

People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University of Ghardaia



Faculty of Nature and Life Sciences and Earth Sciences
Department of Biology

COURSE:
GEOGRAPHIC INFORMATION
SYSTEMS & REMOTE SENSING
For Master Students in Ecology



Dr. OULAD HEDDAR Meriem
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Preface

This pedagogical document presents a rigorous academic course designed for second-year Environmental Sciences students, with the objective of consolidating the theoretical and conceptual foundations of modern spatial techniques. The curriculum offers a precise scientific approach to the principles of Geographic Information Systems (**GIS**) and Remote Sensing (**RS**), emphasizing their application mechanisms for ecosystem monitoring and analysis. To adapt to accelerated technological advancements, an advanced module on Geospatial Artificial Intelligence (**Geo-AI**) has been integrated, establishing itself as an indispensable methodological necessity for contemporary environmental scientific research. This methodological update aims to equip students with the fundamentals of machine learning-assisted spatial modeling for the highly efficient processing and analysis of massive environmental datasets (**Big Spatial Data**). Indeed, current environmental challenges necessitate a transition towards intelligent predictive analysis, thereby enhancing the precision of spatio-temporal variable extrapolation for natural resources. This module aims to provide students with essential geonumerization tools for assessing environmental degradation, managing risks, and developing Decision Support Systems (**DSS**). It thus constitutes a solid and rigorous knowledge base, qualifying researchers to develop integrated prospective environmental studies, effectively contributing to the formulation of conservation policies and the achievement of sustainable development goals.

In conclusion, this academic endeavor is presented to foster expertise capable of leveraging cutting-edge geospatial technologies to devise innovative scientific solutions for complex environmental issues.

General Objectives

- **Theoretical and Conceptual Foundation:** To establish a comprehensive theoretical and scientific foundation in Geographic Information Systems (**GIS**) and Remote Sensing (**RS**) techniques, and to understand the mechanisms of spatial data acquisition and processing pertinent to ecosystems and natural resources.
- **Adaptation to Technological Advancements (Geo-AI):** To integrate Geospatial Artificial Intelligence (**Geo-AI**) concepts and techniques into analytical methodologies,

enabling students to assimilate the fundamentals of massive environmental data (**Big Data**) processing and to construct intelligent predictive models.

- **Development of Methodological and Analytical Skills:** To acquire spatial thinking skills and the critical capacity to employ these integrated techniques for extrapolating environmental phenomena, assessing risks (such as environmental degradation and climate change), and monitoring spatio-temporal changes.
- **Support for Scientific Research and Decision-Making:** To qualify students in the effective and scientifically rigorous use of advanced geospatial tools for their future academic research and theses, and to design precise environmental studies contributing to the development of Decision Support Systems (DSS) to achieve sustainability.

Targeted Scientific and Methodological Competencies

- **Conceptual Understanding of Geospatial Systems:** Ability to deeply understand the nature and structure of spatial data (*vector* and *raster*), and to grasp the physical principles of remote sensing, including the interaction of electromagnetic radiation with various ecological components.
- **Methodological Competence in Spatial Analysis Design:** Acquisition of the competence to identify the most appropriate processing protocols, and to select precise environmental and spectral indicators for studying and evaluating natural phenomena, monitoring environmental degradation, and classifying land use/cover.
- **Theoretical Understanding of Geospatial Artificial Intelligence (Geo-AI) Applications:** Methodological understanding of the foundations for integrating intelligent algorithms (*such as machine learning*) with spatial systems, to comprehend the mechanisms of automatic feature extraction, massive environmental data analysis, and predictive model construction.
- **Critical Interpretation and Rigorous Academic Application:** Development of analytical acumen for extrapolating thematic maps and scientifically interpreting satellite imagery, alongside the acquisition of the ability to formulate spatial problems and rigorously integrate these techniques into scientific research methodologies for future theses and reports.

Prerequisites and Resources

➤ Fundamental Prerequisites

Optimal assimilation of this module's theoretical concepts requires students to possess prior knowledge encompassing:

- **Foundations of Environmental Sciences and Ecosystems:** Mastery of fundamental concepts related to natural resources, environmental dynamics, and vegetation cover interactions, to facilitate the application of spatial techniques to these areas.
- **Principles of Cartography and Topography:** Understanding of map reading rules, geographic coordinate systems, representation scales, and planimetric relief representation methods.
- **Basic Computing Skills:** Proficiency in basic computer and operating system usage, a necessary condition for subsequent easy manipulation of digital data and geospatial software.
- **Basic Concepts in Statistics and Mathematics:** Understanding of preliminary mathematical and statistical principles, which form the cornerstone for comprehending digital image processing algorithms and the foundations of Geospatial Artificial Intelligence.

➤ Resources and Means

To achieve the scientific objectives set for the theoretical courses, the following resources and materials will be utilized:

- **Conceptual Presentations and Flowcharts:** Use of visual aids and graphical structures (flowcharts) to simplify the physical rules of remote sensing and the structuring of *Geo-AI algorithms*.
- **Visual Models of Spatial Outputs:** Display and analysis of applied models of multispectral satellite imagery and thematic maps (*such as environmental degradation maps*), to concretize abstract theoretical concepts.
- **Theoretical Linkage with Software Environments:** Reliance on explanatory theoretical presentations of the capabilities of open-source geospatial software (*such as QGIS*) and cloud platforms, to prepare for a seamless transition to practical field application.

Course Content

CHAPTER I : Geographic Information Systems (GIS)

1. General Introduction to Geographic Information Systems (GIS) and the Environment

- 1.1. Concept of Geographic Information Systems (GIS).
- 1.2. Components of a Geographic Information System.
- 1.3. Importance of GIS in Environmental Studies.
- 1.4. Relationship between Spatial Data and Environmental Decision-Making.
- 1.5. Scientific Conclusion.

2. Maps, Scales, and Coordinate Systems

- 2.1. Introduction to Maps and Their Importance in GIS.
- 2.2. Difference between traditional maps and digital maps.
- 2.3. Concepts of Coordinate Systems and Geographic Reference Systems.
 - 2.3.1. Primary Coordinate Systems
 - 2.3.1.1. Geographic Coordinate System (GCS)
 - 2.3.1.2. Projected Coordinate System (PCS)
 - 2.3.2. Datums
- 2.4. Types of Scales in Maps
- 2.5. Environmental Symbols and Visual Representation

3. Components of Geographic Information Systems (GIS)

- 3.1. The five core components of (GIS)
 - 3.1.1. Data
 - 3.1.2. Hardware
 - 3.1.3. Software
 - 3.1.4. Personnel
 - 3.1.5. Methods

3.2. Characteristics of Spatial and Attribute Data

3.3. Types of Spatial Data: Raster vs. Vector

a. Vector Data

b. Raster Data

4. Spatial Analysis in Environmental Applications

4.1. Concept of Spatial Analysis

a. Buffer

b. Overlay (Spatial Overlay)

c. Spatial Join

4.3. Applications of Spatial Analysis in Environment and Resource Management

5. Data and Output Management

5.1. Data Management within GIS

5.2. Layer Organization and Database Management

5.3. Visualization, Analysis, and Map Production Functions

5.4. Advantages of GIS

5.5. Limitations of GIS

CHAPTER II : Remote Sensing

1. Introduction to Remote Sensing

1. 1. Definition and Environmental Significance of Remote Sensing

1. 2. The Electromagnetic Spectrum and Satellite Image Components

1. 3. Characteristics of Satellite Missions (Landsat, Sentinel, SPOT)

2. Remote Sensing Image Processing

2.1. Geometric Correction

2.2. Radiometric Correction

2.3. Creating Composite Images (RGB Combinations)

2.4. Spectral Analysis of Values

3. Environmental Applications of Remote Sensing

- 3.1. Forest Monitoring
- 3.2. Water Body Monitoring and Quality
- 3.3. Soil Analysis using Remote Sensing
- 3.4. Environmental Pollution Monitoring
- 3.5. Temporal Change Analysis with Time Series

CHAPTER III : Artificial Intelligence in Geoinformatics (GeoAI)

1. Artificial Intelligence in Geoinformatics (GeoAI)

- 1.1. The Concept of GeoAI and the Significance of Integrating AI with Spatial Analysis

2. Environmental Applications of AI in Geoinformatics

- 2.2. Environmental Hazards Prediction
- 2.3. Air Quality and Pollution Analysis
- 2.4. Agricultural and Water Resources Management

3. Advantages of Integrating AI into Geoinformatics

CHAPTER IV : Mini Environnemental Project Design

1. General Introduction to Applied Projects in Geographic Information Systems

- 1. 2. Designing the Environmental Project Using GIS and RS
- 1.3. Selecting the Environmental Problem and Defining the Study Scope

2. Result Analysis and Reporting

- 2.1. General Introduction to Results Analysis and Its Importance
- 2.2. Methods of Results Analysis in Environmental Projects
- 2.3. Representing Results with Maps and Graphs
- 2.4. Preparing Scientific Reports for Project Results
- 2.5. Documenting Data and Sources

3. Final Presentations and Workshop Geographic Information Systems (GIS) and Remote Sensing for the Environment Course

3.1. General Introduction: The Conclusion as a Culmination of the Scientific Journey

3.2. Comprehensive Course Evaluation: From Knowledge to Skill

3.3. Review of Artificial Intelligence and Environmental Analysis Concepts

3.3. Review of Artificial Intelligence and Environmental Analysis Concepts

References

CHAPTER I : Geographic Information Systems (GIS)

1. General Introduction to Geographic Information Systems (GIS) and the Environment

1.1. Concept of Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are computational frameworks designed for the acquisition, storage, analysis, and visualization of spatial and temporal data. They facilitate the comprehension of relationships and interactions among diverse geographic phenomena (Longley et al., 2021). GIS is dedicated to integrating spatial data with attribute data within a unified digital environment. This integration enables precise spatial analyses, supporting decision-making across numerous domains, including environmental resource management, regional planning, and climate change monitoring.

How Does a Geographic Information System (GIS) Work?

From Data to Decision



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1.2. Components of a Geographic Information System

A GIS comprises five interconnected components:

1. **Hardware:** Encompasses computers, input devices, and output devices.
2. **Software:** Includes applications like QGIS and ArcGIS, which provide tools for spatial analysis and processing.
3. **Data:** Constitutes the core of the system, whether in vector or raster formats.
4. **People:** The users responsible for managing and analyzing data.
5. **Methods (or Models):** Refers to the approaches and algorithms employed for data analysis (Burrough, McDonnell, & Lloyd, 2015).

These components operate synergistically to form an integrated environment capable of analyzing environmental problems and deriving precise spatial solutions.

THE FIVE COMPONENTS OF A GEOGRAPHIC INFORMATION SYSTEM (GIS)



A Geographic Information System (GIS) is an integrated system that captures, stores, manages, analyzes, and displays spatial and attribute data to support decision making in a wide range of fields.



1 HARDWARE

The physical equipment used to input, process, store, and output GIS data.

- Computers (Desktop, Laptop)
- Input devices (GPS, Scanner, Digitizer, Keyboard)
- Storage devices
- Printers & Plotters
- Network equipment



2 SOFTWARE

The programs and tools used to manage, analyze, and visualize spatial data.

- GIS Software (QGIS, ArcGIS)
- Database Management Systems (PostgreSQL, MySQL)
- Image Processing Tools
- Analysis and Modeling Tools
- Extensions / Plugins



5 METHODS

The procedures, techniques, and workflows used to collect, manage, analyze, and deliver GIS data and information.

- Data Collection Methods
- Data Management Standards
- Analysis Techniques
- Modeling & Algorithms
- Quality Control
- Workflows & Best Practices



4 PEOPLE

The individuals who design, develop, operate, and use GIS.

- GIS Analysts
- Data Managers
- System Administrators
- Decision Makers
- End Users



DATA

The core of GIS. It includes spatial data that shows "where" things are, and attribute data that describes "what" they are.

Spatial Data (Where?)

- Vector Data (Points, Lines, Polygons)
- Raster Data (Imagery, Grids)



Attribute Data (What?)

- Tables
- Records
- Descriptive Information



HOW THE FIVE COMPONENTS WORK TOGETHER



HARDWARE
Provides the physical platform



SOFTWARE
Runs the tools and functions



DATA
Supplies the raw information



PEOPLE
Operate the system and make decisions



METHODS
Guide the process and ensure quality



**BETTER INFORMATION
BETTER DECISIONS**

SUSTAINABLE FUTURE

WHERE GIS IS APPLIED



ENVIRONMENT
Conservation, monitoring, pollution control



URBAN PLANNING
Land use, zoning, infrastructure, smart cities



AGRICULTURE
Precision farming, soil analysis, crop monitoring



DISASTER MANAGEMENT
Risk assessment, response, recovery



WATER RESOURCES
Water quality, watershed management, resource monitoring



MINING & ENERGY
Site selection, exploration, impact assessment

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1.3. Importance of GIS in Environmental Studies.

GIS plays a pivotal role in supporting environmental decision-making by enabling the analysis of human-environment interactions. Through GIS, it is possible to monitor pollution, estimate deforestation rates, assess changes in land use, and track the impacts of climate change. For instance, a study conducted by the United Nations Environment Programme (UNEP, 2020) demonstrated that the application of GIS and remote sensing in monitoring water quality in the Nile River effectively identified pollution zones and informed environmental policy development.

Common environmental applications of GIS include:

- **Water pollution** monitoring by analyzing pollutant concentrations spatially and temporally.
- **Smart agriculture** through the analysis of soil properties and moisture distribution using satellite data (FAO, 2019).
- **Planning natural** reserves and identifying environmentally sensitive areas.

APPLICATIONS OF GIS IN ENVIRONMENTAL STUDIES



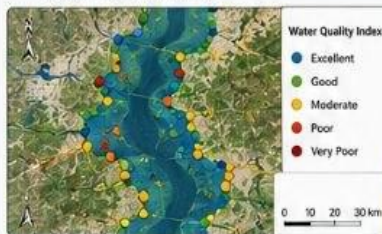
Geographic Information Systems (GIS) provide powerful tools to collect, analyze, visualize and manage environmental data to understand complex relationships and support sustainable environmental management and decision making.



1 WATER QUALITY MONITORING

GIS helps monitor and assess water quality by analyzing the spatial and temporal distribution of pollutants in rivers, lakes and groundwater.

- Mapping pollution sources
- Analyzing pollutant concentrations
- Identifying critical areas
- Supporting water quality management and regulatory decisions



2 DEFORESTATION MONITORING

GIS and remote sensing are used to detect, monitor and quantify changes in forest cover over time.

- Land cover classification
- Change detection analysis
- Estimating deforestation rates
- Supporting forest conservation policies



3 SMART AGRICULTURE

GIS supports precision agriculture by analyzing soil, moisture, and crop conditions to improve productivity and resource efficiency.

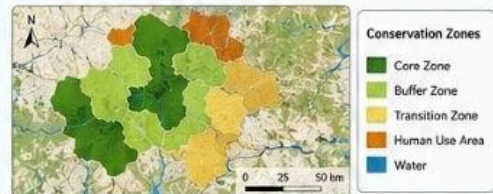
- Soil and land suitability analysis
- Monitoring crop health
- Irrigation planning
- Yield estimation and risk assessment



4 NATURE RESERVE PLANNING

GIS is used to identify ecologically sensitive areas and plan protected areas to conserve biodiversity and natural habitats.

- Identifying sensitive habitats
- Analyzing species distribution
- Assessing ecological connectivity
- Supporting protected area planning and management



OTHER ENVIRONMENTAL APPLICATIONS



AIR POLLUTION MONITORING

Mapping air quality and analyzing pollution dispersion.



CLIMATE CHANGE ANALYSIS

Modeling climate impacts and assessing vulnerable areas.



NATURAL HAZARD MANAGEMENT

Floods, landslides, droughts risk mapping and early warning systems.



LAND USE / LAND COVER ANALYSIS

Monitoring land use changes and supporting sustainable land management.



WASTE MANAGEMENT PLANNING

Selecting suitable sites and optimizing waste collection routes.

KEY TECHNOLOGIES USED WITH GIS



Remote Sensing



GPS



Drones



Field Sensors



Databases



Cloud Computing

HOW GIS SUPPORTS ENVIRONMENTAL DECISIONS



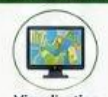
Data Collection



Data Management



Spatial Analysis



Visualization



Interpretation



Decision Making



Sustainable Environment

BENEFITS OF GIS IN ENVIRONMENTAL STUDIES

- ✓ Integrates spatial and attribute data for better understanding
- ✓ Visualizes environmental problems clearly
- ✓ Supports accurate analysis and modeling
- ✓ Improves decision making and policy planning
- ✓ Promotes sustainable development and conservation



1.4. Relationship between Spatial Data and Environmental Decision-Making

Modern environmental management relies on the concept of "*Evidence-Based Decision Making*." GIS furnishes a robust spatial database, empowering environmental planners to analyze the projected impacts of policies and human activities on ecosystems, vegetation cover, and biodiversity before their implementation.

For instance, when evaluating the construction of a new dam, GIS can be utilized to assess the anticipated effects on biodiversity and local communities (Goodchild, 2020).



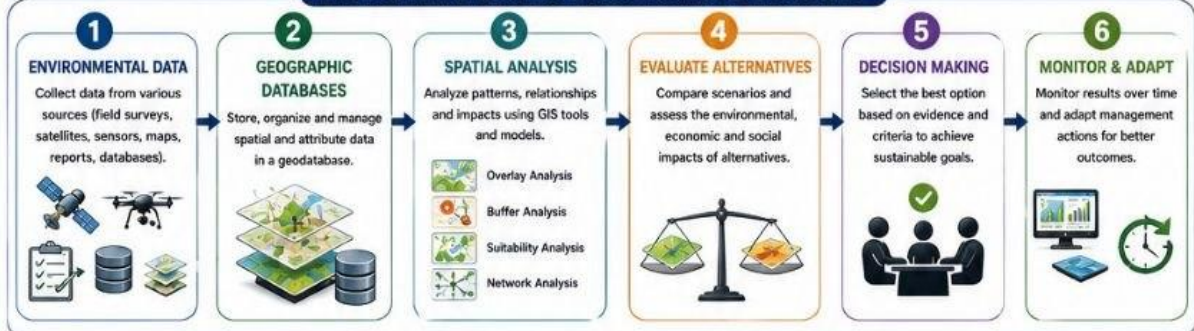
GIS AND ENVIRONMENTAL DECISION MAKING



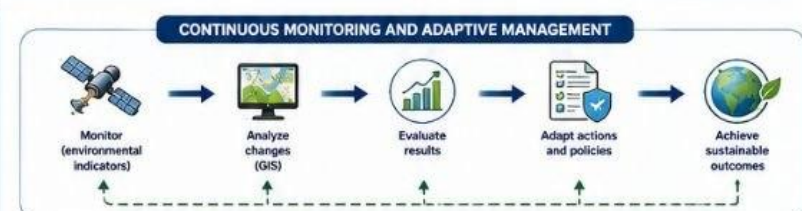
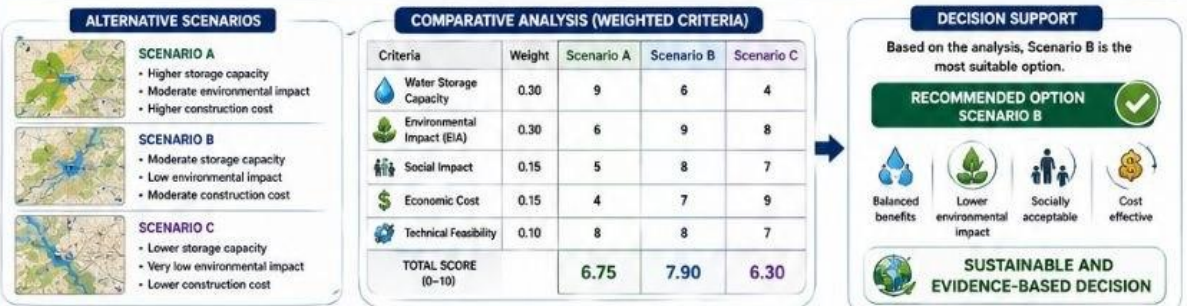
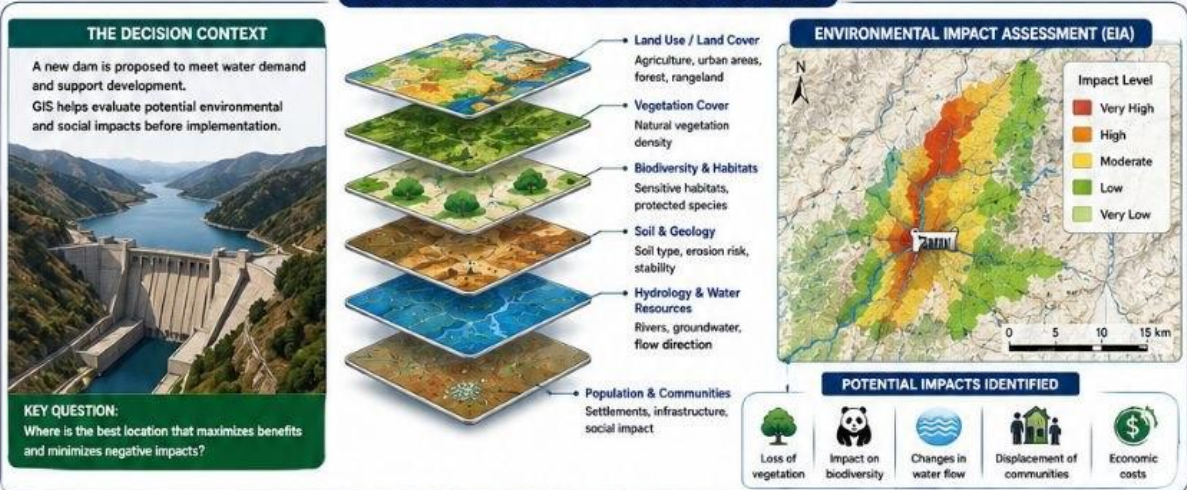
Geographic Information Systems (GIS) transform environmental data into valuable information and insights that support evidence-based decisions for a sustainable future.



FROM SPATIAL DATA TO ENVIRONMENTAL DECISIONS



APPLICATION EXAMPLE: BUILDING A NEW DAM



GIS SUPPORTS THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS



“Good decisions are built on good data, smart analysis, and a clear vision for a sustainable future.”



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1.5. Scientific Conclusion

GIS stands as a transformative analytical tool that has revolutionized the comprehension and management of ecosystems by integrating spatial data with environmental analysis. It enables the visualization of complex human-nature interrelationships, thereby assisting decision-makers in formulating more precise and sustainable environmental policies. This lecture serves as a foundational element for understanding subsequent course topics. Future sessions will build upon these principles, delving into advanced spatial analysis concepts and the application of environmental remote sensing techniques.

2. Maps, Scales, and Coordinate Systems

2.1. Introduction to Maps and Their Importance in GIS:

Maps are recognized as the visual language of geography, serving as crucial tools for comprehending spatial relationships between natural and human phenomena. Robinson et al. (2019) define a map as a "symbolic representation of Earth's surface, or a part thereof, highlighting spatial relationships between features." Within the GIS framework, maps have transcended their traditional role as static, paper-based drawings. They have evolved into dynamic spatial databases that can be continuously analyzed and updated (Longley et al., 2021).

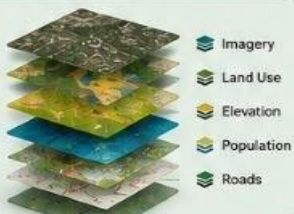
2.2.Difference between traditional maps and digital maps

Feature	Traditional Maps (Paper)	Digital Maps (Computer)
Medium	Paper or printed	Digital
Spatial Accuracy	Fixed, limited by drawing scale	Multi-scale, zoomable for analysis
Update Capability	Difficult, requires reprinting	Easy and fast via GIS software
Integration	Limited	High integration with other data via GIS
Interaction/Analysis	Viewing only	Interactive and analytical (spatial analysis, modeling, queries)

The transition from paper-based to digital mapping represents a significant cognitive shift. Digital maps are not merely visual representations; they are interactive and analytical tools, enabling spatial analysis, modeling, environmental forecasting, and spatial querying (Kraak & Ormeling, 2020).

COMPARISON BETWEEN TRADITIONAL MAPS & DIGITAL MAPS

Key differences in medium, accuracy, updateability, integration, and interactivity

TRADITIONAL MAPS	COMPARISON CRITERIA	DIGITAL MAPS
 Paper-based Printed on paper or other physical materials.	 MEDIUM	Digital format Stored and displayed on computers, mobile devices, or web platforms. 
 Lower accuracy Limited by manual measurement, printing quality, and scale constraints.	 ACCURACY	Higher accuracy Based on precise spatial data, GPS, remote sensing, and advanced processing. 
 Difficult to update Changes require re-drawing and re-printing, which is time-consuming and costly.	 UPDATEABILITY	Easy to update Data can be edited and updated quickly in real time. 
 Limited integration Usually stands alone and cannot easily integrate with other data sources.	 INTEGRATION	High integration Can integrate multiple data layers (e.g., imagery, elevation, statistics, attributes). 
 No interactivity Static display; users cannot interact with the map.	 INTERACTIVITY	Highly interactive Zoom, query, analyze, measure, and visualize in 2D/3D; user-driven exploration. 
 TRADITIONAL MAPS Useful for reference, education, and areas with limited technology access.		DIGITAL MAPS Essential for modern analysis, decision-making, and smart spatial solutions. 



Digital maps offer superior accuracy, flexibility, and analytical power, making them indispensable in today's spatial decision-support systems.



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2.3. Concepts of Coordinate Systems and Geographic Reference Systems

Coordinates are defined as numerical systems used to pinpoint the exact location of any feature on Earth's surface. These are typically measured using lines of longitude and latitude within a Geodetic Reference System.

2.3.1. Primary Coordinate Systems:

2.3.1.1. Geographic Coordinate System (GCS): This system, based on Earth's spherical shape, uses degrees (latitude and longitude) to define locations. The World Geodetic System 1984 (WGS84) is the most widely adopted GCS, commonly utilized in GPS devices and Google Maps.

2.3.1.2. Projected Coordinate System (PCS): A PCS transforms the Earth's spherical surface onto a flat, two-dimensional plane (a map). It is essential for precise analysis, such as calculating distances and areas. Common examples include

- Universal Transverse Mercator (UTM)
- Lambert Conformal Conic.

In Algeria, the most commonly utilized cartographic projection systems include the Universal Transverse Mercator (UTM) with the WGS 84 datum, a variant of the Universal Transverse Mercator (UTM) system using the AA datum, and Lambert Algérie.

Universal Transverse Mercator (UTM) projection system of Algeria encompasses four distinct zones. These are all situated in the Northern Hemisphere and defined by specific longitudinal bands relative to the Greenwich Prime Meridian:

1. UTM North Zone **29**: Spanning from 8.67° West to 3° West longitude.
2. UTM North Zone **30**: Ranging from 3° West to 4° East longitude.
3. UTM North Zone **31**: Covering 4° East to 9° East longitude.
4. UTM North Zone **32**: Extending from 9° East to 12° East longitude.

2.3.2. Datums :

A Datum is fundamentally a mathematical model employed to define the shape, precise location, and center of the Earth. Illustrative examples of datums include:

- WGS84 (World Geodetic System 1984): A widely adopted global datum.
- Palestine 1923: Recognized as a historical local datum.
- ETRS89 (European Terrestrial Reference System 1989): A datum specific to Europe.
- Clarke 1880: particularly concerning France and Africa.

The accurate selection of a coordinate system and datum is critical for ensuring high precision in environmental analysis, especially when integrating data layers from diverse sources (Goodchild, 2020).



GEOGRAPHIC COORDINATE SYSTEM (GCS)

VS.

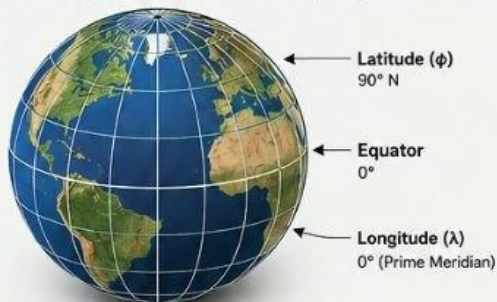
PROJECTED COORDINATE SYSTEM (PCS)



Understanding the Difference for Accurate Spatial Analysis and Mapping

GEOGRAPHIC COORDINATE SYSTEM (GCS)

A coordinate system that uses an ellipsoid to represent positions on the Earth's surface with angular units (latitude and longitude).



Example: WGS 84 (EPSG: 4326)
Units: Degrees (°)

PROJECTED COORDINATE SYSTEM (PCS)

A coordinate system that represents locations on a flat surface using linear units (meters or feet) through a map projection.



Example: WGS 84 / UTM Zone 32N (EPSG: 32632)
Units: Meters (m)



Based on an ellipsoid model of the Earth. Coordinates are expressed as latitude (ϕ) and longitude (λ).



Angular units: degrees (°).
Range: Latitude -90° to 90°,
Longitude -180° to 180°.



Represents the Earth in its true curved (3D) shape.



High accuracy for global datasets and small-scale maps.



Distances, areas and directions are not preserved; calculations are not reliable in degrees.



Used for data capture (GPS), global databases, and web mapping.



WGS 84 (EPSG: 4326)
NAD83 (EPSG: 4269)
ETRS89 (EPSG: 4258)

DEFINITION



Based on a mathematical projection that converts the curved surface of the Earth to a flat plane.



UNITS



Linear units: meters (m) or feet (ft).
Values are expressed in a Cartesian (X, Y) coordinate plane.



SHAPE & SURFACE



Represents the Earth on a flat (2D) surface. Distortion of area, shape, distance or direction is inevitable.



ACCURACY



High accuracy for large-scale maps and local/regional analysis within the projection's area of use.



DISTANCE, AREA & DIRECTION



Allows reliable measurement of distance, area, and direction within the valid extent of the projection.



USE IN GIS



Used for analysis, measurement, planning, engineering, and map production.



EXAMPLES



UTM Zones (e.g., 32N – EPSG: 32632)
Web Mercator (EPSG: 3857)
State Plane Coordinate Systems



GCS – On the Ellipsoid (3D)



PCS – On the Plane (2D)



WHEN TO USE GCS?

- ✓ When working with global datasets
- ✓ For data collection using GPS
- ✓ When sharing data across different systems
- ✓ For web mapping and visualization



KEY TAKEAWAY

GCS defines where you are on Earth.
PCS defines where you are on a map.
Both are essential and complementary in GIS for accurate spatial analysis and decision making.

WHEN TO USE PCS?

- ✓ When accuracy in measurement is critical
- ✓ For local or regional spatial analysis
- ✓ For engineering, planning and design
- ✓ For map production and reporting



2.4. Types of Scales in Maps :

Map scale represents the ratio between a distance on a map and the corresponding real-world distance on the Earth's surface. There are three primary types of map scales:

- **Numeric Scale:** Expressed as a ratio (e.g., **1:50,000**), where 1 unit on the map represents **50,000** units in reality (e.g., **1 cm** on the map equals **500 meters** on the ground).
- **Graphic Scale (Bar Scale):** A visual line divided into segments, indicating the relationship between map distance and real-world distance.
- **Verbal Scale:** A statement describing the relationship (e.g., "**1 cm** represents **500 meters**").

The choice of scale depends on the study's nature:

- large-scale maps (e.g., **1:5,000**) are used for detailed local studies (e.g., soil quality analysis), while
- small-scale maps (e.g., **1:250,000**) are suitable for regional or national studies.

2.5. Environmental Symbols and Visual Representation :

Symbols form the language of maps, conveying environmental information without words. Colors, shapes, and lines are used to represent various phenomena. For instance:

- Blue for water sources.
- Green for vegetation.
- Brown for contour lines (elevations).
- Red for urban areas or at-risk regions.

Effective cartographic design, encompassing visual elements, is a fundamental factor in clearly communicating scientific messages (Dent, Torguson, & Hodler, 2018).

3. Components of Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are comprised of an integrated collection of components that interact to process spatial and attribute data, transforming them into valuable information for environmental and developmental decision-making. These components constitute the structural framework of a GIS and include: **Data, Hardware, Software, Personnel, and Methods.**

5.6.The five core components of (GIS)

5.6.1. Data

Data serves as the fundamental element of any GIS, representing the raw material from which analyses and models are constructed. Data is categorized into two primary types:

- **Spatial Data:** Describes the geographical location of features within space, such as the position of forests or river channels.
- **Attribute Data:** Characterizes the properties of features, for instance, soil type or water salinity levels.

Collected from diverse sources like aerial photographs, satellite imagery, field surveys, and paper maps, data acquisition has evolved. Remote sensing, in particular, has become a principal source for precise spatial data that fuels GIS.

5.6.2. Hardware

Hardware refers to all physical components essential for GIS operation, including:

- Desktop or portable computers equipped with robust processors.
- Storage units designed to accommodate large spatial databases.
- Data input devices, such as optical scanners and Global Positioning System (GPS) units.
- Data output units, such as printers and cartographic display devices.

These components collectively form the infrastructure that enables users to **collect, analyze, store, and output** spatial information.

5.6.3. **Software**

Software constitutes the operational engine of a GIS, facilitating data management, analysis, and visualization. Prominent global GIS software platforms include:

- Esri's **ArcGIS**.
- The open-source **QGIS**.
- **ERDAS Imagine**, specializing in satellite image processing.

Each software package offers diverse tools for spatial analysis, environmental modeling, and interactive map generation.

5.6.4. **Personnel**

The human component is paramount in any GIS. Without skilled geographic analysts or environmental specialists possessing a deep understanding of spatial data, the technology remains ineffective. Personnel typically include:

- Developers of spatial databases.
- Environmental data analysts.
- Decision-makers who utilize GIS outputs to inform environmental policies.

5.6.5. **Methods:**

Methods comprise a set of defined rules and procedures that govern system operation, dictate the mechanisms for data processing, and guide map production. Sound methodologies ensure accuracy, continuous updating, and user-friendliness in environmental applications like pollution assessment or sustainable resource planning.

THE FIVE CORE COMPONENTS OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Integrated Framework for Spatial Data Management and Decision Support

A Geographic Information System (GIS) integrates five fundamental components that work together to capture, manage, analyze, and visualize **spatial and attribute data** for effective environmental and development decision-making.



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5.7. Characteristics of Spatial and Attribute Data

Spatial data is characterized by its linkage to geographic coordinates (X, Y, and occasionally Z for elevation), whereas attribute data is stored in tabular format and associated with specific spatial entities. For instance, when depicting a river on a map, its spatial data would be represented as a polyline, while its attribute data might include details such as river type, length, pollution level, and flow rate. This integration between spatial and attribute dimensions bestows upon Geographic Information Systems their potent analytical capabilities in environmental contexts.

5.8.Types of Spatial Data: Raster vs. Vector

a. Vector Data: Represents geographic features using points, lines, and polygons.

- **Point:** Depicts discrete locations, such as a monitoring station or a water well.
- **Line:** Represents linear features, such as rivers or roads.
- **Polygon:** Outlines areal features, such as lakes or forests.

Vector data is optimally employed when high spatial precision is critical, making it ideal for detailed administrative and environmental mapping.

b. Raster Data: Comprises a grid of pixels or cells, where each cell holds a numerical value indicative of a specific characteristic at its location. Raster data is used to represent continuous phenomena such as temperature, soil types, or vegetation cover. This data type is extensively utilized in remote sensing and environmental modeling applications.

SPATIAL DATA

The Power of Linking Where Things Are

VS

ATTRIBUTE DATA

with What They Are Like

In GIS, spatial data shows the location and shape of features on the Earth, while attribute data describes the characteristics or properties of those features. Together, they form complete, meaningful, and analyzable information.

SPATIAL DATA

Where things are



Maps

Digital maps represent real-world features and their locations.



Coordinates

Features are defined using geographic coordinates (X, Y, and sometimes Z).



Geometric Types

Spatial data is stored as Points, Lines, and Polygons.



Satellite Imagery

Remote sensing provides up-to-date and large-area spatial information.



GPS & Field Data

GPS and field surveys capture precise locations on the ground.



THE LINK

Connecting Location with Description



Each spatial feature is linked to a record in the attribute table using a unique ID.



EXAMPLE: A RIVER

Spatial Component	Attribute Component
River Geometry	- Length: 85.3 km - Water Type: Freshwater - Pollution Level: Low - Flow Rate: 12.4 m³/s - Basin Area: 1250 km² - Status: Active

ATTRIBUTE DATA

What things are like



Data Tables

Information about features is stored in structured tables.

ID	Land Use	Area (ha)
1	Forest	125.6
2	River	85.3
3	Agriculture	210.4
4	Urban	65.7
5	Wetland	42.1
...		



Feature Attributes

Each feature has descriptive characteristics or properties.

- Forest Type
- Soil Type
- Water Quality
- Population Density
- Pollution Level
- ...



Databases

Attributes are stored in databases and linked to spatial features.

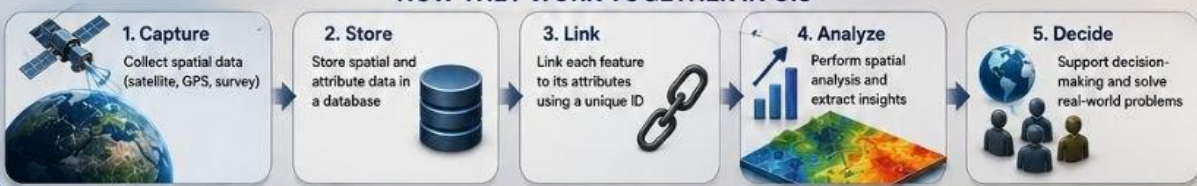


Examples

Environmental, social, economic, and physical descriptions.



HOW THEY WORK TOGETHER IN GIS



KEY TAKEAWAY

Spatial data tells us WHERE, attribute data tells us WHAT. When linked together in GIS, they turn data into knowledge and knowledge into action.



Environmental Monitoring



Disaster Management



Resource Management



Urban Planning



Agricultural Analysis



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- ✓ Better Data
- ✓ Better Analysis
- ✓ Better Decisions
- ✓ Better World



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6. Spatial Analysis in Environmental Studies

Spatial Analysis is recognized as the fundamental strength of Geographic Information Systems (GIS). It transforms raw spatial data into **actionable spatial knowledge that is crucial for environmental decision-making**.

This analytical approach facilitates the comprehension of patterns and interrelationships among geographical phenomena, exemplified by identifying pollution hotspots, assessing flood risks, or planning land use. As articulated by Longley et al. (2015), spatial analysis is "the beating heart of GIS" due to its capacity to convert data into logical, location-based decisions.

4.1. Concept of Spatial Analysis

Spatial analysis encompasses a series of mathematical and logical operations applied to geographic data. Its primary objectives are to identify spatial patterns and ascertain relationships among diverse phenomena. For instance, spatial analysis can be used to:

- Pinpoint the locations of human activities in proximity to water sources (e.g., for pollution analysis).
- Determine safe distances between industrial facilities and residential areas.
- Monitor changes in vegetation cover over time using satellite imagery.

Spatial analysis can be categorized into three principal levels:

1. **Descriptive Analysis:** Characterizes spatial phenomena, such as density or distribution.
2. **Inferential Analysis:** Infers causal relationships between different phenomena.
3. **Predictive Analysis:** Forecasts future changes, such as urban expansion.

SPATIAL ANALYSIS

THE HEART OF GIS DECISION-MAKING

Transforming Geographic Data into Environmental Intelligence

WHAT IS SPATIAL ANALYSIS?

Spatial analysis is the collection of mathematical and logical operations performed on geographic data to discover patterns, relationships, and trends that support environmental decision-making.

SPATIAL ANALYSIS

THE ENGINE OF GIS

WHY IT MATTERS

- Understand spatial patterns and processes
- Evaluate environmental issues and risks
- Optimize resource management
- Support sustainable development
- Enable evidence-based policy and planning

THREE LEVELS OF SPATIAL ANALYSIS

1

DESCRIPTIVE ANALYSIS

What is happening?



- Describes and summarizes spatial patterns.
- Measures density, distribution, frequency, and spread.
- Example: Mapping the density of air pollution across a city.



2

INFERENTIAL ANALYSIS

Why is it happening?



- Infers relationships and causal interactions.
- Identifies correlations between spatial phenomena.
- Example: Analyzing the relationship between land use and water quality.



3

PREDICTIVE ANALYSIS

What will happen?



- Predicts future trends and spatial changes.
- Uses models to simulate and forecast outcomes.
- Example: Predicting urban expansion in the next 20 years.



FROM DATA TO DECISIONS

RAW SPATIAL DATA

- Satellite imagery
- Field surveys (GPS)
- Environmental sensors
- Maps and existing datasets

SPATIAL ANALYSIS PROCESSES

- Measurement
- Buffering
- Overlay
- Spatial Join
- Proximity
- Interpolation
- Modeling

ENVIRONMENTAL KNOWLEDGE

- Patterns revealed
- Relationships identified
- Risks assessed
- Opportunities discovered
- Scenarios predicted

INFORMED DECISIONS & ACTIONS

- Environmental planning
- Risk management
- Resource allocation
- Policy formulation
- Sustainable development

EXAMPLES OF ENVIRONMENTAL APPLICATIONS

POLLUTION MONITORING

FLOOD RISK ASSESSMENT

LAND USE PLANNING

BIODIVERSITY CONSERVATION

CLIMATE CHANGE ANALYSIS

NATURAL RESOURCE MANAGEMENT

BENEFITS OF SPATIAL ANALYSIS

- Better Understanding
- Better Decisions
- Cost Effective
- Time Saving
- Sustainable Future

"Spatial analysis turns data into knowledge, knowledge into action, and action into a better environment."

POWERED BY GIS TECHNOLOGY

- Data Integration
- Analysis Tools
- Visualization
- Modeling

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4.2. Essential Tools in Spatial Analysis

a. Buffer

The Buffer operation involves creating a proximity zone around a specified geographic feature (e.g., a river or road) at a predefined distance. In environmental studies, this tool is vital for delineating areas directly impacted by human or natural activities.

Examples include:

- Establishing a 500-meter buffer zone around groundwater sources to designate areas where construction or industrial discharge is prohibited.
- Studying the impact of roads on biodiversity within forested regions.

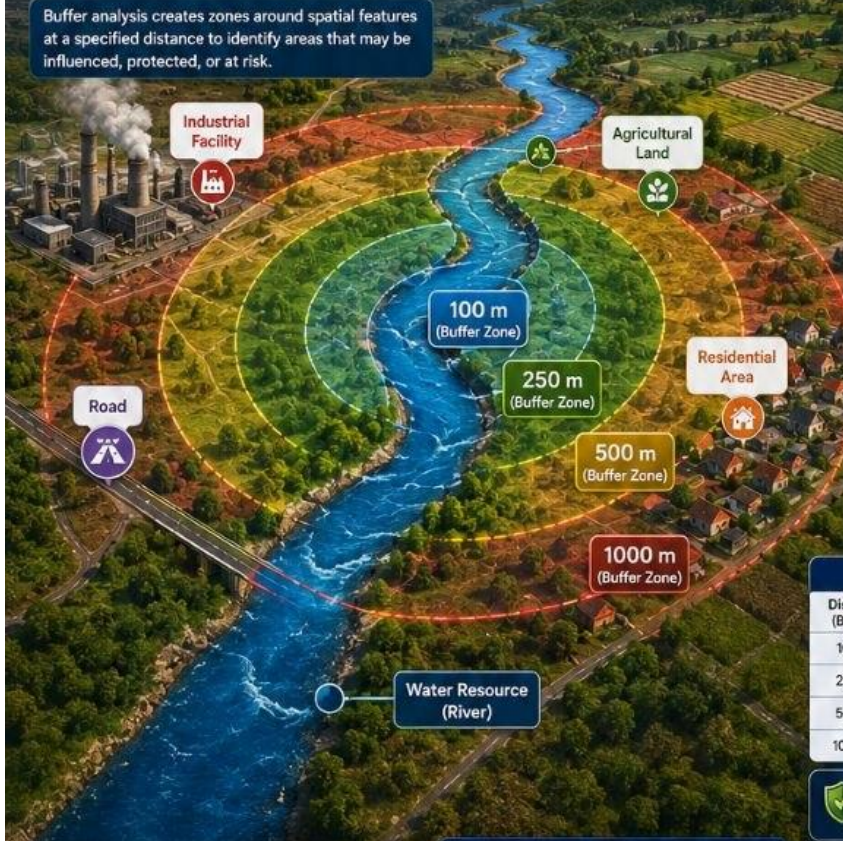
According to Chang (2019), the Buffer tool is among the most frequently employed in environmental analysis, as it facilitates the identification of sensitive areas for proactive management. Figure 2 illustrates the creation of a buffer zone around a river to safeguard water resources from pollution.

BUFFER ANALYSIS: PROTECTING ENVIRONMENTAL RESOURCES



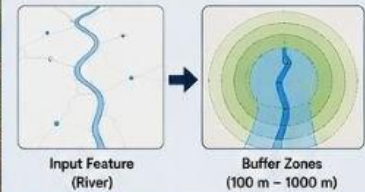
Using Distance-Based Analysis for Sustainable Environmental Planning

Buffer analysis creates zones around spatial features at a specified distance to identify areas that may be influenced, protected, or at risk.



WHAT IS BUFFER ANALYSIS?

A buffer is a zone that is created around a spatial feature at a specified distance. It helps identify areas that require protection or management.



EXAMPLE APPLICATIONS

- Create a 500 m buffer around groundwater sources to restrict construction or industrial discharge.
- Study the impact of roads on biodiversity in forest ecosystems.
- Identify settlements or industries within sensitive environmental zones.
- Support decision-making for land-use planning and environmental protection.

BUFFER ZONES & RISK LEVELS

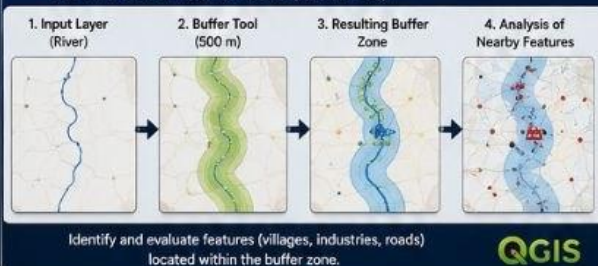
Distance (Buffer)	Risk Level	Description	Color
100 m	Very High Risk	Direct impact zone	Blue
250 m	High Risk	Strong influence zone	Green
500 m	Moderate Risk	Potential impact zone	Yellow
1000 m	Low Risk	Minimal influence zone	Red

Buffer zones help protect essential resources by defining safe distances from potential sources of pollution or disturbance.

BUFFER ANALYSIS WORKFLOW



BUFFER ANALYSIS IN QGIS (EXAMPLE)



ANALYSIS RESULT: FEATURES WITHIN 500 m BUFFER



BENEFITS OF BUFFER ANALYSIS

- Protects natural resources
- Reduces pollution and contamination risks
- Supports ecosystem conservation
- Improves land-use planning
- Promotes sustainable development

KEY TAKEAWAY

Buffer analysis is one of the most powerful GIS tools for environmental protection. It helps us understand distance-based impacts and supports evidence-based decisions for a healthier and more sustainable future.



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b. Overlay (Spatial Overlay)

Spatial Overlay is the process of integrating two or more layers of spatial data to uncover their inherent spatial relationships. This technique is applied when analyzing areas where multiple phenomena intersect, such as:

- Overlapping soil type layers with slope layers to identify agricultural suitability.
- Superimposing factory locations with water source locations to delineate environmental hazard zones.

This operation is foundational to geographic analysis, enabling **the generation of new maps that depict interactions between phenomena**. Burrough & McDonnell (1998) described overlay operations as "the mechanism that transforms disparate data into complex knowledge revealing spatio-temporal relationships.

c. Spatial Join

Spatial Join is an operation used to link attribute tables based on geographical location, rather than relying on common numerical keys. This is useful for instances like:

- Joining a schools layer with a residential areas layer to ascertain the population count surrounding each school.
- Linking a water well layer with a soil type layer to explore the relationship between water quality and soil characteristics.

This type of analysis is particularly valuable in **environmental statistical analysis** for identifying intricate spatial relationships among phenomena.

4.3. Applications of Spatial Analysis in Environment and Resource Management

Spatial analysis has become an indispensable tool in the management of environmental systems. Its most significant applications include:

- **Environmental Risk Assessment:** Determining distances between pollution sources (e.g., factories, landfills) and environmentally sensitive areas (e.g., rivers, forests).
- **Land-Use Planning:** Utilizing spatial overlay to identify optimal locations for agricultural or urban development.
- **Water Resource Management:** Analyzing well locations, drainage basins, and soil types to evaluate water sustainability.

- **Environmental Hazard Estimation:** Using slope analysis and Digital Elevation Models (DEMs) to predict hazards like landslides or floods.
- **Environmental Change Monitoring:** Integrating remote sensing data with spatial analysis to track phenomena such as urban sprawl or deforestation.

7. Data and Output Management

Effective data management is a cornerstone for the success of any geoscientific or environmental project. Spatial data within GIS transcends mere files; it constitutes an interconnected framework of spatial layers and associated descriptive information. This framework necessitates meticulous organization and ongoing maintenance to ensure data accuracy, reliability, and utility for subsequent analysis and map generation. As articulated by Chang (2019), GIS data management is inherently both an art and a science, integrating scientific precision with systematic informational organization.

5.1. Data Management within GIS

Data management in GIS commences with establishing a **clear organizational hierarchy** for project files. Typically, projects are structured into primary directories such as

- **Raw_Data** (for original, unprocessed data)
- **Processed_Data** (for refined and cleaned datasets)
- **Maps** (for final map outputs)
- **Documents** (for accompanying reports and textual materials).

It is imperative to assign clear and descriptive names to all layers and files (e.g., '*Land Use_2025.shp*,' or '*Water Quality_Zones.tif*') to facilitate comprehension of their content and context. This structured approach is vital for preventing errors during analysis, particularly in intricate environmental projects involving numerous layers depicting diverse phenomena like climate, soil, vegetation cover, and water resources.

5.2. Layer Organization and Database Management

Every GIS project incorporates a multitude of **spatial layers**, stored in various formats. Common examples include:

- **Shapefile (.shp):** The predominant format for representing vector data (points, lines, polygons).
- **GeoTIFF (.tif):** Used for raster data, such as aerial imagery and elevation models.
- **Geodatabase (.gdb):** A robust spatial database capable of storing extensive quantities of information within a single file.

GIS software environments, such as **QGIS** and **ArcGIS Pro**, provide comprehensive controls over layer properties, including their arrangement, transparency, and symbology. This systematic organization extends beyond visual aesthetics; it fundamentally **facilitates sophisticated spatial analysis** that relies on the intricate interaction among different layers.

5.3. Visualization, Analysis, and Map Production Functions

Visualization represents the critical phase where raw digital data is transformed into interactive **maps that visually convey geographic realities**. Key visualization functions within GIS include:

- **Symbology:** Employed to differentiate phenomena through varied colors, symbols, or patterns. For instance, red might denote high environmental risk areas, while green signifies safe zones.
- **Classification:** Involves categorizing data into distinct groups (e.g., high, medium, low) to simplify interpretation and understanding.
- **Visual Analysis:** Enables researchers to identify and interpret spatial patterns, such as urban expansion or the distribution of industrial facilities.

Subsequent to visualization, the **Map Production stage constitutes** the ultimate objective of a GIS project. These final maps serve as crucial outputs for environmental reports, academic presentations, and informed administrative decision-making processes.

5.4. Advantages of GIS

GIS offers distinct advantages by integrating spatial and statistical analysis capabilities within a unified digital environment. Notable benefits include:

- **Integration of Diverse Data Sources:** Facilitates the merging of data from various origins, such as GPS, satellite imagery, and field surveys.

- **Efficient Environmental Information Management:** Empowers environmental organizations to construct large, continuously updated spatial databases.
- **Facilitated Updates:** Allows for direct updating within the system in response to real-world changes (e.g., new infrastructure, alterations in vegetation cover).
- **Production of High-Precision Maps:** Generates accurate maps that significantly contribute to sustainable development initiatives and governmental policies.
- **Analysis of Spatial Relationships and Interconnections:** Aids in comprehending the interdependencies between phenomena, such as the relationship between population density and air pollution.

5.5. Limitations of GIS

Despite its potent analytical capabilities, GIS faces several inherent challenges:

- **High Cost of Data Acquisition:** Requires specialized hardware, software, and significant investment in data collection.
- **Complexity of Training:** Necessitates advanced technical and geographical expertise from users.
- **Issue of Data Accuracy:** The precision of spatial data can vary considerably depending on its source, potentially impacting the reliability of analytical outcomes.
- **Temporal Constraints:** Large-scale projects, particularly when utilizing high-resolution imagery, often demand extensive processing times.

Longley et al. (2015) underscore that the success of any GIS project hinges on a judicious balance between data quality and available resources, given that achieving higher accuracy often correlates with increased costs.



SPATIAL LAYERS AND GEODATABASE MANAGEMENT

Managing Spatial Data Through Structured Layer Systems

TYPES OF SPATIAL DATA

1. Shapefile (.shp)

- Points
- Lines
- Polygons

2. GeoTIFF (.tif)

- Satellite Imagery
- DEM (Elevation)
- Raster Data

3. Geodatabase (.gdb)

- Integrated Spatial Database
- Large-scale Environmental Information
- Stores Multiple Layers in One File

LAYERS PANEL (QGIS)

LAYER MANAGEMENT TOOLS

Layer Order

Transparency Control

Symbology & Styling

Filtering & Querying

Zoom & Navigation

Editing Layers

GEODATABASE ADVANTAGES

- ✓ Stores multiple feature classes in one database
- ✓ Maintains relationships between layers
- ✓ High performance for large datasets
- ✓ Supports topology and data integrity
- ✓ Ideal for environmental projects

FROM RAW DATA TO ANALYZED LAYERS

LAYER EXAMPLES IN AN ENVIRONMENTAL PROJECT

KEY TAKEAWAY

A well-organized layer structure and geodatabase management ensure data accuracy, efficient analysis, and high-quality map production in GIS projects.

BENEFITS OF EFFECTIVE LAYER MANAGEMENT

Improves Accuracy

Enhances Efficiency

Ensures Data Integrity

Supports Better Decision-Making

Enables Advanced Spatial Analysis

Promotes Sustainable Environmental Management

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CHAPTER II : Remote Sensing

2. Introduction to Remote Sensing

This chapter marks a pivotal shift in the course, transitioning students from analyzing pre-existing spatial data to engaging directly with its primary source: satellite imagery. A robust comprehension of remote sensing is foundational for a precise scientific and technical interpretation of Earth's surface, underpinning numerous Geographic Information Systems (GIS) applications in environmental and natural resource management.

1.1. Definition and Environmental Significance of Remote Sensing

Remote sensing is defined as the scientific discipline and technical methodology for acquiring information about the Earth's surface without direct physical contact. This is achieved through the use of sensors deployed on various platforms, such as aircraft or artificial satellites. The technique fundamentally relies on analyzing electromagnetic (**EM**) radiation, whether reflected or emitted, from natural and anthropogenic features (e.g., forests, water bodies, soil, urban structures).

Its environmental significance stems from its utility as a tool for continuous and periodic monitoring of changes occurring on the Earth's surface. Specifically, remote sensing is employed for:

- **Monitoring vegetation cover** and identifying degraded or deforested areas.
- **Tracking water quality** through spectral reflection analysis of aquatic environments.
- **Detecting environmental pollution** in soil, water, or air.
- **Observing phenomena** such as desertification and land-use change.

A key advantage contributing to its profound importance is its capacity to cover extensive geographical areas rapidly, furnishing researchers and decision-makers with a comprehensive, multi-dimensional environmental perspective without the necessity for costly or repetitive field surveys.

2.2. The Electromagnetic Spectrum and Satellite Image Components

The electromagnetic (EM) spectrum encompasses the entire range of wavelengths emitted or reflected by EM radiation, spanning from gamma rays to radio waves. Within the context of remote sensing, particular attention is given to wavelengths within the visible, infrared, and occasionally microwave portions of this spectrum. The efficacy of each wavelength type varies in its capacity to penetrate the Earth's atmosphere and detect specific natural phenomena.

Satellite images are not merely photographic captures but rather digital representations comprising spectral values assigned to each pixel. Each pixel corresponds to a defined geographical area on the Earth's surface and contains a numerical value, known as a Digital Number (DN), which quantifies the intensity of reflected or emitted radiation from that specific area. These DNs form the fundamental basis for spectral analysis operations, which are subsequently utilized in land cover classification.

2.3. Characteristics of Satellite Missions (Landsat, Sentinel, SPOT)

Each Earth observation satellite possesses distinctive characteristics defined by its spatial, temporal, and spectral resolutions. Key examples include:

- ❖ **Landsat:** One of the oldest and most established terrestrial monitoring programs, initiated in 1972. It typically offers spatial resolutions ranging between 15 and 30 meters, with its data being instrumental in long-term environmental studies.
- ❖ **Sentinel:** A series of satellites launched by the European Space Agency (ESA), providing imagery with spatial resolutions up to 10 meters. Its data is updated every few days, making it highly effective for monitoring rapid changes in land cover.
- ❖ **SPOT:** A French program renowned for its very high spatial resolution (up to 1.5 meters in some versions). It is frequently employed in detailed urban and agricultural planning applications.

The variety among these satellites also extends to the number of spectral bands they capture, which directly dictates the type and sophistication of analysis that can be performed on the resulting imagery.

REMOTE SENSING: SEEING THE EARTH WITHOUT TOUCHING IT

WHAT IS REMOTE SENSING?

Remote sensing is the science and technology of collecting information about the Earth's surface without direct contact. It uses sensors on satellites or aircraft to detect reflected or emitted electromagnetic radiation from natural and man-made features.

COLLECTING ENVIRONMENTAL INFORMATION WITHOUT DIRECT CONTACT

HOW IT WORKS

- 1 Energy from the Sun
- 2 Energy reflected or emitted from Earth's surface
- 3 Sensors on satellites capture the energy
- 4 Data transmitted to ground stations

POWERFUL ENVIRONMENTAL APPLICATIONS

1 FOREST MONITORING

Tracks changes in forests and vegetation over time

- Detects deforestation
- Monitors forest degradation
- Assesses vegetation health
- Estimates biomass

Forest Change Detection

2 WATER QUALITY MONITORING

Monitors the quality and health of water bodies

- Detects algal blooms
- Measures turbidity
- Monitors pollutants
- Maps water temperature

Algal Bloom Detection

3 ENVIRONMENTAL POLLUTION DETECTION

Detects and monitors pollution in air, water, and soil

- Air pollution monitoring
- Water contamination
- Soil pollution assessment
- Industrial impact analysis

Industrial Pollution Mapping

4 DESERTIFICATION MONITORING

Tracks land degradation and desertification processes

- Land degradation mapping
- Soil erosion monitoring
- Drought impact assessment
- Land-use change detection

Land Degradation Mapping

WHY REMOTE SENSING IS ESSENTIAL

Monitors large areas quickly and efficiently

Provides continuous and repeatable observations

Supports data-driven environmental decisions

Reduces time and cost of field surveys

Supports sustainable development and conservation

WIDE COVERAGE

FREQUENT MONITORING

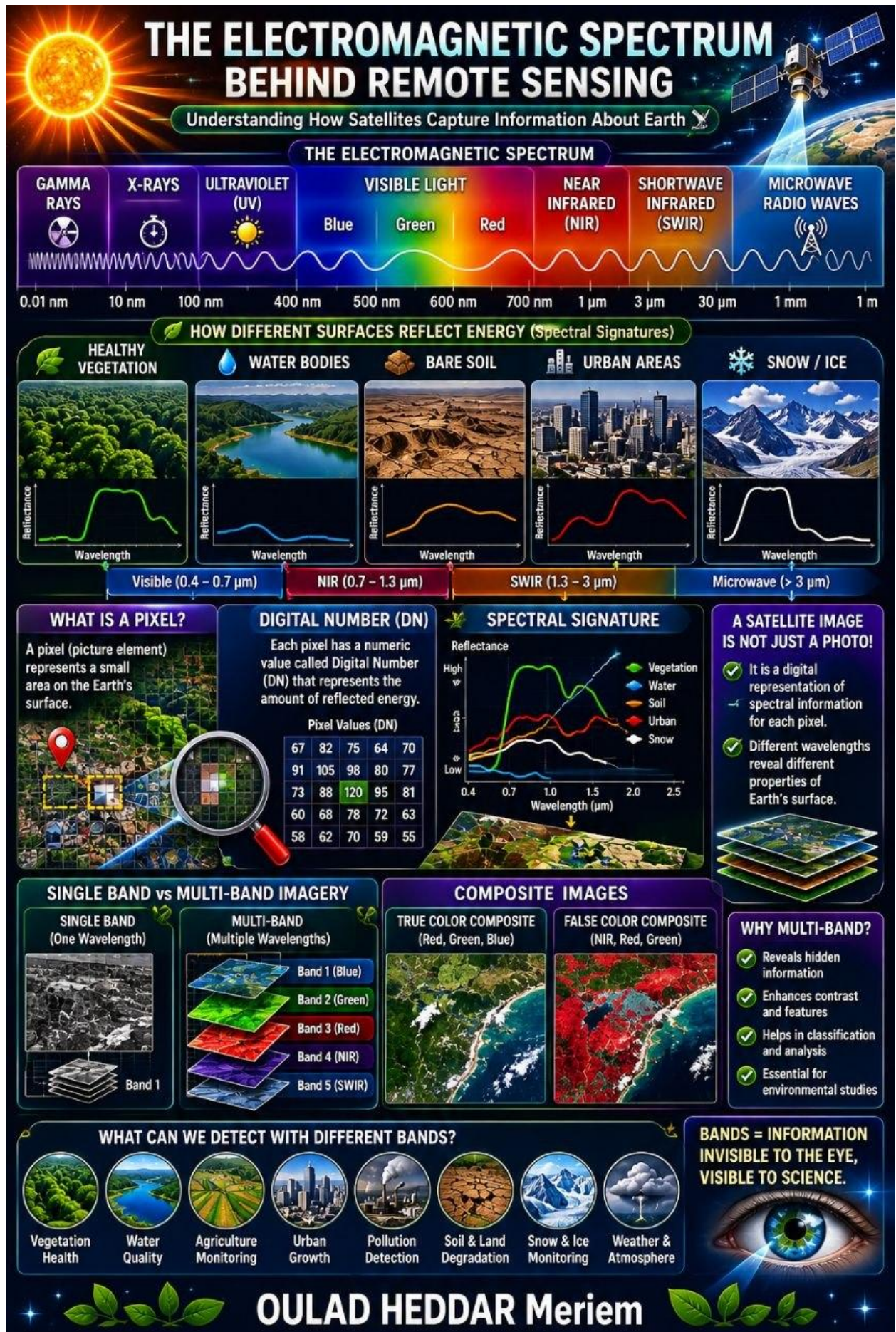
HIGH ACCURACY

ENVIRONMENTAL PROTECTION

BETTER DECISIONS FOR OUR PLANET

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3. Remote Sensing Image Processing

This course, students transition from fundamental display to advanced scientific processing, enhancement, and analysis of satellite imagery. This critical stage aims to extract precise and actionable geospatial and environmental intelligence. Image processing essentially refines raw data, boosting clarity and accuracy to convert mere visual representations into robust scientific instruments for spatial analysis.

2.1. Geometric Correction

Satellite images, despite their high resolution, can exhibit spatial distortions originating from various acquisition factors such as satellite movement, Earth's curvature, and topographic relief. Geometric correction is the process of realigning the image to its true ground coordinates, ensuring precise correspondence with existing geographic maps or other aerial imagery. This process primarily utilizes Ground Control Points (**GCPs**) identifiable features with precisely known geographic coordinates that are located within the image. Upon successful correction, the imagery becomes georeferenced, making it fully compatible with Geographic Information Systems (**GIS**) for accurate measurement and analysis. This step is indispensable for detailed environmental studies (e.g., monitoring land-use change, urban expansion), as even minor spatial offsets (**e.g., a few meters**) can lead to erroneous analytical conclusions.

2.2. Radiometric Correction

Satellite images are also subject to radiometric distortions stemming from variable solar illumination, sensor viewing angles, and atmospheric conditions (e.g., haze, clouds). The primary objective of radiometric correction is to mitigate these effects and calibrate Digital Numbers (**DNs**) to accurately represent the true surface reflectance. This typically involves advanced correction models that consider factors such as the Sun-Earth distance and illumination angles. Radiometric correction is vital for time-series environmental analysis, ensuring that observed differences between images acquired at different times genuinely reflect environmental changes rather than mere variations in image acquisition parameters.

2.3. Creating Composite Images (RGB Combinations)

Satellite imagery comprises multiple spectral bands, each capturing reflectance values across a specific segment of the electromagnetic spectrum. By combining these bands, various composite images can be generated to highlight diverse features relevant to the analytical objective. **RGB** composite imagery relies on assigning three selected spectral bands to the Red (**R**), Green (**G**), and Blue (**B**) display channels.

Natural Color Composite: For instance, assigning bands **1**, **2**, and **3** (or equivalent visible bands) to blue, green, and red channels, respectively, creates an image that closely approximates how the scene appears to the human eye.

False Color Composite: Conversely, employing a combination like bands **3**, **4**, and **5** (often **Near-Infrared**, **Red**, and **Green** respectively) can render vegetation in red hues. This is particularly useful because healthy vegetation exhibits high reflectance in the Near-Infrared (**NIR**) region (e.g., **band 5**), making it appear distinct. Such false-color composites significantly aid in precise vegetation analysis, facilitating differentiation between forests and agricultural lands, or identifying moist versus arid regions.

2.4. Spectral Analysis of Values

Every material on the Earth's surface possesses a unique "spectral signature," defined by its characteristic reflectance pattern across different spectral bands. For example:

- Water absorbs most Near-Infrared (NIR) radiation, consequently appearing dark in imagery.
- Healthy vegetation strongly reflects NIR radiation, thus appearing bright red in false-color composites.
- Bare soil typically reflects visible light more than vegetation but less intensely than many rock types.

Analyzing these distinct spectral values enables the differentiation of various land cover types, forming the foundational principle for subsequent Digital Classification processes.

GEOMETRIC CORRECTION IN REMOTE SENSING

— ALIGNING SATELLITE IMAGERY WITH REAL-WORLD GEOGRAPHY

WHY GEOMETRIC CORRECTION IS NECESSARY?

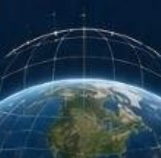
Satellite images are often geometrically distorted due to several factors. This causes spatial misalignment with real-world locations. Geometric correction ensures accuracy for mapping and analysis.

SOURCES OF GEOMETRIC DISTORTION



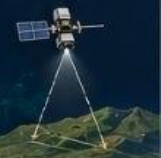
SATELLITE MOTION

Movement of the satellite during image acquisition.



EARTH CURVATURE

Curvature of the Earth affects image geometry.



SENSOR ANGLE

Off-nadir viewing angle causes displacement.



TERRAIN EFFECTS

Elevation changes cause relief displacement.

GEOMETRIC CORRECTION WORKFLOW

1 RAW DISTORTED IMAGE



The original satellite image contains geometric distortions and is not aligned with real world coordinates.

2 GROUND CONTROL POINTS



Identify GCPs in the image and match them with known real-world coordinates (e.g., road intersections, corners, bridges, landmarks).

3 GEOMETRIC TRANSFORMATION



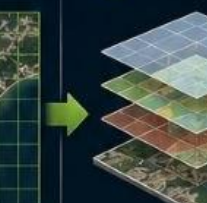
Apply mathematical transformation (e.g., polynomial, affine, or rubber sheeting) to remove distortion and align the image to real-world coordinates.

4 GEOREFERENCED IMAGE



The corrected image is now accurately aligned with maps and other spatial datasets. Ready for GIS analysis.

5 GIS ANALYSIS

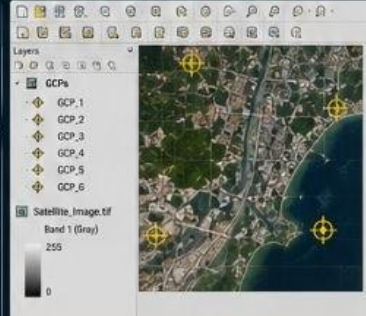


Use the georeferenced image in GIS for accurate measurement, analysis, and decision making.

GCP COLLECTION & TRANSFORMATION

Collect GCPs using:

- GPS Survey
- Topographic Maps
- High-Resolution Aerial Imagery
- Field Knowledge



GCP TABLE			
ID	Image (X,Y)	Map (X,Y)	Error (m)
1	245.3, 512.6	528735.2, 4089236.5	0.45
2	1024.8, 488.2	530112.7, 4089410.3	0.38
3	779.6, 1024.1	529645.1, 4090753.2	0.52
4	132.7, 989.4	528620.8, 4090522.7	0.41
5	980.5, 120.3	530945.0, 4092011.4	0.36
6	1156.6, 820.8	531205.4, 4090320.6	0.47

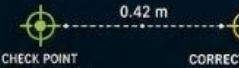
RMS Error: 0.43 m ✓

Transformation: 2nd Order Polynomial

ACCURACY ASSESSMENT

After correction, accuracy is evaluated by comparing check points with reference data.

- RMSE (Root Mean Square Error) measures positional accuracy.
- Lower RMSE = Higher accuracy and reliability.



CHECK POINT (REAL WORLD) CORRECTED POINT (IMAGE)

0.42 m

RMSE = 0.42 m ✓ EXCELLENT

WHY GEOMETRIC CORRECTION IS ESSENTIAL FOR ENVIRONMENTAL STUDIES



URBAN GROWTH ANALYSIS

Accurate alignment allows precise measurement of urban expansion.



LAND COVER CHANGE DETECTION

Correct alignment ensures reliable change detection over time.



ENVIRONMENTAL MONITORING

Precise location data is critical for tracking floods, deforestation, and land degradation.



ACCURATE MEASUREMENT

Distances, areas, and patterns are measured accurately in GIS.

KEY TAKEAWAYS



Geometric correction aligns satellite images with real-world coordinates.



Uses GCPs and mathematical transformations to remove distortion.



Essential for accurate mapping, analysis, and environmental decision making.



Improves reliability of spatial data in GIS and remote sensing applications.

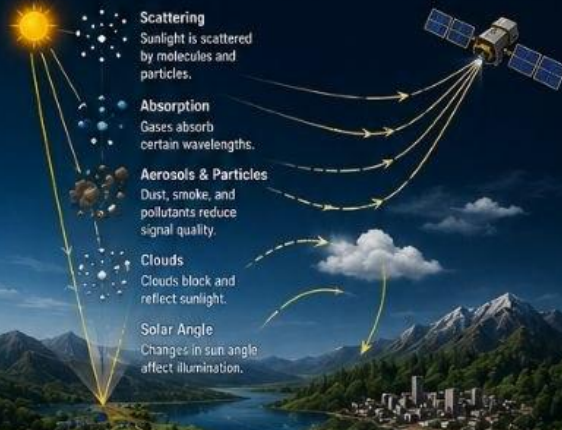
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RADIOMETRIC CORRECTION: REVEALING TRUE SURFACE CONDITIONS

REMOVING ATMOSPHERIC EFFECTS FOR ACCURATE ENVIRONMENTAL MONITORING

1. ATMOSPHERIC EFFECTS DISTORT SATELLITE IMAGERY

As sunlight travels through the atmosphere, it interacts with gases, particles, and water vapor, altering the signal received by the sensor.



Result: Distorted Digital Numbers (DN) – Not true surface reflectance!

2. RADIOMETRIC CORRECTION PROCESS

RAW DIGITAL NUMBERS (DN)

Values affected by atmospheric conditions and sensor geometry.



ATMOSPHERIC CORRECTION

Models estimate and remove atmospheric effects such as scattering, absorption, and path radiance.



SURFACE REFLECTANCE

Values represent the true reflectance of the surface, independent of atmospheric conditions.



RELIABLE ENVIRONMENTAL ANALYSIS

Accurate information for monitoring and decision making.



3. BEFORE AND AFTER RADIOMETRIC CORRECTION

BEFORE CORRECTION (RAW DATA)



Problems:

- Haze and atmospheric scattering
- Low contrast
- Different dates not comparable
- Reduced information content



AFTER CORRECTION (SURFACE REFLECTANCE)

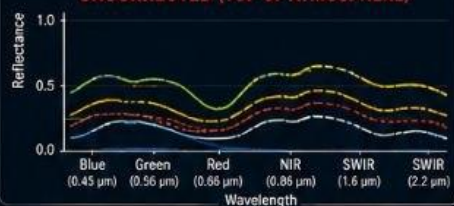


Improvements:

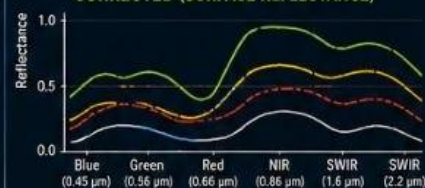
- Atmosphere effects removed
- Higher contrast
- Data from different dates comparable
- More reliable for analysis and mapping

4. SPECTRAL REFLECTANCE: UNCORRECTED vs CORRECTED

UNCORRECTED (TOP OF ATMOSPHERE)



CORRECTED (SURFACE REFLECTANCE)



Why It Matters?

Corrected reflectance reveals the real behavior of surfaces, enabling accurate comparison across time and space.

5. APPLICATIONS IN ENVIRONMENTAL MONITORING

VEGETATION MONITORING



Accurate assessment of vegetation health, growth, and stress.

WATER QUALITY ASSESSMENT



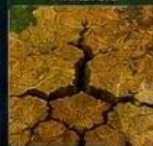
Better detection of water turbidity, algae, and contamination.

CLIMATE & CHANGE STUDIES



Reliable time-series analysis for climate trend detection.

LAND DEGRADATION ANALYSIS



Monitor soil degradation, desertification, and land productivity.

6. GENERAL WORKFLOW



Input Satellite Data (DN)



Radiometric Correction (Atmospheric Model)



Surface Reflectance Output



Environmental Analysis & Mapping



KEY TAKEAWAYS



Atmospheric effects distort the true signal received by satellites.



Radiometric correction removes these effects to retrieve true surface reflectance.



Corrected data enable accurate, reliable, and comparable environmental analyses.



Essential for informed decision-making and sustainable resource management.



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4. Environmental Applications of Remote Sensing

This module, Environmental Applications of Remote Sensing, signifies a transition from the purely **technical aspects to the analytical and applied** dimensions within the field. Remote sensing has emerged as an indispensable tool for studying environmental dynamics, monitoring changes over time, and safeguarding ecosystems, offering repeated, accurate coverage over vast areas at reduced temporal and material costs.

3.1. Forest Monitoring

Forests are highly susceptible to anthropogenic impacts, including deforestation, urban encroachment, and fires. Satellite imagery from platforms like **Landsat** and **Sentinel-2** is utilized to monitor forest cover via spectral indicators reflective of vegetation health and density. The Normalized Difference Vegetation Index (**NDVI**), derived from near-infrared (**NIR**) and red (**RED**) reflectance, is a prevalent technique. High **NDVI** values (**0.6-1**) typically denote dense, healthy vegetation, while lower values signify sparse or degraded areas or barren land. This methodology enables the tracking of **deforestation** and **reforestation** efforts, as well as the estimation of biomass carbon sequestration, providing crucial data for climate change understanding.

3.2. Water Body Monitoring and Quality

Water bodies, vital natural resources, can be effectively monitored using remote sensing. Visible and near-infrared spectral bands facilitate the delineation of lakes and rivers, tracking changes in their extent over time. Spectral analysis aids in assessing water quality parameters such as **turbidity** and **algal bloom** occurrence, often employing indices like the Normalized Difference Water Index (**NDWI**) to differentiate water from land. In coastal zones, satellite imagery is instrumental in monitoring **coastal erosion**, **sedimentation**, and sea-level fluctuations – phenomena directly linked to climate change.

3.3. Soil Analysis using Remote Sensing

Soil characteristics can be analyzed through their unique interaction with electromagnetic radiation, particularly within the shortwave infrared (**SWIR**) spectral range. This technique is

employed to assess **soil moisture** content, **salinity levels**, and **land degradation**. Satellite platforms such as **Landsat 8** and **MODIS** provide recurrent data, enabling the tracking of desertification and the identification of vulnerable areas prone to agricultural productivity loss. Such data are integral to developing soil degradation maps that support sustainable agricultural planning.

3.4. Environmental Pollution Monitoring

Remote sensing offers critical tools for detecting and monitoring environmental **pollution sources**. Specialized satellites, such as **Sentinel-5P**, are capable of tracking atmospheric industrial pollutants like nitrogen dioxide (**NO₂**) and sulfur dioxide (**SO₂**). Water pollution, conversely, can be detected by analyzing changes in the spectral reflectance of water bodies, where increases in turbidity or green band reflectance may indicate heightened levels of algae or contaminants. Furthermore, in urban areas, the phenomenon of Urban Heat Islands (**UHIs**) can be monitored using thermal infrared data from satellites like **Landsat 8** (Thermal Bands **10/11**), aiding in the analysis of thermal pollution and urban sprawl impacts.

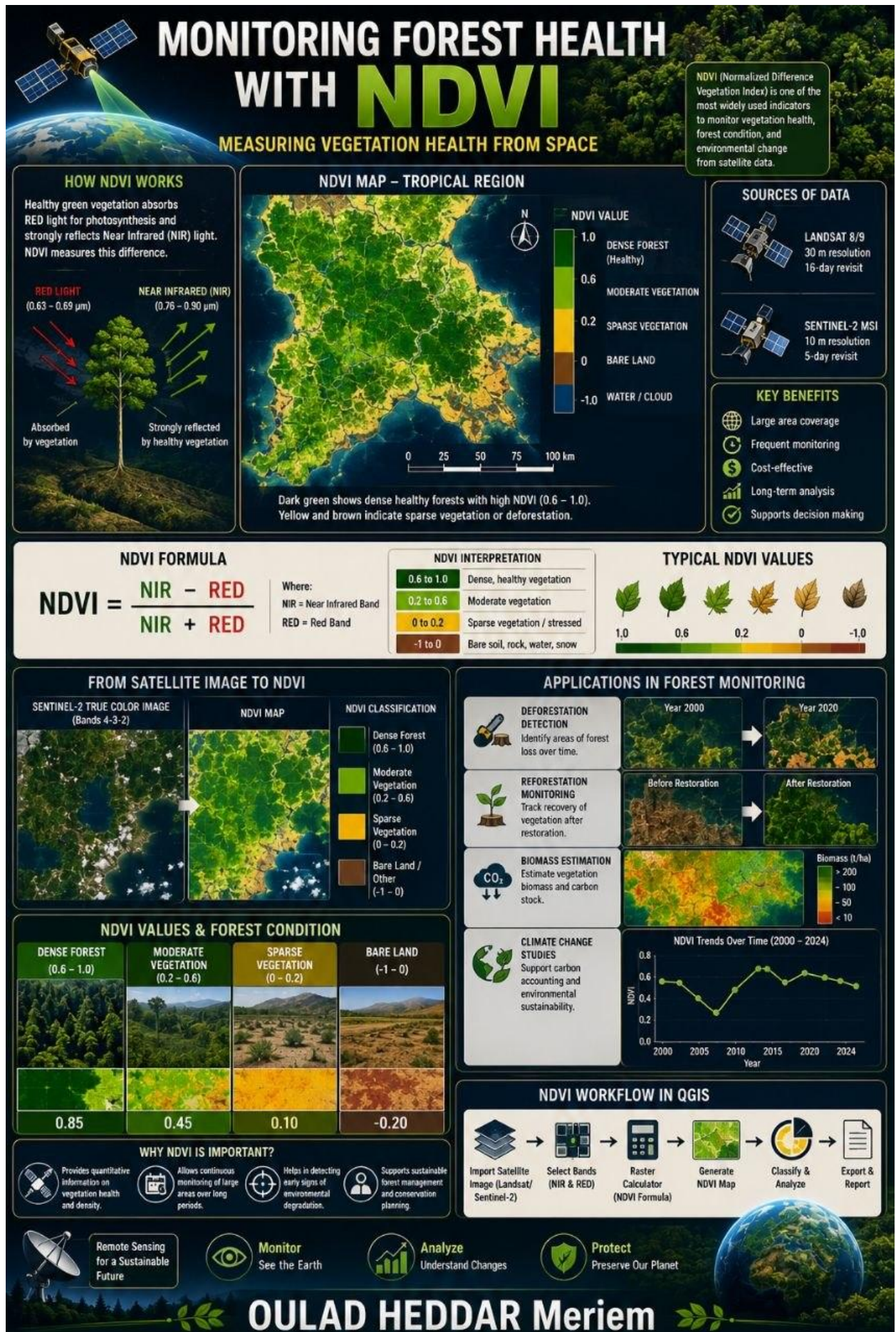
3.5. Temporal Change Analysis with Time Series

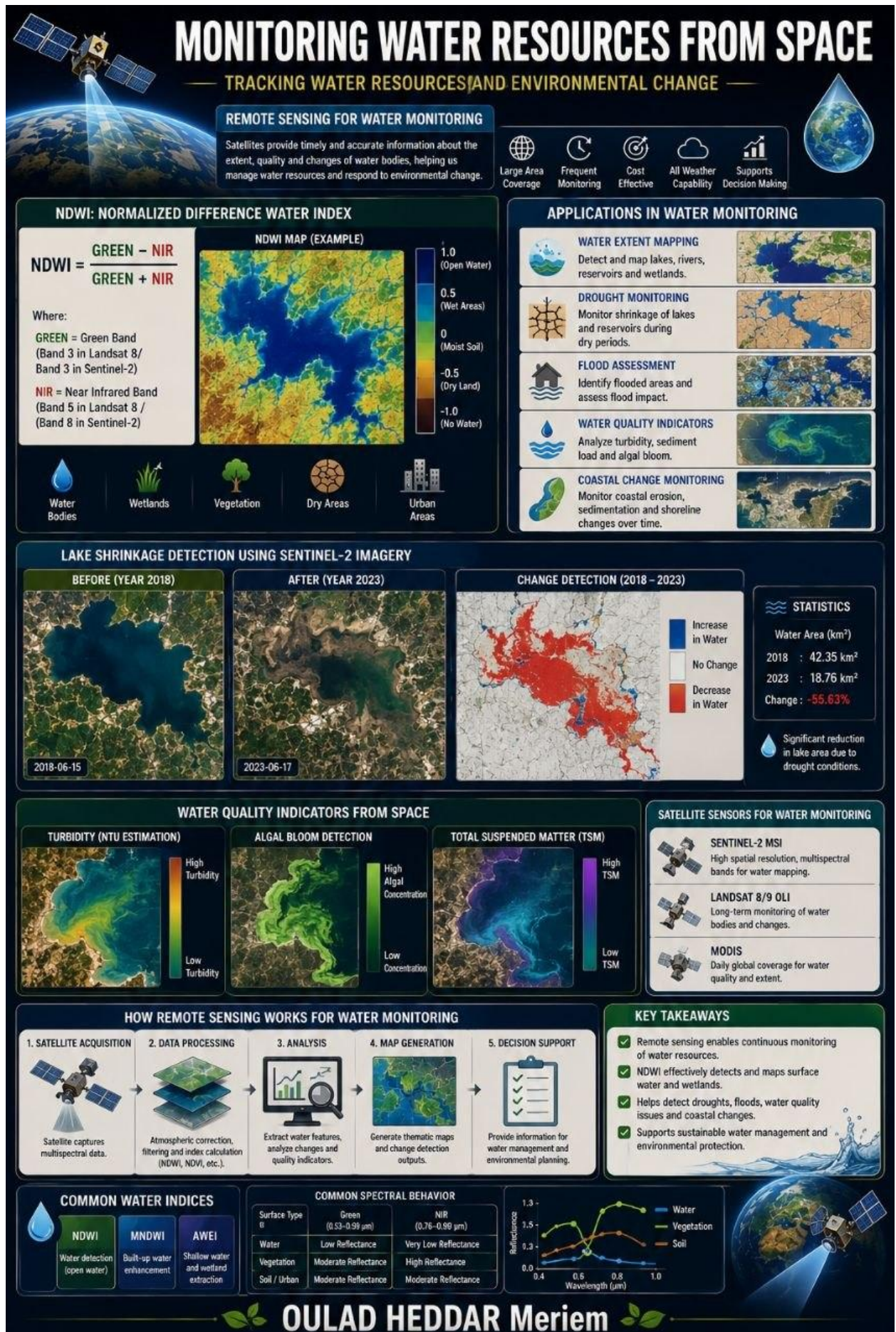
Temporal analysis, utilizing time series data sequential images of the same area captured over different periods is fundamental for studying **dynamic land cover changes**.

- Key applications include monitoring forest retreat, urban expansion
- The desiccation of rivers and lakes
- Agricultural development.

Temporal comparisons are performed by analyzing images taken at regular intervals, often after radiometric and geometric corrections. Common techniques include **Image Differencing** and **Post-classification Comparison**, both designed to identify areas that have undergone significant change.

Environmental remote sensing applications demonstrate the profound capability of satellite imagery to serve as a precise tool for informed environmental decision-making. Its utility spans critical areas such as **forest monitoring** and **health assessment, water and pollution surveillance, and land-use change tracking**. Integrating this rich dataset within Geographic Information Systems (**GIS**) enables the construction of comprehensive environmental models, pivotal for urban planning, natural resource management, and mitigating the impacts of climate change. This foundation in remote sensing cultivates a systematic approach to understanding the intricate **relationship between Earth and spectral signatures**, empowering students to interpret significant environmental transformations through the lens of precise spatial data.





CHAPTER III : Artificial Intelligence in Geoinformatics (GeoAI)

3. Artificial Intelligence in Geoinformatics (GeoAI)

This chapter represents a qualitative leap in the Geographic Information Systems (**GIS**) and Remote Sensing course, as students delve into one of the latest scientific and technical trends in the field: **the integration of Artificial Intelligence (AI) with spatial analysis**.

In recent decades, **GIS** and Remote Sensing (**RS**) have transitioned from descriptive tools into inferential systems capable of learning, predicting, and decision-making. This transformation would not have occurred without the introduction of **AI** specifically **Machine Learning** and **Deep Learning** into the core of geoinformatics.

3.1.The Concept of GeoAI and the Significance of Integrating AI with Spatial Analysis

The term Geospatial Artificial Intelligence (**GeoAI**) is an acronym representing the intersection of Artificial Intelligence (**AI**) and Geospatial Data. It refers to the use of AI algorithms, particularly machine learning algorithms, to analyze patterns in spatial data and extract information that is difficult to access using traditional methods.

Historically, GIS relied on simple logical analysis, such as **Overlay** operations or spatial **Buffering**. However, in recent years, it has shifted towards **Predictive Analytics** capable of discovering hidden relationships between variables.

GeoAI technologies encompass the following fields:

- **Machine Learning:** Algorithms such as Decision Trees, Random Forests, and Artificial Neural Networks (**ANN**).
- **Deep Learning:** The use of Convolutional Neural Networks (**CNN**) to analyze high-resolution satellite imagery.
- **Geospatial Intelligence:** Extracting geographic information to support environmental, urban, and security decision-making.

Integrating AI with spatial analysis enables the processing of massive amounts of spatial data with speed and accuracy, alongside the ability to learn from past examples, rendering these systems more capable of **predicting future environmental phenomena**.

4. Environmental Applications of AI in Geoinformatics

Environmental applications are among the fields that benefit most from GeoAI, as they rely on the analysis of massive satellite images and time series data. The most prominent of these applications include:

2.1. Environmental Change Detection

AI algorithms can analyze satellite imagery over time to detect areas that have undergone changes, such as deforestation, urban expansion, or lake desiccation. For example, Convolutional Neural Networks (**CNNs**) can distinguish subtle patterns in images, differentiating between temporary seasonal changes and permanent alterations in land cover.

2.2. Environmental Hazards Prediction

AI is utilized in analyzing weather, topography, and soil data to predict floods, landslides, and droughts. For instance, the **Random Forest** algorithm can identify the factors most influential in flood probability, such as slope gradient, precipitation volume, and soil type.

2.3. Air Quality and Pollution Analysis

Satellite data (e.g., **Sentinel-5P**) is integrated with ground sensor networks to train a machine learning model capable of predicting the levels of air pollutants like **NO₂** and **PM 2.5** in the near future. Furthermore, AI can be used to detect pollution "hotspots" in major cities.

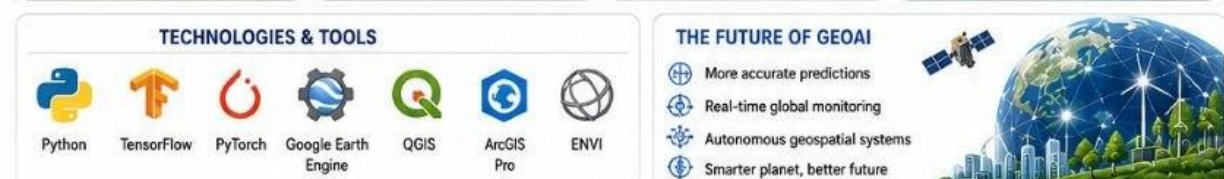
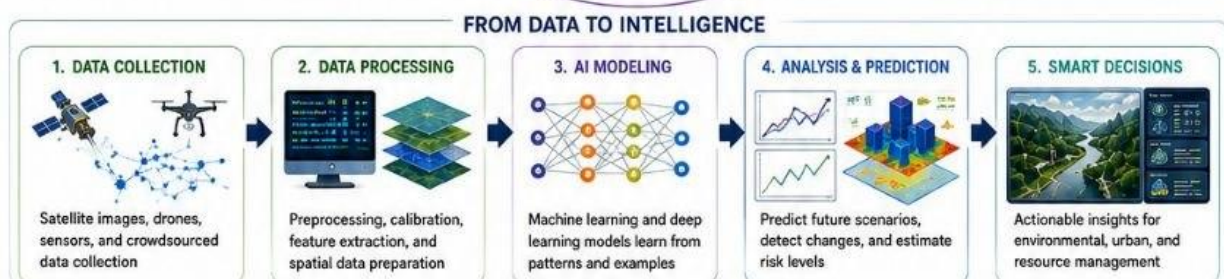
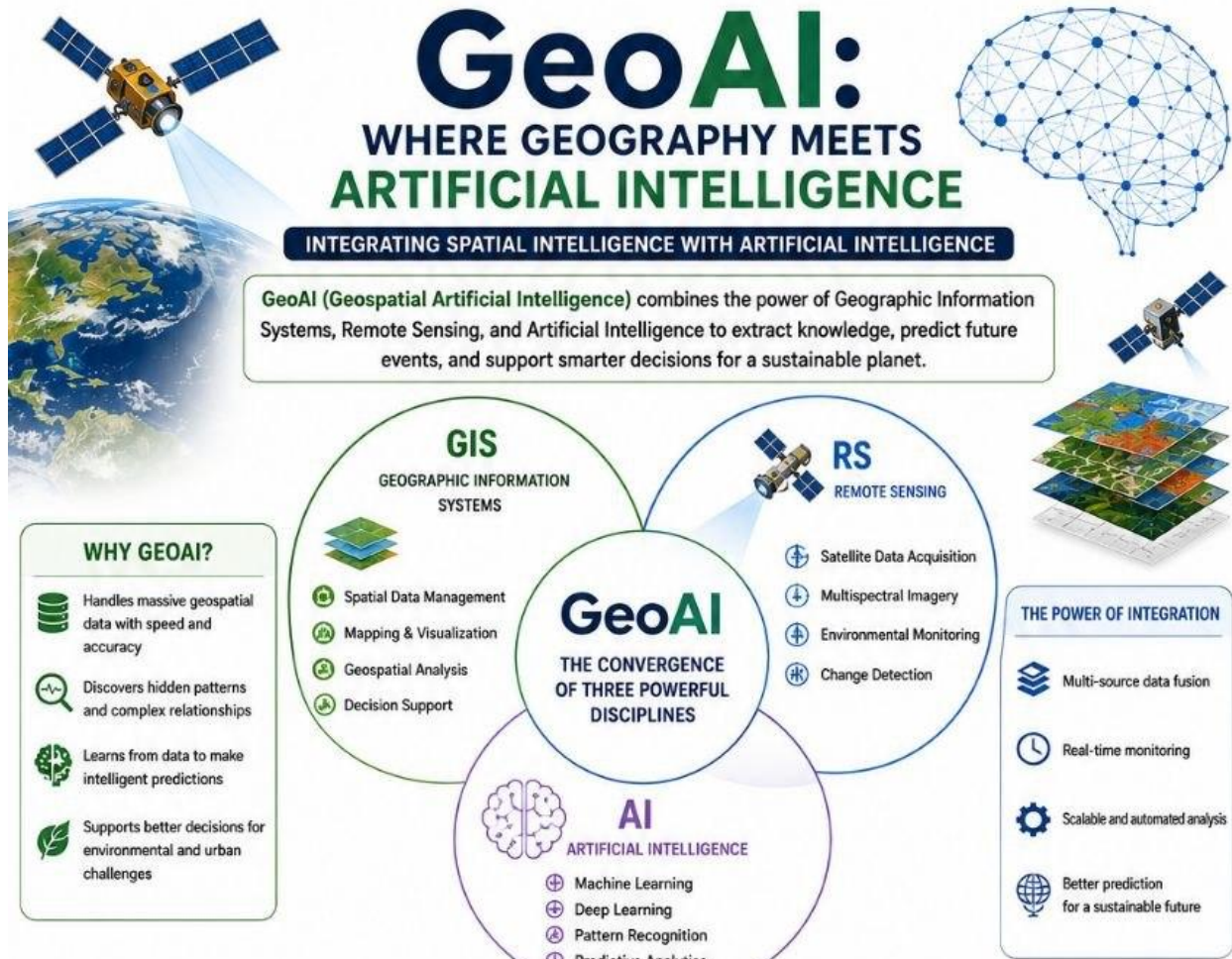
2.4. Agricultural and Water Resources Management

GeoAI is employed to estimate soil moisture or automatically detect crops from high-resolution satellite imagery. Deep learning algorithms like **U-Net** can analyze agricultural fields and delineate their boundaries automatically, aiding in irrigation management and sustainable water use.

5. Advantages of Integrating AI into Geoinformatics

Integrating AI into GIS offers key advantages:

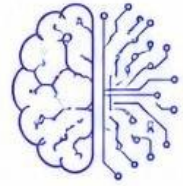
- ❖ Speed and accuracy in processing Big Spatial Data.
- ❖ The ability to self-learn from historical data to provide future predictions.
- ❖ Reducing human intervention in classification and analysis processes, thereby minimizing human error.
- ❖ Multi-source integration among satellite imagery, field data, and environmental sensors.



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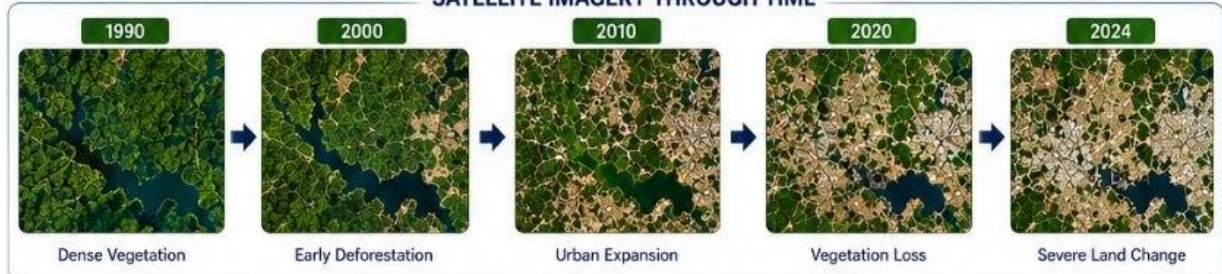


DEEP LEARNING FOR ENVIRONMENTAL CHANGE DETECTION

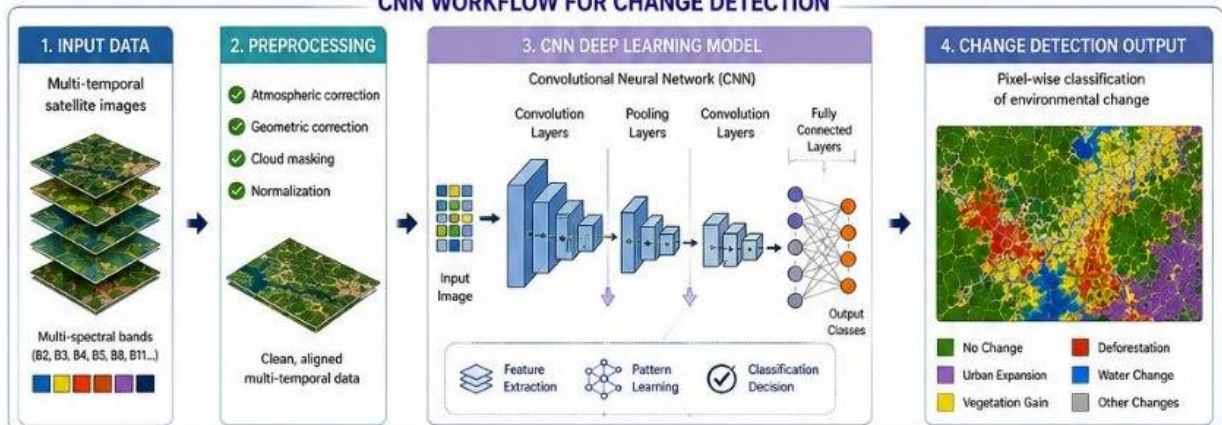


Using Convolutional Neural Networks (CNN) to detect, classify, and monitor environmental changes from satellite imagery through time.

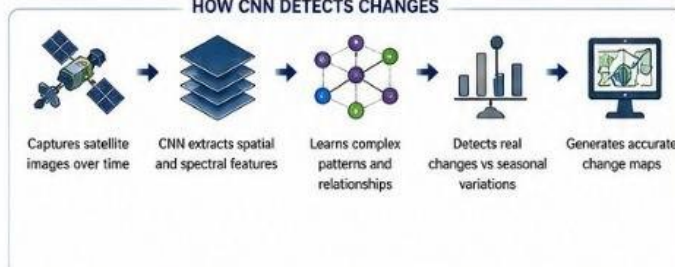
SATELLITE IMAGERY THROUGH TIME



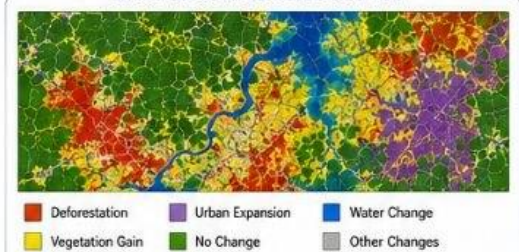
CNN WORKFLOW FOR CHANGE DETECTION



HOW CNN DETECTS CHANGES



EXAMPLE CHANGE DETECTION MAP



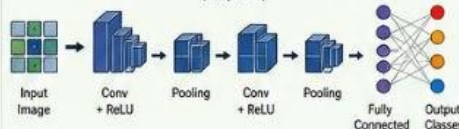
APPLICATIONS OF CNN IN ENVIRONMENTAL CHANGE DETECTION



ADVANTAGES OF DEEP LEARNING (CNN)

- Automatically learns complex spatial features
- High accuracy in change detection
- Distinguishes real changes from seasonal noise
- Works with large-scale multi-temporal data
- Supports fast, automated environmental monitoring

CNN ARCHITECTURE EXAMPLE (Simplified)



KEY TAKEAWAYS

- CNNs transform raw satellite data into intelligence.
- Enables precise and automated change detection.
- Essential for sustainable environmental monitoring and decision-making.



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CHAPTER IV : Mini Environnemental Project Design

1. General Introduction to Applied Projects in Geographic Information Systems

In this session, students begin to integrate what they have learned during the previous weeks into a mini-project that applies the theoretical knowledge and practical skills acquired in **GIS** and **Remote Sensing** to a real-world environmental issue.

Applied projects represent the core of the educational process in this field, as they translate **concepts into realistic analysis and reveal the student's ability to process and analyze data**, and produce environmentally significant scientific maps.

Applied projects are a powerful tool for developing spatial reasoning, as well as quantitative and qualitative analysis skills. Through these projects, students acquire skills in planning, data management, interpreting results, and presenting outputs in a scientific format applicable to environmental decision-making.

1. 2. Designing the Environmental Project Using GIS and RS

Designing an environmental project is defined as the process of identifying a specific environmental problem, collecting appropriate data, analyzing it using GIS and RS tools, and presenting the results as maps and spatial analyses that aid in understanding the phenomenon and proposing solutions.

The design involves the following fundamental steps:

1. Identifying the Environmental Problem: Such as water pollution, vegetation degradation, soil erosion, or unplanned urban expansion. The problem must be spatially analyzable using available spatial data and satellite imagery.

2. Defining Project Objectives and Research Questions: For example: Which areas are most affected by groundwater pollution? What is the extent of vegetation change over the last decade?

3. Determining the Spatial and Temporal Scope of the Study: Students select a specific area (e.g., a governorate, river basin, or nature reserve) and a defined time period (e.g., 2000–2020) based on data availability and the project's relevance to current environmental issues.

4. Data Collection: This includes spatial data (digital maps, road networks, soil layers, water sources, etc.) and attribute data (environmental statistics, water quality records, pollution rates, etc.). It also encompasses satellite data captured by satellites like **Sentinel-2** or **Landsat 8** to analyze land cover or environmental quality.

5. Selecting Analysis Tools: Appropriate GIS tools (such as spatial analysis or spatial **Overlay**) and remote sensing tools (such as spectral analysis or the **NDVI** index) are selected according to the nature of the project.

1.3. Selecting the Environmental Problem and Defining the Study Scope

Choosing a suitable environmental problem is one of the most critical stages of the project. The problem must be:

- Clear and spatially analyzable.
- Supported by available spatial and satellite data.
- Of environmental or developmental significance in the selected region.

Examples of potential projects:

- Analyzing river water pollution using satellite data and water quality indices.
- Tracking urban sprawl on agricultural lands between 2000 and 2020.
- Assessing forest degradation caused by fires using thermal spectral indices.
- Identifying areas most vulnerable to soil erosion based on slope and rainfall.



THE ENVIRONMENTAL GIS PROJECT WORKFLOW



FROM ENVIRONMENTAL QUESTIONS TO SPATIAL DECISION-MAKING

WHAT IS AN ENVIRONMENTAL GIS PROJECT?



An environmental GIS project uses spatial data and remote sensing to analyze real-world environmental problems and produce maps and insights to support better decisions for a sustainable future.



KEY BENEFITS



Understand environmental problems



Support evidence-based decisions



Visualize and communicate spatial information



Promote sustainable resource management



Protect ecosystems and public health

1

ENVIRONMENTAL PROBLEM IDENTIFICATION



Identify a real environmental issue that can be analyzed spatially.

Examples: Water pollution, Deforestation, Urban sprawl, Soil erosion, Habitat loss.



2

RESEARCH QUESTIONS & OBJECTIVES



Define clear research questions and objectives to guide the project analysis.

Examples: Which areas are most affected by pollution? How has land cover changed over time?



3

STUDY AREA SELECTION



Define the spatial and temporal scope of your study.

Examples: Choose a region (Province, Watershed, City) and a time period (e.g., 2000–2020).



4

DATA COLLECTION



Collect spatial, attribute, and environmental data.

- Vector data (rivers, roads, land use)
- Field data (water quality, soil samples)
- Environmental statistics



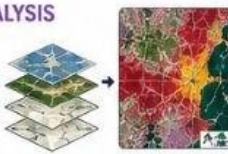
5

GIS & REMOTE SENSING ANALYSIS



Analyze the data using GIS and remote sensing techniques.

- Image processing (NDVI, LST, indices)
- Spatial analysis (Buffer, Overlay, Clip)
- Change detection & modeling



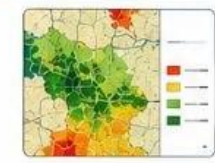
6

ENVIRONMENTAL MAPPING



Create maps that show the spatial patterns and results of your analysis.

- Thematic maps
- Risk maps
- Change maps



7

DECISION SUPPORT & RECOMMENDATIONS



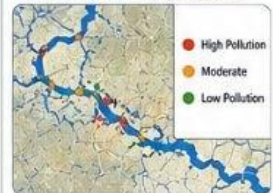
Use your results to support decision-making and propose solutions.

- Identify priority areas
- Recommend management actions
- Support sustainable planning

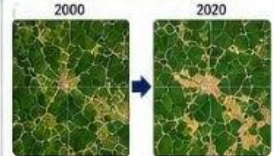


EXAMPLE PROJECTS

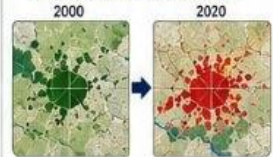
WATER POLLUTION ASSESSMENT



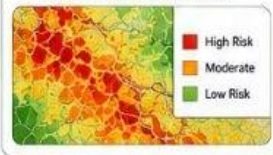
DEFORESTATION MONITORING



URBAN EXPANSION ANALYSIS



SOIL EROSION ASSESSMENT



TOOLS & DATA SOURCES

SOFTWARE



SATELLITE DATA



DATA SOURCES



THE POWER OF GIS & REMOTE SENSING



Monitor the Environment



Analyze Spatial Patterns



Support Smart Decisions



Promote Sustainability



Build a Better Future

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DESIGNING AN ENVIRONMENTAL GIS PROJECT



BUILDING A SUCCESSFUL GIS AND REMOTE SENSING RESEARCH PROJECT

Designing a project is the foundation of successful environmental analysis. It ensures that the right data, methods, and tools are used to answer real-world environmental questions.

PROJECT SUCCESS FACTORS

- ✓ Clear objectives and questions
- ✓ Relevant and reliable data
- ✓ Proper tools and methods
- ✓ Well-defined study area
- ✓ Logical workflow and timeline
- ✓ Accurate analysis and interpretation



1 DEFINE THE ENVIRONMENTAL PROBLEM



Clearly identify the environmental issue that needs to be analyzed using GIS and remote sensing.

EXAMPLES

- Water Pollution
- Forest Degradation
- Urban Sprawl
- Soil Erosion



2 DEVELOP RESEARCH OBJECTIVES & QUESTIONS



Set clear objectives and research questions to guide your analysis and ensure focused results.

EXAMPLES

- What are the most affected areas by water pollution?
- How has land cover changed over the last 20 years?
- What factors influence soil erosion in the study area?



3 DEFINE SPATIAL AND TEMPORAL SCOPE



Select the study area and the time period that best fit your research problem and data availability.

CONSIDERATIONS

- Choose a clear geographical boundary (e.g., watershed, city, province)
- Select time range (e.g., 2000–2020)
- Ensure data availability for the chosen period



4 COLLECT SPATIAL DATA



Gather all necessary spatial and attribute data required for your project.

DATA TYPES

- Vector Data: roads, rivers, land use, administrative boundaries
- Raster Data: DEM, soils, land cover maps
- Attribute Data: field measurements, statistics, water quality records



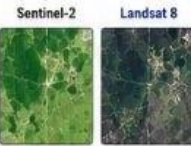
5 ACQUIRE SATELLITE IMAGERY



Obtain satellite images suitable for analysis based on your study area and objectives.

SOURCES

- Sentinel-2 (10 m, 5-day revisit)
- Landsat 8/9 (30 m, 16-day revisit)
- Other sources: MODIS, PlanetScope, SPOT, ASTER



6 SELECT ANALYTICAL METHODS AND TOOLS



Choose the appropriate GIS and remote sensing methods to analyze your data and answer your research questions.

EXAMPLES OF METHODS

- NDVI for vegetation analysis
- Change detection
- Buffer analysis
- Overlay analysis
- Raster Calculator
- Spatial statistics



DATA SOURCES

VECTOR DATA

- OpenStreetMap
- GADM
- HydroSHEDS
- Global Forest Watch

SATELLITE DATA

- Copernicus Copernicus Hub (Sentinel)
- USGS Earth Explorer
- LANDSAT (NASA)
- MODIS (NASA)

FIELD & STATISTICAL DATA

- Field Surveys
- Water Quality Records
- Environmental Statistics
- Meteorological Data

EXAMPLE PROJECT IDEAS

- Assessing Water Quality of a River
- Monitoring Deforestation in a Forest
- Analyzing Urban Expansion
- Evaluating Soil Erosion Risk
- Detecting Forest Fire Impact

PROJECT DESIGN CHECKLIST



- ✓ Problem clearly defined
- ✓ Objectives and questions set
- ✓ Study area and time defined
- ✓ Data sources identified
- ✓ Tools and methods selected
- ✓ Project plan and timeline ready

EXPECTED OUTCOMES

- Clear understanding of the environmental issue
- Spatial analysis and meaningful results
- Thematic maps and visual outputs
- Scientific report and documentation
- Actionable recommendations



PROJECT DESIGN AT A GLANCE



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2. Result Analysis and Reporting

2.1. General Introduction to Results Analysis and Its Importance

After executing spatial operations and environmental analysis in a GIS and RS project, the phase of **analyzing results and generating reports follows**. This is one of the most critical stages in applied geographical research.

This phase aims to interpret the digital outputs, maps, and graphs resulting from **spatial analysis and transform them into comprehensible scientific information** usable by decision-makers and researchers.

Results analysis is not limited to merely displaying numbers or maps; rather, it requires a logical, scientific interpretation of the spatial and temporal relationships between environmental phenomena.

For instance, if spatial analysis reveals an increase in the Normalized Difference Vegetation Index (**NDVI**) in a specific area between 2010 and 2020, it is necessary to interpret whether this is due to an increase in natural vegetation cover, afforestation policies, or perhaps a change in sensing methods or the agricultural season.

2.2. Methods of Results Analysis in Environmental Projects

Analyzing results requires adopting a scientific approach that links numerical data to spatial phenomena. These methods include:

1. Spatial Statistical Analysis:

Used to measure the relationships between environmental variables, such as the correlation between population density and air or water pollution levels.

Tools used include:

- ❖ **Moran's I:** To measure spatial clustering or dispersion.
- ❖ **Hot Spot Analysis:** To identify environmentally "hot" areas with statistically significant high or low values.

2. Temporal Analysis: Compares spatial data across different time periods to identify trends of change.

Example: Tracking urban expansion in cities over 20 years using Landsat imagery.

3. Comparative Analysis: Compares the results of different studies or regions to highlight environmental discrepancies.

Example: Comparing two regions regarding groundwater pollution rates or soil slope.

4. Qualitative Analysis: Relies on interpreting spatial phenomena through maps, satellite imagery, and field descriptions, such as assessing the impact of urban sprawl on natural habitats.

2.3. Representing Results with Maps and Graphs

Maps are the primary language through which GIS results are translated into a comprehensible visual format.

Methods for representing results include:

- ❖ **Thematic Maps:** Such as land cover maps, pollution maps, or slope maps.
- ❖ **Temporal Maps:** Illustrate changes in a phenomenon across different periods (e.g., before and after urban expansion).
- ❖ **Graphs:** Such as bar or line graphs that display numerical changes in environmental values.
- ❖ **Pie Charts:** To illustrate land use percentages or vegetation cover proportions.

It is highly recommended that maps are designed with correct cartographic standards regarding colors, scale, title, and legend. Colors should accurately represent the phenomena (e.g., green for vegetation, blue for water, red for urban areas).

2.4. Preparing Scientific Reports for Project Results

Preparing a scientific report is the stage where analysis and findings are integrated into a comprehensive scientific document.

The report typically consists of the following sections:

- A. Executive Summary:** Briefly outlines the environmental problem and the main findings.
- B. Project Introduction:** Clarifies the study's objective and its environmental significance.
- C. Methodology:** Describes the analysis tools, data types, and satellite imagery used.
- D. Results and Analysis:** Includes maps, tables, graphs, and their detailed interpretations.
- E. Discussion:** Interprets the results and links them to previous studies and scientific literature.

F. Conclusions and Recommendations: Proposes environmental solutions or future policies.

G. References List: Documents all sources and data used according to the APA 7th edition citation style.

2.5. Documenting Data and Sources

Data documentation is essential in every GIS and RS project to ensure credibility and data reusability.

Specific details must be mentioned, such as:

- Data Source: (e.g., USGS, Copernicus, OpenStreetMap).
- Data Type: (Vector, Raster).
- Spatial and Temporal Resolution.
- Date of Data Acquisition.
- Software Used: (e.g., QGIS, SNAP, ENVI).

It is preferable to include an appendix table in the report containing these details for every data layer utilized.

Through this session, students learn how to transform data and analyses into a comprehensive spatial scientific narrative told through maps and reports.

The final session will be dedicated to presenting these projects and discussing their results with peers, an exercise that simulates the experience of researchers at specialized scientific conferences.



ENVIRONMENTAL RESULTS ANALYSIS IN GIS & REMOTE SENSING



— TRANSFORMING SPATIAL DATA INTO ENVIRONMENTAL UNDERSTANDING —

After performing spatial analysis and environmental assessments, the next crucial step is to analyze results, interpret patterns, and extract meaningful insights for better environmental decision-making.

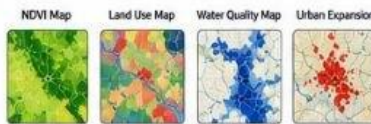
WHY RESULTS ANALYSIS IS IMPORTANT

- Supports evidence-based decisions
- Reveals spatial and temporal patterns
- Identifies risks, problems, and opportunities
- Guides sustainable resource management
- Helps policymakers and stakeholders

1 SPATIAL ANALYSIS RESULTS



- Perform spatial analysis using GIS & Remote Sensing tools.
- Generate maps, indices, statistics, and outputs.



2 ENVIRONMENTAL INTERPRETATION



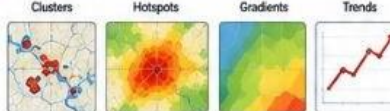
- Interpret the results in the context of environmental conditions.
- Understand what the patterns and values mean.



3 PATTERN RECOGNITION



- Identify spatial patterns such as clusters, trends, and hotspots.
- Use maps, charts, and spatial statistics.



4 TREND IDENTIFICATION



- Analyze changes over time to identify increasing or decreasing trends.
- Compare different time periods.



5 SCIENTIFIC CONCLUSIONS



- Draw conclusions based on evidence and analysis.
- Relate findings to environmental issues and research questions.



6 ENVIRONMENTAL DECISION SUPPORT

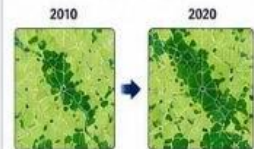


- Apply findings to support planning, management, and policy decisions.
- Propose solutions and future actions for sustainable development.

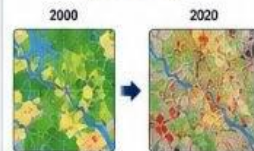


EXAMPLE APPLICATIONS

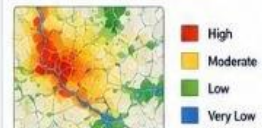
NDVI CHANGE ANALYSIS (2010 - 2020)



LAND USE CHANGE DETECTION (2000 - 2020)



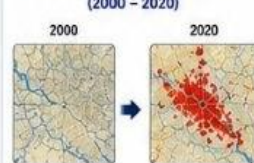
AIR POLLUTION ASSESSMENT (PM2.5 CONCENTRATION)



WATER QUALITY ASSESSMENT



URBAN EXPANSION MONITORING (2000 - 2020)



TYPES OF ANALYSIS OUTPUTS

MAPS



- Thematic Maps
- Risk Maps
- Change Maps
- Suitability Maps

SATELLITE IMAGERY



CHARTS & GRAPHS



- Bar Charts
- Line Graphs
- Pie Charts
- Histograms

STATISTICAL TABLES

Class	Area (km ²)	Percentage (%)
Forest	1250.5	35.6
Agriculture	1420.2	40.4
Urban	680.3	19.4
Water	160.7	4.6
Total	3511.7	100.0

INDICES & INDICATORS



BEST PRACTICES FOR RESULTS ANALYSIS

- Use accurate and reliable data
- Apply appropriate analysis methods
- Interpret results in context
- Validate with field data when possible
- Communicate results clearly
- Use appropriate visualizations

FROM DATA TO DECISIONS



TOOLS & SOFTWARES



OULAD HEDDAR Meriem



SPATIAL STATISTICS AND HOT SPOT ANALYSIS



DISCOVERING HIDDEN SPATIAL PATTERNS IN ENVIRONMENTAL DATA

Spatial statistics helps us understand how environmental variables are distributed across space so we can identify clusters, trends, and high-risk areas for better decision-making.

1 MORAN'S I MEASURE SPATIAL CLUSTERING

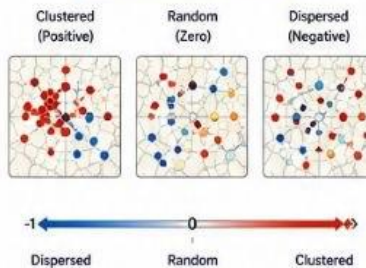


- Moran's I measures spatial autocorrelation to determine if values are clustered, dispersed, or random.
- Values range from -1 to +1.

MORAN'S I VALUES

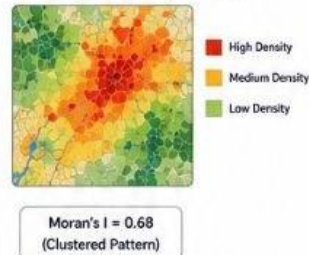
- > 0 : Clustered
- = 0 : Random
- < 0 : Dispersed

SPATIAL AUTOCORRELATION PATTERNS



EXAMPLE APPLICATION

Population Density Clustering



TOOLS IN GIS

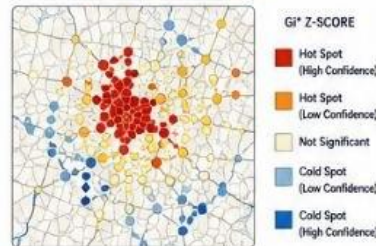


2 HOT SPOT ANALYSIS IDENTIFY HIGH-RISK AREAS



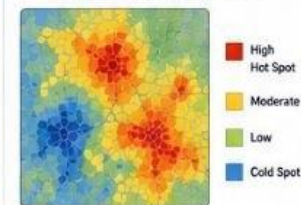
- Hot Spot Analysis identifies statistically significant clusters of high (hot) and low (cold) values.
- Helps prioritize areas that need attention or action.

HOT SPOT ANALYSIS MAP



EXAMPLE APPLICATION

Air Pollution (PM2.5) Hot Spots



TOOLS IN GIS

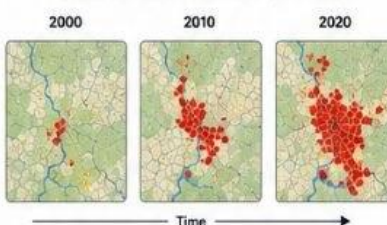


3 TEMPORAL ANALYSIS TRACK ENVIRONMENTAL CHANGE



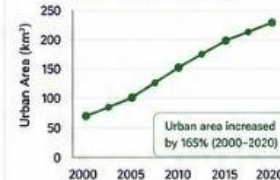
- Temporal analysis compares spatial data across time to identify changes and trends.
- Useful for monitoring urban growth, deforestation, water bodies, and more.

URBAN EXPANSION OVER TIME (2000 - 2020)



EXAMPLE APPLICATION

Urban Growth Monitoring



TOOLS IN GIS



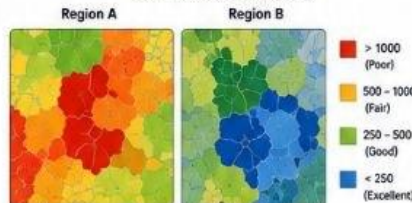
4 COMPARATIVE ANALYSIS COMPARE MULTIPLE REGIONS



- Comparative analysis compares environmental conditions between different areas.
- Helps identify differences and best practices.

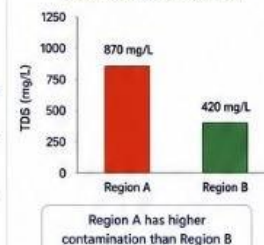
GROUNDWATER QUALITY COMPARISON

Total Dissolved Solids (mg/L)



EXAMPLE APPLICATION

Water Quality Comparison



TOOLS IN GIS



BENEFITS OF SPATIAL STATISTICS & HOT SPOT ANALYSIS



ANALYZE • INTERPRET • UNDERSTAND • ACT

OULAD HEDDAR Meriem

3. Final Presentations and Workshop Geographic Information Systems (GIS) and Remote Sensing for the Environment Course

3.1. General Introduction: The Conclusion as a Culmination of the Scientific Journey

Represents the concluding phase of the course. It is not merely a review of **the content but an evaluation and cognitive integration workshop** that bridges what students have learned theoretically and practically over the preceding weeks.

In this session, the final projects prepared by the students are presented and collectively analyzed. The discussion focuses on how to translate academic knowledge into practical tools for solving real-world environmental problems.

This week functions as what is known in international universities as a **Capstone Workshop**, where students interact as professionals rather than just learners. They present their environmental analyses supported by digital maps, satellite imagery, analytical models, and Geospatial Artificial Intelligence (**GeoAI**) indicators.

3.2. Comprehensive Course Evaluation: From Knowledge to Skill

The session begins with a collective evaluation panel supervised by the professor, reviewing the core phases of the course: from **fundamental GIS concepts**, through **spatial analysis**, **remote sensing**, and **satellite image processing**, **culminating in GeoAI applications** and **integrated environmental analysis**.

Each student is asked to briefly describe how their skills have evolved in:

- Analyzing spatial data.
- Interpreting satellite imagery.
- Designing thematic maps.
- Applying environmental indices such as NDVI or NDBI.
- Utilizing classification tools, temporal analysis, and predictive modeling.

Reflective questions are also posed, such as:

How can GIS be employed to protect natural resources in your country?

What were the most prominent challenges faced during fieldwork or data processing?

3.3. Review of Artificial Intelligence and Environmental Analysis Concepts

Before proceeding to the final presentations, a brief segment is dedicated to reviewing the **concepts of Artificial Intelligence in geospatial environmental analysis (GeoAI)**. This serves to assess the students' comprehension of integrating these cutting-edge technologies into geoinformatics.

The discussion encompasses:

- ✚ Machine Learning algorithms in satellite image analysis, such as Random Forest and Support Vector Machine (SVM).
- ✚ Deep Learning applications for the automated recognition of environmental change patterns.
- ✚ The significance of AI in predicting climate change and monitoring natural hazards like floods and forest fires.

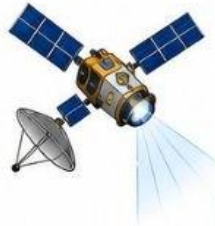
Furthermore, applied examples from recent international research are reviewed, such as the **European Space Agency's Copernicus AI Lab project**, which utilizes AI to analyze Sentinel data for monitoring marine pollution and vegetation cover dynamics.

3.4. Lessons Learned from the Course

During this concluding discussion, students deduce the **connections between concept and application**, reviewing how digital geographic tools have contributed to understanding complex environmental issues.

Key lessons learned include:

- The environment is an interconnected spatial system that can be deeply understood through multi-source data analysis.
- Satellite imagery is not merely an observational tool, but an analytical instrument capable of predicting future transformations.
- AI minimizes processing time and enhances accuracy in detecting environmental patterns.
- Producing a successful map or analytical model requires scientific understanding, critical thinking, and professional ethics in data handling.

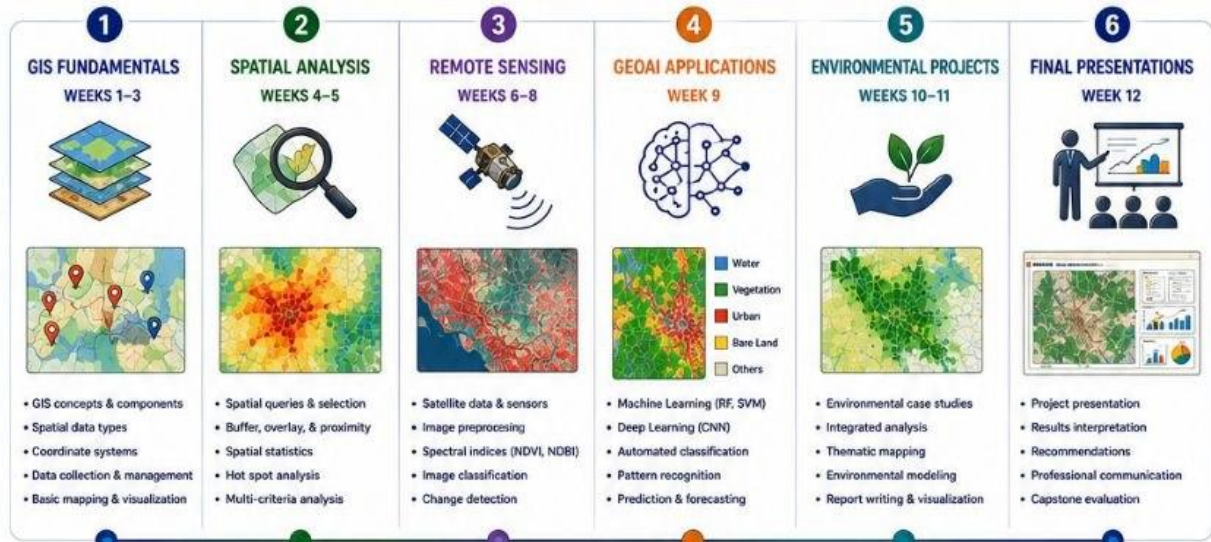


THE GIS & REMOTE SENSING LEARNING JOURNEY

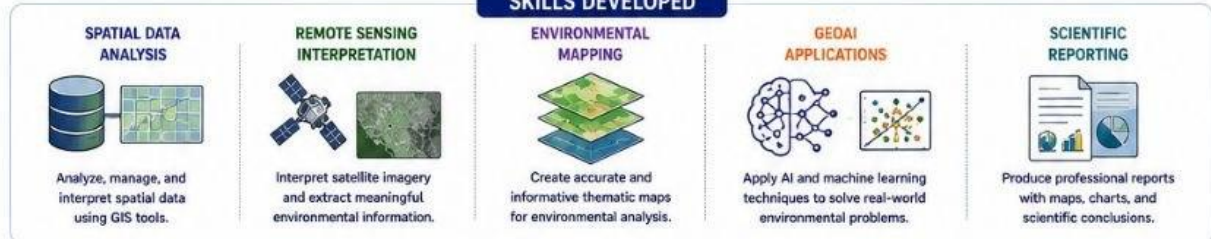


A CAPSTONE WORKSHOP EXPERIENCE

A 12-week transformative journey from foundational concepts to advanced GeoAI applications, environmental analysis, and professional project presentation.



SKILLS DEVELOPED



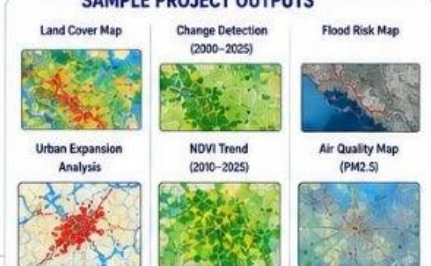
WHAT YOU LEARNED EACH WEEK



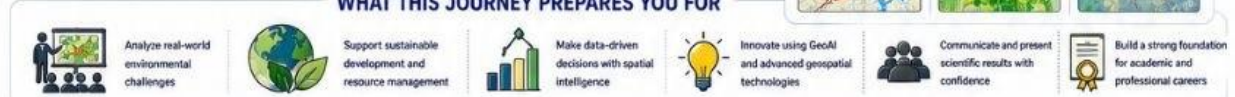
TOOLS & TECHNOLOGIES USED



SAMPLE PROJECT OUTPUTS



WHAT THIS JOURNEY PREPARES YOU FOR



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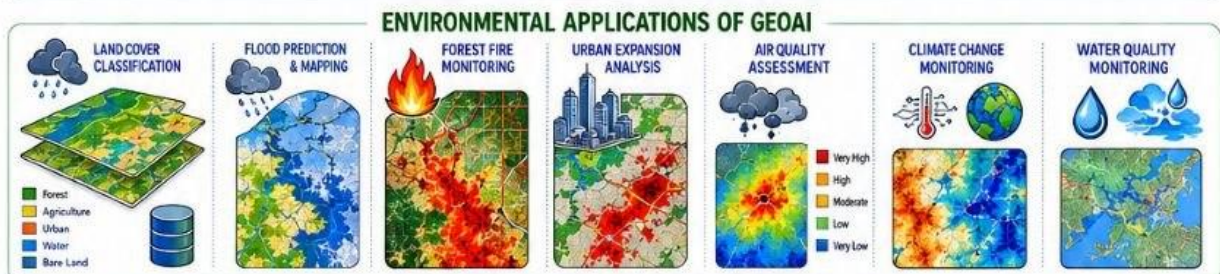
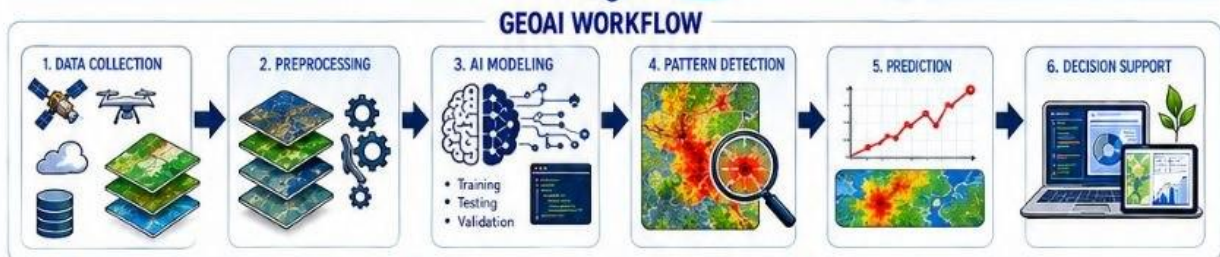


GEOAI AND ENVIRONMENTAL INTELLIGENCE

ARTIFICIAL INTELLIGENCE TRANSFORMING ENVIRONMENTAL ANALYSIS



GeoAI combines Geographic Information Systems, Remote Sensing, and Artificial Intelligence to understand, predict, and manage environmental changes more accurately and efficiently.



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