remote sensing because it converts image data into thematic maps. There are two main types of classification: supervised and unsupervised.

In supervised classification, the user selects sample areas (training data) for each class, and the algorithm classifies the rest of the image based on these samples. In unsupervised classification, the computer automatically groups pixels based on their spectral similarity without prior knowledge. The output is a classified image where each pixel belongs to a specific category.

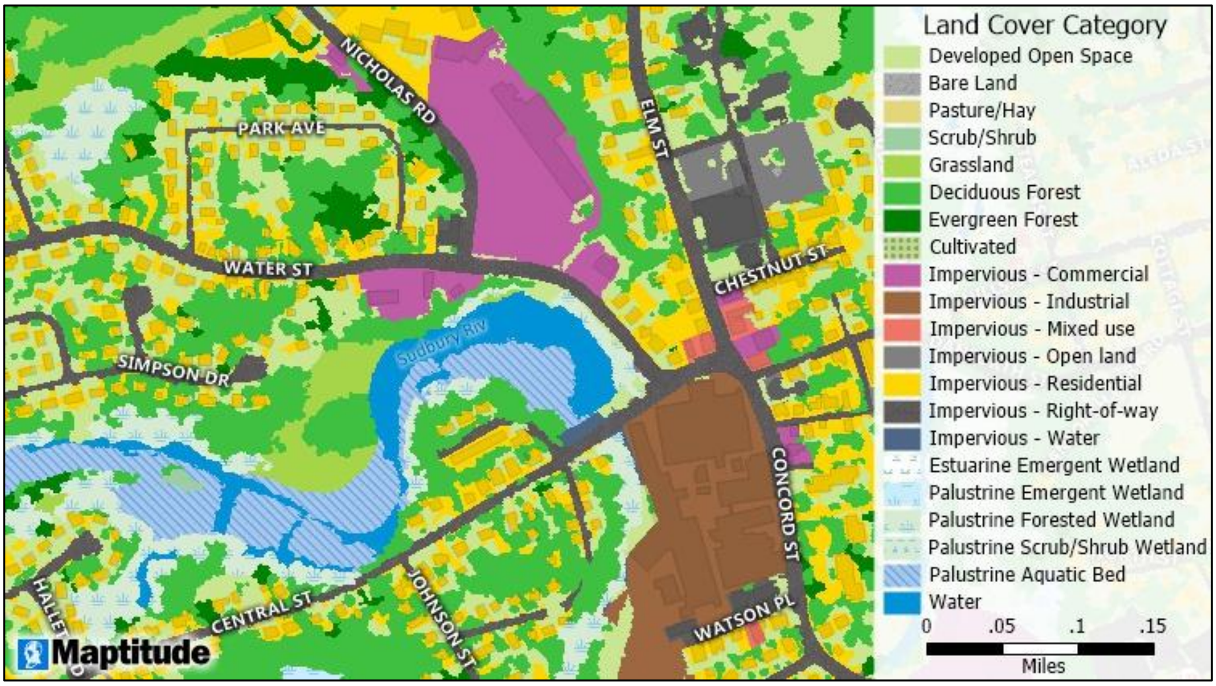


Figure 10: Example of Classified Image

Conclusion

Image analysis is essential for extracting useful information from remote sensing data.

- Visual interpretation relies on human expertise

- Image processing improves data quality
- Classification transforms images into thematic maps.

Together, these methods allow scientists and decision-makers to better understand and manage the Earth's surface.

4. Applications of Remote Sensing

Remote sensing has become an essential tool in many scientific and practical fields. Its ability to provide continuous, large-scale, and multi-temporal data makes it highly valuable for monitoring and managing natural and human environments.

In this section, we focus on three important application domains: forestry, agriculture, and land cover analysis, particularly rural and urban changes.

4.1 Forestry

Remote sensing plays a crucial role in forest management and environmental conservation. It allows scientists and decision-makers to monitor forest conditions over large and often inaccessible areas.

Using satellite imagery, it is possible to assess forest density, detect illegal logging, monitor deforestation, and evaluate forest health.

For example, by comparing satellite images from different dates, analysts can detect changes in forest cover. A decrease in vegetation density may indicate deforestation or forest degradation. Remote sensing is also widely used to monitor forest fires in near real-time, helping authorities respond quickly and reduce damage.

4.2 Agriculture

In agriculture, remote sensing is used to improve productivity and optimize resource management. It provides valuable information about crop conditions, soil moisture, and irrigation needs. One of the most important tools in this field is vegetation indices, such as the NDVI (Normalized Difference Vegetation Index), which measures plant health based on spectral reflectance.

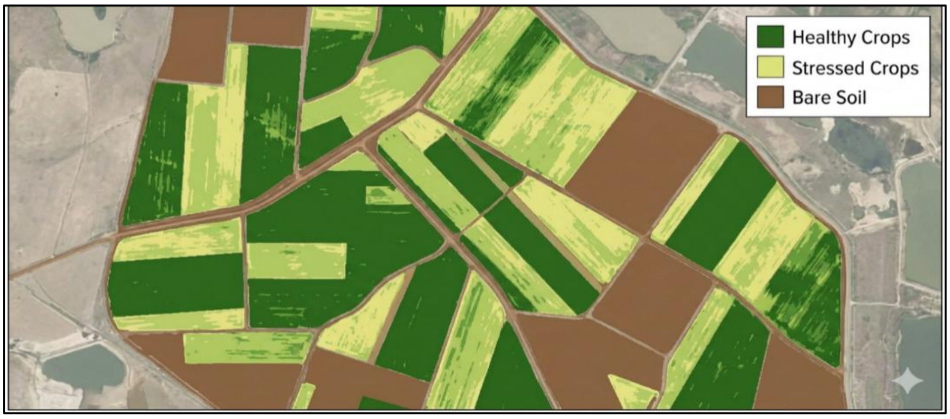


Figure 11: Crop Monitoring

Healthy vegetation reflects more near-infrared radiation and less visible red light. By analyzing this difference, remote sensing can identify areas where crops are stressed due to lack of water, pests, or disease. This allows farmers to take targeted actions instead of treating entire fields, which saves time, water, and resources.

4.3 Land Cover (Rural/Urban Changes)

Remote sensing is widely used to analyze land cover and detect changes between rural and urban areas. This is particularly important for understanding urban expansion, population growth, and environmental impact. By comparing images acquired at different times, it is possible to identify how land use evolves.

Urban areas typically appear with bright tones and complex patterns, while rural areas are more homogeneous and dominated by vegetation.

Remote sensing helps detect:

Expansion of cities

Conversion of agricultural land into urban zones

Environmental impacts such as loss of green spaces

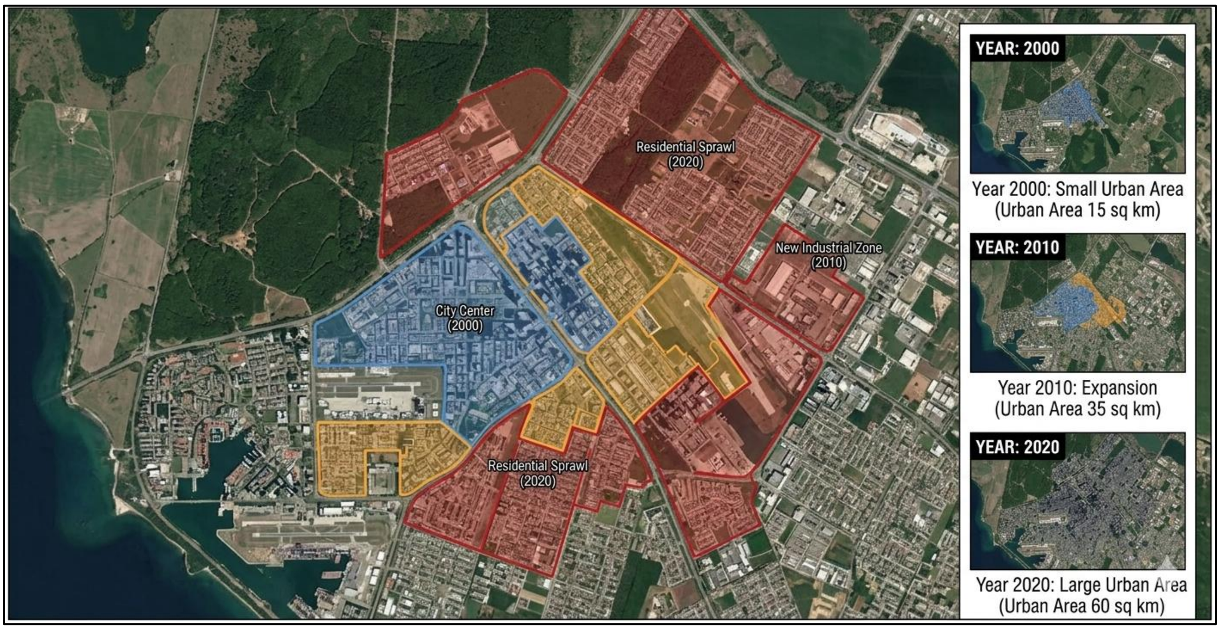


Figure 12: Urban Expansion

This information is essential for urban planning and sustainable development.

Remote sensing provides powerful tools for:

- Monitoring forests and protecting ecosystems
- Improving agricultural productivity

➢ Analyzing land cover and urban growth

These applications demonstrate how remote sensing contributes to sustainable development and environmental management.

5. Geographic Data

Geographic data represents information about objects, features, or phenomena that have a location on the Earth's surface. In remote sensing and GIS, geographic data is used to store, analyze, and visualize spatial information.

There are three main types of geographic data:

➢ Raster data
➢ Vector data
➢ Alphanumeric (attribute) data

Each type has specific characteristics and is used for different purposes in spatial analysis.

5.1 Raster Data

Raster data is a grid-based data structure composed of pixels (cells), where each pixel has a value representing information such as color, temperature, or elevation.

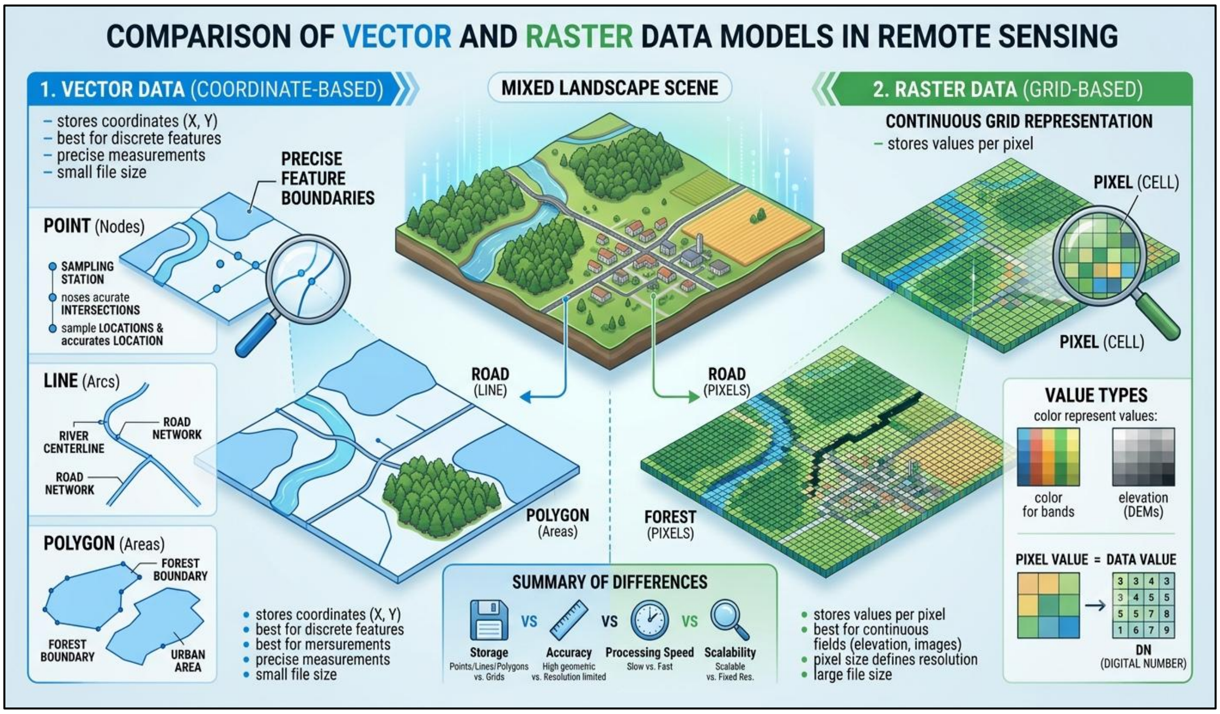


Figure 13. The difference between Raster and Vector Data

This format is commonly used in remote sensing because satellite images are naturally stored as raster data.

Each cell in the raster represents a specific area on the ground. For example, a satellite image with a spatial resolution of 10 meters means that each pixel corresponds to a 10m × 10m area.

Raster data is particularly suitable for:

- Continuous data (temperature, elevation)
- Image processing and classification

However, it can require large storage space, especially for high-resolution images.

5.2 Vector Data

Vector data represents geographic features using geometric shapes such as points, lines, and polygons. Unlike raster data, vector data is more precise and is commonly used for mapping discrete objects.

Vector data is ideal for representing features with clear boundaries, such as administrative borders, roads, and buildings.

It is widely used in GIS for:

- Mapping infrastructure
- Urban planning
- Navigation systems

Table 10: Types of Vector Data

Type	**Geometric Representation**	**Dimensionality**	**Primary Spatial Attributes**	**Remote Sensing Example**
Point	A single isolated coordinate tuple (\(X, Y\))	0-D (No length, no area)	Marks specific locations without showing physical size.	Groundwater wells, individual trees, light poles, sample points.
Line	An ordered sequence of connected vertices	1-D (Has length, no area)	Measures distances, tracks continuous networks, and paths.	Paved highways, natural river channels, power grid cables.
Polygon	A closed loop of connected lines enclosing an area	2-D (Has length and perimeter area)	Measures total area, boundaries, and spatial volume.	Building footprints, agricultural crop fields, city zones, lakes.

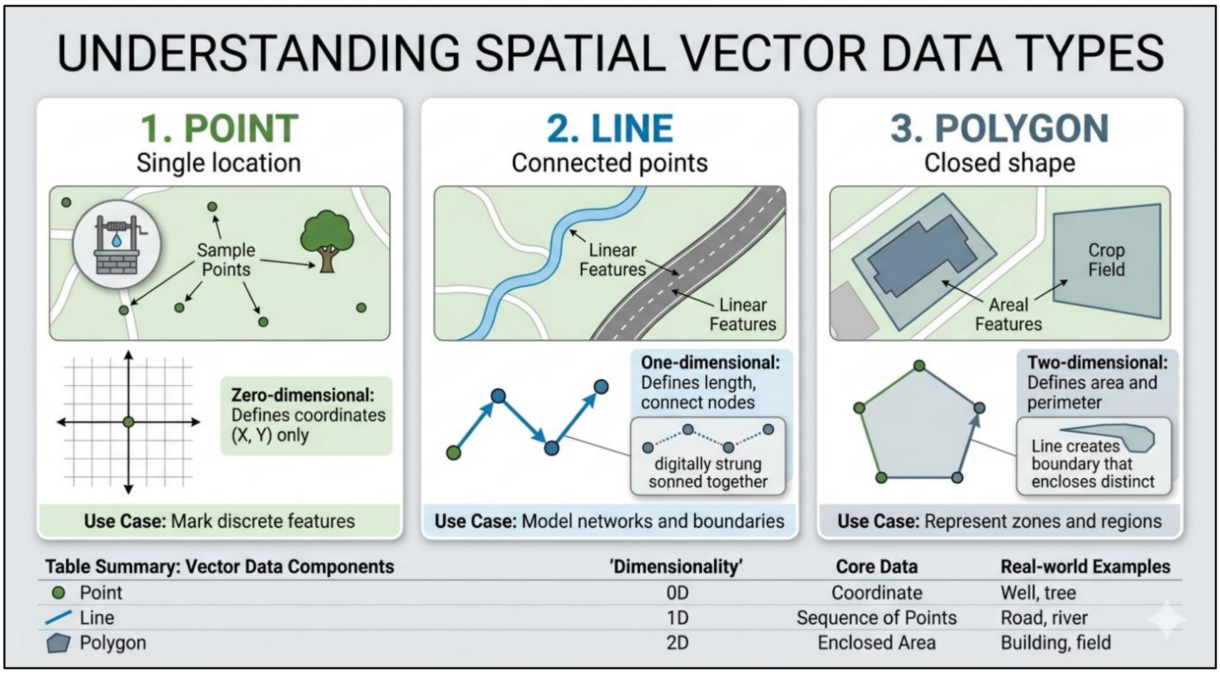


Figure 14: Vector Data Types

Compared to raster data, vector data requires less storage and provides higher geometric accuracy.

5.3 Alphanumeric Data

Alphanumeric data (also called attribute data) provides descriptive information about geographic features. It is usually stored in tables and linked to spatial data (raster or vector). This type of data does not represent location directly but adds meaning to spatial features.

Table 11: Example of Alphanumeric Data

Feature ID	Land Use Type	Area (ha)	Population	Environmental Focus / Risk Factors
1	Urban	150	5,000	High impervious surface runoff, urban heat islands
2	Agriculture	300	1,200	Nitrate & ammonium runoff, high fertilizer usage
3	Forest	500	200	Soil erosion control, high biodiversity index

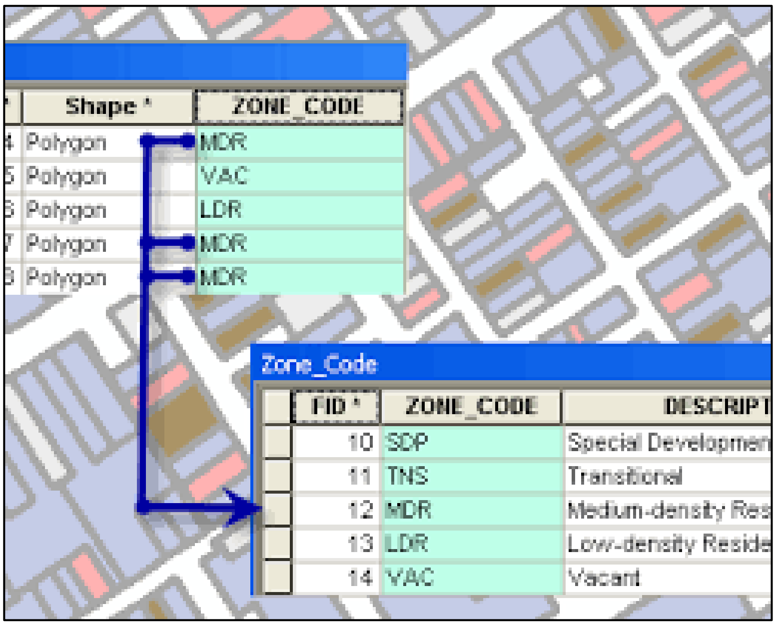


Figure 15: Link Between Spatial and Attribute Data

For example, a polygon representing a city on a map can be linked to a table containing its population, land use type, and area.

This combination of spatial and alphanumeric data allows for advanced analysis such as:

- Querying (“select all urban areas”)
- Statistical analysis
- Decision-making support

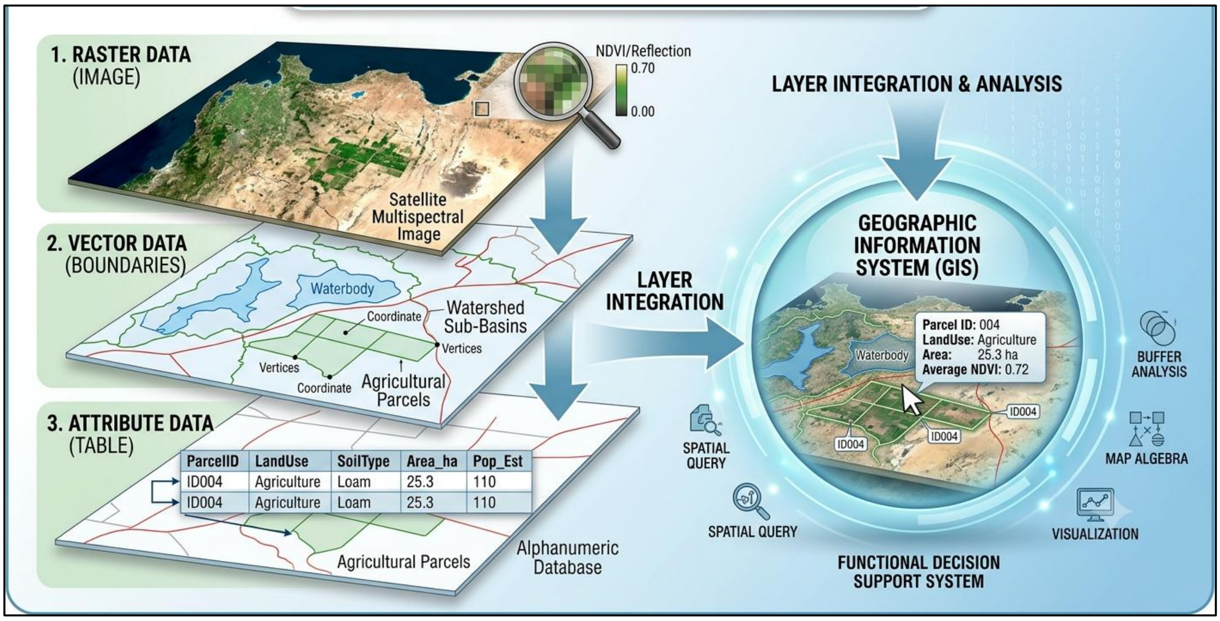


Figure 16: Integration of Geographic Data

Conclusion

Geographic data is essential for analyzing and interpreting remote sensing information:

- Raster data is used for images and continuous phenomena
- Vector data represents discrete geographic features
- Alphanumeric data provides descriptive information

Together, these data types form the foundation of spatial analysis in GIS and remote sensing.

6. GIS Data Models (Les modèles des SIG)

Geographic Information Systems (GIS) use specific data models to represent, store, and analyze spatial information. A data model defines how geographic features are structured and how their relationships are described.

There are two fundamental GIS data models:

- The metric model (spaghetti model)
- The topological model

These models differ mainly in how they represent spatial relationships between geographic objects.

6.1 The Metric Model (Spaghetti Model)

The metric model, also known as the spaghetti model, is the simplest way to represent spatial data in GIS. In this model, geographic features such as points, lines, and polygons are stored independently, without any information about their spatial relationships. Each object is treated as a separate entity, and there is no connection between them, even if they overlap or intersect.

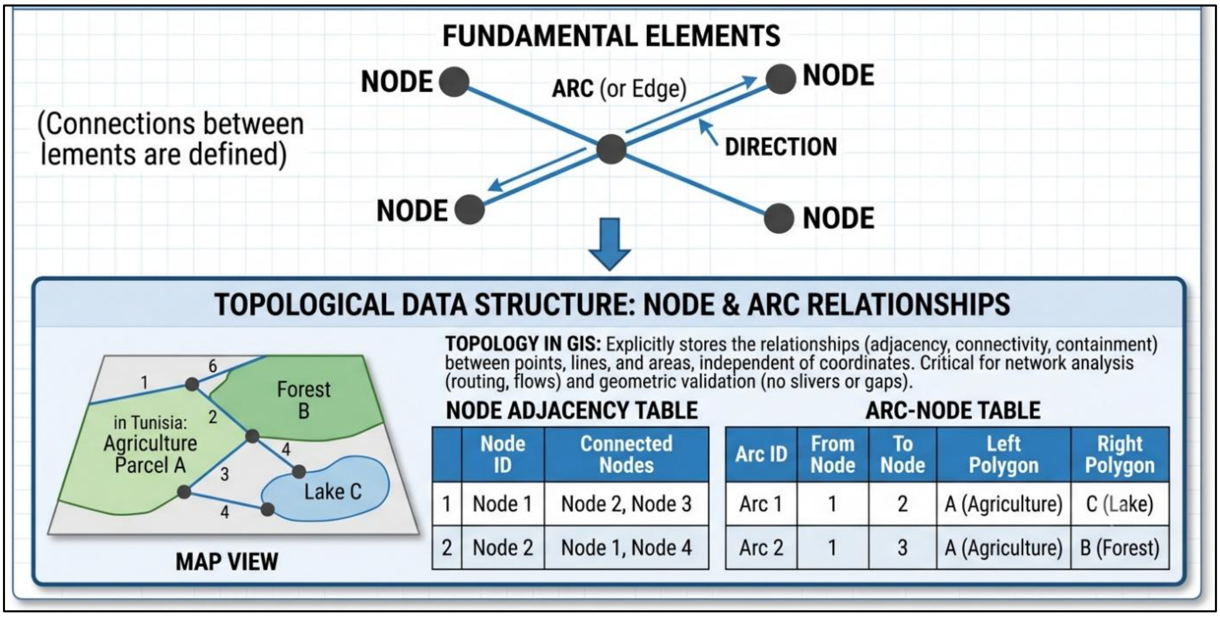
In this model, two roads that intersect are stored as separate lines without any indication that they cross each other. This makes the model simple and easy to use, but limits its analytical capabilities.

For example, it is difficult to perform network analysis (such as finding the shortest path) because the relationships between objects are not defined.

6.2 The Topological Model

The topological model is a more advanced data model that explicitly stores spatial relationships between geographic features. These relationships include connectivity, adjacency, and containment.

In this model, geographic elements are not only defined by their geometry but also by how they relate to each other.



	Node ID	Connected Nodes
1	Node 1	Node 2, Node 3
2	Node 2	Node 1, Node 4

Arc ID	From Node	To Node	Left Polygon	Right Polygon
Arc 1	1	2	A (Agriculture)	C (Lake)
Arc 2	1	3	A (Agriculture)	B (Forest)

Figure 17: Topological Model Representation

For example, in a road network:

- Intersections are represented as nodes
- Roads are represented as edges
- Areas are represented as polygons

This structure allows GIS to perform complex analyses such as:

- Shortest path calculation
- Network analysis
- Spatial queries

Advantages and Limitations of the Topological Model

In contrast to the Spaghetti Model, the **Topological Model** explicitly stores spatial relationships (such as connectivity, adjacency, and containment) in a relational database. While it provides the analytical intelligence required for advanced Geographic Information Systems (GIS) work, it comes with a trade-off in computational complexity.

Below is an analysis of the specific points outlined in your core structure:

1. The Advantages

- **Supports Complex Analysis:** Because connectivity is explicitly defined by node and arc tables, the software can perform advanced spatial modeling. For instance, it can trace downstream water pollution vectors through a complex hydrological network or execute network routing optimizations without needing to compute intersecting coordinates on the fly.
- **No Data Redundancy:** In a topological model, shared boundaries—such as the perimeter line separating an agricultural zone from an adjacent forest—are stored

as a single arc ($Edge$). This single-line storage eliminates geometric duplication, resulting in optimized file sizing and cleaner data management.

- **Accurate Relationships:** The model enforces strict mathematical logic. Neighboring polygons inherently "know" they are adjacent based on Left/Right polygon tables. This structural integrity guarantees absolute geometric accuracy, completely preventing common digitizing errors like overlapping gaps or sliver polygons during spatial layers overlay.

2. The Limitations

- **More Complex Data Structure:** Instead of storing a simple list of coordinate strings (X, Y), a topological database must simultaneously maintain multiple interconnected lookup indices, including **Node Adjacency Tables**, **Arc-Node Tables**, and **Polygon Topology Tables**. This multi-layered structure makes data schemas significantly harder to modify or reverse-engineer manually.
- **Requires More Processing Power:** Every time a vector feature is modified, moved, or deleted, the GIS software cannot simply update a local coordinate. It must recalculate and rebuild the topological relationships across the entire dataset to verify network consistency, resulting in higher CPU and processing overhead.
- **Harder to Build and Enforce:** Creating topologically clean data requires rigorous data compilation workflows. Inputs must go through strict validation phases—such as setting snapping tolerances and executing cleaning algorithms—to eliminate dangles and unclosed loops before the database can successfully compile the relationship matrices.

Table 12 : Summary Comparison

Criterion	**Spaghetti Model**	**Topological Model**
Data Integrity	Low (Slivers and gaps are common)	High (Enforced by mathematical rules)
Network Tracing	Impossible	Native (Built-in via Node/Arc logic)
Storage Strategy	Redundant boundaries stored twice	Single shared boundary arcs
Computational Overhead	Minimal (Fast display rendering)	Substantial (Constant index rebuilding)

Summary Comparison Matrix

To put this in perspective for remote sensing and GIS workflows, here is how the two primary vector models compare across these key characteristics:

Metadata (La Métadonnée)

Metadata is often described as “data about data.” In the context of remote sensing and GIS, metadata provides detailed information that describes the content, quality, condition, and characteristics of a dataset. Without metadata, geographic data can be difficult to interpret, reuse, or validate. Metadata ensures that users understand how the data was collected, processed, and how it should be used.

Metadata includes information such as:

- Who created the data
- When it was created
- How it was produced
- What it represents
- Its accuracy and limitations

For example, a satellite image without metadata would not indicate:

- The acquisition date
- The spatial resolution
- The sensor used

This makes metadata essential for scientific reliability and data sharing.

The Role of Metadata

In GIS and Remote Sensing, metadata is frequently described as "data about data." Without metadata, a spatial dataset is just a collection of raw numbers, pixels, or vectors with no geographic or historical context.

Key Elements of Metadata

The parameters listed in Table 33 represent the critical structural documentation required to validate any environmental dataset:

Identification (What is it?): Provides the official title and abstract summary. Knowing a file represents a Land cover map lets users understand its thematic purpose before opening it.

Source (Where did it come from?): Identifies the origin, such as Satellite imagery (e.g., Sentinel-2 or Landsat-8). This is vital for tracking data lineage and verifying scientific reliability.

Date (When was it captured?): Specifies the time of acquisition (2024-05-10). In environmental studies, timing is crucial—a satellite image from May captures spring vegetation, whereas one from August captures dry season characteristics.

Resolution (What is the detail level?): Defines the cell size or minimum mapping unit (10 m). A 10 m spatial resolution means each pixel covers a 10 m×10 m area on the ground, dictating the maximum scale of analysis.

Projection (Where is it anchored?): Defines the Coordinate Reference System (CRS), such as UTM (Universal Transverse Mercator). Aligning projections is mandatory; overlaying a UTM dataset onto a geographic coordinate system (WGS84 in degrees) without conversion results in massive displacement errors.

Accuracy (How reliable is it?): Specifies quality control bounds (±5 m). This vertical or horizontal margin of error tells engineers if the data is precise enough for local planning or only suitable for broad regional modeling.

The Operational Flow of Metadata

Figure outlines the logical pipeline that transforms raw digital records into actionable scientific information:

Geographic Data⟶[Metadata]⟶Understanding & Proper Use

Geographic Data: This is the raw file package—such as a multi-band raster TIF file or a vector shapefile. On its own, it is just an abstract array of digital numbers (DN) or coordinate strings.

[Metadata]: This serves as the indispensable bridge, decoding the raw system files by providing the exact parameters defined in Table 33 (the sensor used, projection bounds, acquisition date, and validation lineage).

Understanding & Proper Use: Armed with this documentation, the researcher or engineer avoids major analytical blunders (such as misinterpreting outdated land boundaries, mixing incompatible spatial resolutions, or misaligning coordinate systems during a layer overlay). It guarantees that data integration is scientifically valid and reproducible.

Metadata acts like an identity card for geographic data. It helps users determine whether the dataset is suitable for their needs. For instance, if a researcher wants to study urban expansion, they need to know:

- The date of the image (temporal relevance)
- The resolution (level of detail)
- The coordinate system (for mapping accuracy)

Without this information, the analysis could lead to incorrect conclusions.

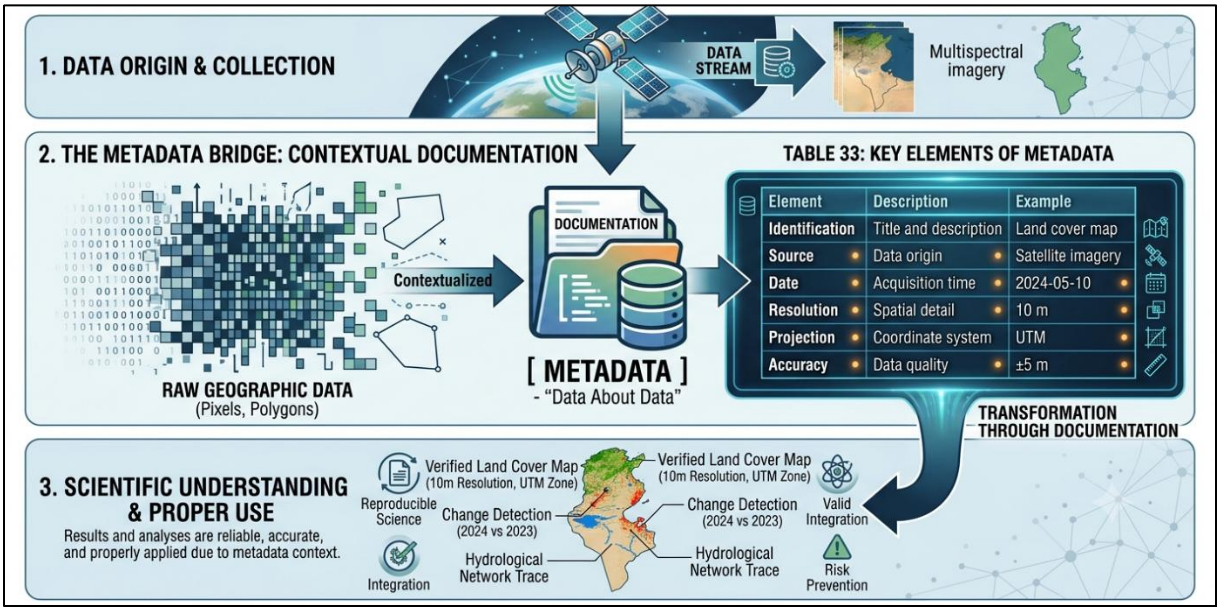


Figure 18. The Role of Metadata

Types of Metadata

Metadata can be classified into different categories depending on its purpose.

To ensure consistency and interoperability, metadata is often created following international standards. These standards define how metadata should be structured and documented, making it easier to share data between systems and organizations.

Consider a satellite image used for agricultural analysis. Its metadata may include:

Sensor: Sentinel-2

Spatial resolution: 10 m

Date: June 2023

Coordinate system: UTM Zone 32N

This information allows the user to correctly interpret vegetation conditions and compare data over time.

Chapter 2

The Role of GIS (Geographic Information Systems)

Geographic Information Systems (GIS) play a central role in modern spatial analysis. They allow the collection, storage, processing, analysis, and visualization of geographic data. GIS is not only a software system but also a complete workflow that transforms raw spatial data into meaningful information for decision-making.

The role of GIS can be divided into five major functions:

- Abstraction
- Acquisition
- Archiving
- Analysis
- Display

Each function represents a key step in the life cycle of geographic information.

1. Abstraction

Abstraction is the process of simplifying the real world into a digital geographic model. Since the real world is complex and continuous, GIS must represent it using simplified objects.

In this step, reality is transformed into:

Points

Lines

Polygons

Raster grids

This simplification is essential because computers cannot directly represent real-world complexity.

For example:

A tree becomes a point

A river becomes a line

A forest becomes a polygon

This transformation allows spatial data to be stored and processed digitally.

Abstraction is essential because:

It reduces complexity

It enables computation

It standardizes geographic information

Without abstraction, GIS systems would not be able to function.

2. Acquisition

Data acquisition is the process of collecting geographic information from different sources. This is the starting point of any GIS project.

Data can be obtained from:

Remote sensing satellites

GPS devices

Field surveys

Existing maps

Aerial photography

Sources of GIS Data

In Geographic Information Systems (GIS) and spatial analysis, data acquisition is the critical first step. Geographic data is collected using various platforms and methods, depending on the required scale, spatial resolution, and the nature of the environmental or infrastructural study.

Here is an analysis of each primary data source outlined in Table :

1. Satellite Imagery (Earth Observation)

- **Mechanism:** Sensors mounted on spaceborne satellites detect electromagnetic radiation reflected or emitted from the Earth's surface. This data is captured as continuous gridded layers (**Raster data**).
- **Examples (Landsat, Sentinel):** * **Landsat (NASA/USGS):** Provides valuable historical continuity dating back decades, making it excellent for monitoring long-term changes in land use or environmental degradation.
    - **Sentinel (ESA):** Offers high spatial (10 m) and temporal resolution, which is highly effective for active monitoring of water quality parameters, surface water variations in reservoirs, and agricultural health indicators (such as NDVI).

2. GPS (Position Data)

- **Mechanism:** Global Navigation Satellite Systems (GNSS) receivers calculate precise geometric coordinates (X, Y, Z) on the surface of the Earth by triangulating signals from global satellite constellations.
- **Field Measurements:** This is a vital source of primary vector data (points). It is used during fieldwork to ground-truth satellite images, map the precise boundaries of localized agricultural runoff zones, or log the exact locations of water sampling stations and wells.

3. Aerial Photos (Aircraft Images)

- **Mechanism:** High-resolution cameras mounted on low-altitude platforms capture localized, highly detailed imagery of the terrain below.
- **Drone Mapping (UAVs):** Unmanned Aerial Vehicles have revolutionized this category by providing an affordable way to capture ultra-high-resolution imagery (often down to centimeter scale) on demand. This is highly useful for mapping localized plant species distributions, fine-scale geomorphological features, or tracking immediate soil erosion along river valleys.

4. Maps (Existing Data)

- **Mechanism:** This involves utilizing legacy geographic information that has already been compiled, verified, and published. Often, paper maps are digitized (converted from analog to vector or raster formats) to serve as base layers.
- **Topographic Maps:** These provide essential reference frameworks, including elevation contours, river network centerlines, and established administrative boundaries, allowing researchers to contextualize newly acquired remote sensing data within a known, stable geographic reference system.

Table 13. Sources of GIS Data

Data Source	Primary Format in GIS	Ideal Application Scale	Key Advantage
Satellite Imagery	Raster (Grid)	Regional / Global	Large spatial coverage, repetitive monitoring
GPS / GNSS	Vector (Points/Lines)	Local / Field	High positional accuracy, real-time collection
Aerial Photos / Drones	Raster (High Res)	Localized / Catchment	Ultra-fine details, completely on-demand capture
Existing Maps	Vector or Raster	Variable	Provides historical baseline and topography

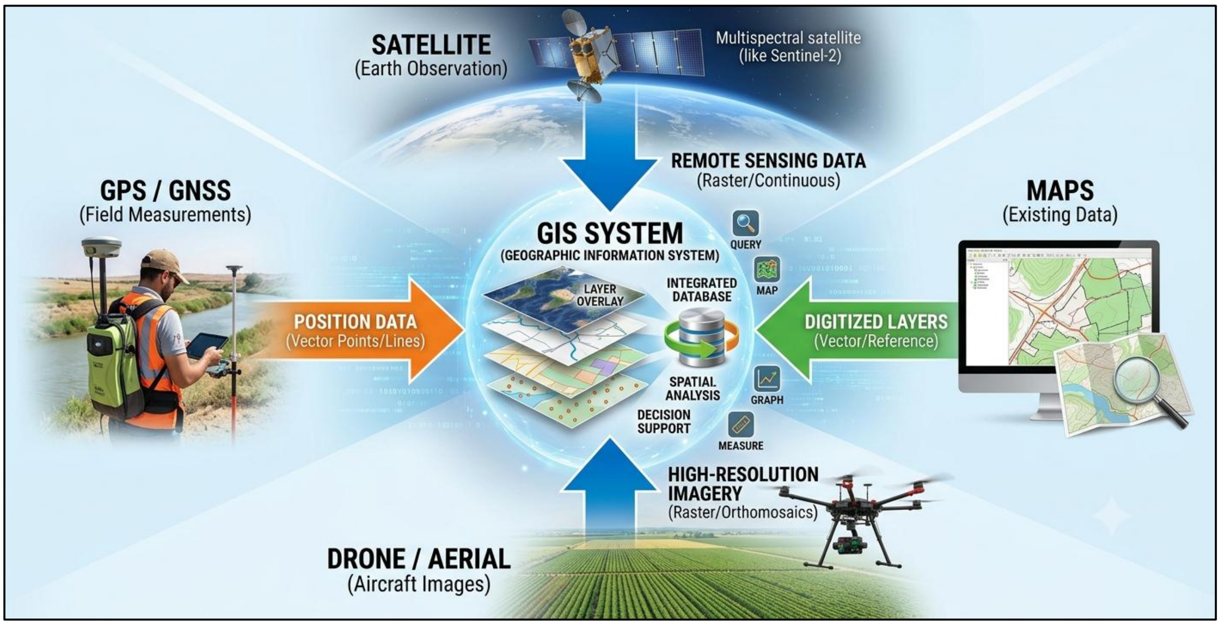


Figure 19: Data Acquisition Sources

Data acquisition ensures that GIS systems are constantly updated. Modern GIS relies heavily on real-time data from satellites and GPS devices.

For example:

- Emergency response uses live satellite images
- Urban planning uses drone surveys
- Agriculture uses GPS field mapping

The quality of GIS output depends directly on the quality of data acquisition.

3. Archiving (Storage)

Archiving refers to the storage and organization of geographic data in a structured database. GIS systems manage large volumes of spatial and attribute data.

Data must be stored efficiently to allow:

Fast retrieval

Easy updating

Long-term preservation

For example:

- A city polygon is stored in spatial data
- Its population is stored in attribute data
- Its source and accuracy are stored in metadata

Together, they form a complete geographic dataset.

Archiving is important because:

- It prevents data loss
- It ensures data consistency
- It supports long-term analysis

4. Analysis

Analysis is the most powerful function of GIS. It allows users to extract meaningful information from spatial data.

GIS analysis includes:

- Spatial queries
- Overlay analysis
- Buffer analysis
- Network analysis
- Statistical modeling

GIS analysis helps answer questions such as:

- Where are the high-risk flood zones?
- Which areas are suitable for agriculture?
- What is the shortest route between two points?

Analysis transforms GIS from a mapping tool into a decision-support system.

5. Display (Visualization)

Display is the final stage of GIS processing. It involves presenting geographic data in a visual format such as maps, charts, and 3D models.

Visualization helps users understand complex spatial information easily.

Examples include:

- Population density maps
- Climate maps
- Urban expansion maps

Visualization is essential for communication and decision-making.

Good visualization:

- Improves understanding
- Supports decision-making
- Communicates results clearly

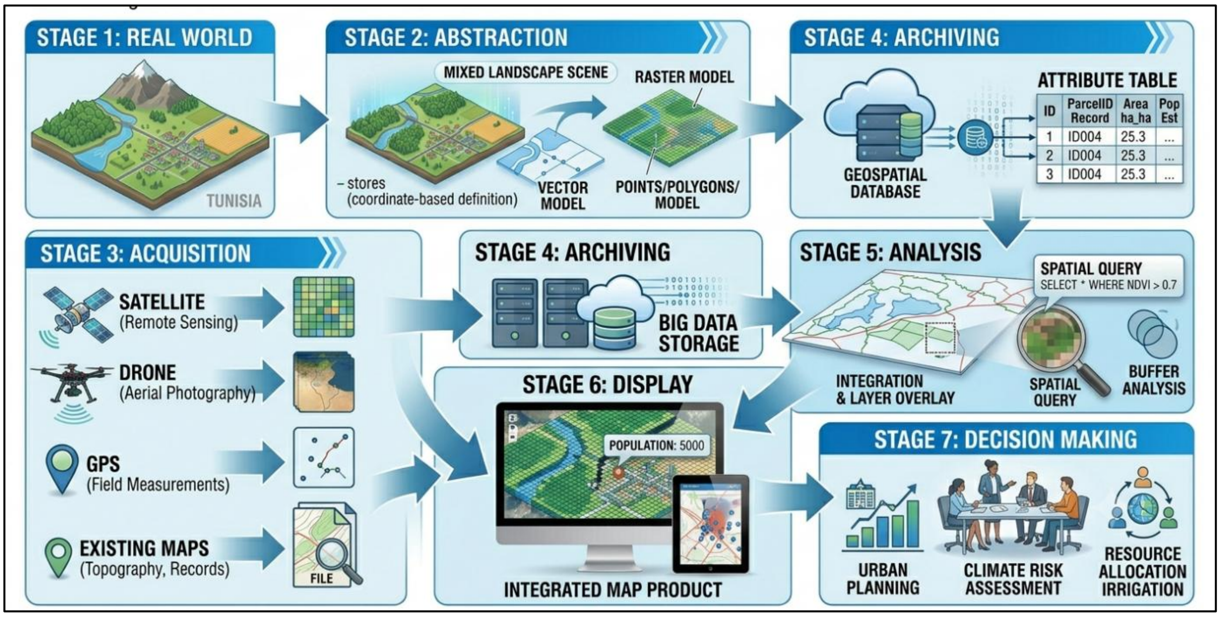


Figure 20: GIS Workflow

Chapter III

Implementation (La mise en place) of GIS

Introduction

The implementation phase of Geographic Information Systems (GIS) represents the operational stage where a designed GIS project becomes functional. After data collection, modeling, and analysis planning, implementation ensures that the system is correctly installed, configured, and used for real-world applications.

This phase is essential because it transforms theoretical GIS design into practical tools for decision-making. It is mainly composed of two major steps:

- Initialization (Initialisation)
- Execution / Realization (Réalisation)

These two stages ensure that GIS systems are properly prepared and effectively used to solve spatial problems.

1. Initialization (Initialisation)

1.1 Definition

Initialization is the first step in GIS implementation. It refers to the preparation of all technical and organizational components required for the system to function correctly.

This stage includes installing software, preparing data, defining coordinate systems, and structuring databases.

Without proper initialization, GIS results may be inaccurate or inconsistent.

1.2 Components of Initialization

Initialization involves several essential components:

- Hardware setup (computers, servers, GPS devices)
- Software installation (GIS platforms)
- Data preparation and cleaning
- Definition of coordinate reference systems
- Database design and structuring

1.3 Data Preparation

Data preparation is one of the most important steps in initialization. It includes:

- Removing errors
- Converting formats
- Aligning spatial data
- Standardizing attribute tables

Poor data preparation leads to incorrect analysis results.

1.4 Coordinate System Definition

A coordinate system is essential for correctly positioning geographic data. All datasets must use the same system to ensure spatial alignment.

Common coordinate systems include:

- Geographic Coordinate System (latitude/longitude)
- Projected Coordinate System (UTM)

1.5 Importance of Initialization

Initialization ensures:

- Data compatibility
- System stability
- Accurate spatial analysis
- Efficient processing

Without it, GIS outputs may be misleading or incorrect.

2. Realization (Réalisation)

2.1 Definition

Realization is the operational phase where the GIS system is actively used for analysis, visualization, and decision-making.

At this stage, GIS becomes a functional tool applied to real-world problems.

2.2 GIS Operations in Realization

During realization, users perform several operations:

- Spatial analysis
- Map production
- Data querying
- Modeling and simulation
- Decision support

2.3 Spatial Analysis

Spatial analysis is the core of realization. It allows the identification of patterns and relationships in geographic data.

Common techniques include:

Buffer analysis

Overlay analysis

Network analysis

Spatial queries

2.4 Map Production

GIS allows the creation of thematic maps that represent spatial phenomena.

Examples include:

- Population density maps
- Climate maps
- Land use maps
- Risk maps
- Maps are essential for communication and decision-making.

2.5 Decision Support

One of the most important roles of GIS realization is supporting decision-making.

GIS helps decision-makers:

- Identify suitable locations
- Assess risks
- Plan infrastructure
- Manage natural resources

GIS Decision Applications

The comprehensive GIS workflow culminates in the **Decision Making** phase. A Geographic Information System (GIS) transitions from an analytical tool to a functional Decision Support System (DSS) by converting raw layers and spatial queries into actionable engineering and management solutions.

Here is a detailed breakdown of the strategic decision-making applications across the core fields outlined in **Table 5**:

1. Urban Planning: Road Construction

- **The Decision Challenge:** Determining the most cost-effective, least disruptive, and geotechnically stable path for new transportation infrastructure.
- **The GIS Solution:** Engineers overlay multiple vector layers—such as land ownership parcels, existing utilities, and municipal zoning—with raster layers like Digital Elevation Models (DEMs) and slope maps. By executing a **least-cost path analysis**, the system automatically calculates the optimal route that minimizes steep inclines, avoids protected environmental zones, and minimizes property expropriation costs.

2. Environment: Pollution Control

- **The Decision Challenge:** Identifying vulnerable zones, tracing contaminant plumes, and enforcing regulatory boundaries to protect vital ecosystems and water resources.
- **The GIS Solution:** By integrating remote sensing imagery (e.g., detecting chlorophyll-a or suspended sediments in water bodies) with spatial point data from field sampling stations, environmental managers map areas of high vulnerability. In a watershed sub-basin, for example, a GIS can run **buffer analyses** around agricultural zones to locate areas with high nitrate or ammonium runoff risks, helping authorities target specific zones for strict agricultural runoff controls.

3. Agriculture: Irrigation Planning

- **The Decision Challenge:** Maximizing crop yields and optimizing water resource allocation in areas facing drought or water scarcity.
- **The GIS Solution:** Analysts combine multi-spectral satellite imagery (calculating the Normalized Difference Vegetation Index, or NDVI, to assess crop health) with raster soil moisture data and topographic layers. This integrated spatial dataset allows agricultural engineers to identify precise zones experiencing water stress. Decisions can then be made to deploy localized precision irrigation networks, ensuring water is allocated exactly where the terrain and plant health demand it.

4. Disaster Management: Flood Evacuation

- **The Decision Challenge:** Designing rapid, safe evacuation protocols and prioritizing rescue operations during severe weather or dam-breach events.
- **The GIS Solution:** During a crisis, real-time radar satellite imagery (which penetrates cloud cover to map the exact extent of surface water) is integrated with high-resolution topographic data and population density tables. By running predictive flood-inundation models, emergency management teams can pinpoint which residential blocks will be submerged first. The system automatically identifies operational road networks that remain above the flood line, enabling commanders to establish optimized evacuation routes and place rescue hubs safely out of harm's way.

Table 14. Summary of GIS Decision Support Benefits

Field	Spatial Data Input	GIS Tool Used	Actionable Decision Outcome
Urban Planning	DEMs, Slope, Land Parcels	Least-Cost Path Analysis	Optimal, stable road routing with minimal construction costs.
Environment	Hydrology, Water Sampling Points	Proximity Buffers & Watershed Delineation	Targeted enforcement of pollution boundaries and buffer zones.
Agriculture	NDVI (Satellite), Soil Maps	Map Algebra & Zonal Statistics	Variable-rate irrigation scheduling and water conservation.
Disaster Management	Radar Imagery, Population Layers	Spatial Overlay & Network Routing	Safe evacuation corridors and optimized emergency resource placemen

2.6 Real-Time GIS Applications

Modern GIS systems can operate in real time using satellite and sensor data. Examples:

- Weather monitoring
- Traffic management
- Disaster response systems

2.7 Importance of Realization

The realization phase transforms GIS from a passive database into an active decision-support system.

It provides:

- Real-time insights
- Predictive modeling
- Efficient planning tools

Conclusion

The implementation phase of GIS consists of two essential steps:

Initialization prepares the system by installing software, organizing data, and defining coordinate systems.

Realization uses the system for analysis, mapping, and decision-making.

Together, these steps ensure that GIS becomes a powerful tool for solving real-world spatial problems.

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