Geographic Information Systems (GIS)

The GIS is a comprehensive software created for generating, collecting, storing, processing, controlling, and displaying any kind of geographical information. Such systems are regarded as crucial resources for the geoinformatics scientific field. GIS employs basic concepts from geography, cartography, and geodesy to enable users to create queries, present data in maps, analyze spatial data, and display the outcomes of every part of the selected features on raster maps.

The data overlay is a structural feature of GIS. Every type of data has a unique data layer. GIS enables the analysis and fusion of numerous data layers to produce final data and deliverables. The ability to create final thematic digital maps that respond to user needs is provided by the integration of several data layers (Figure 2.2).

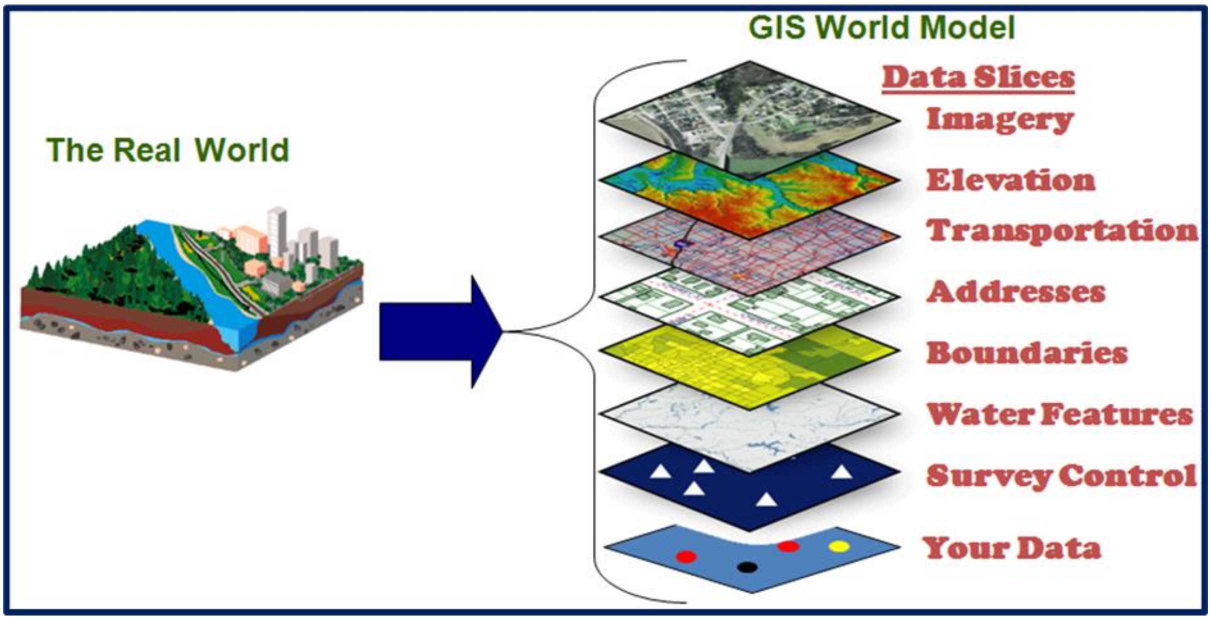


Figure (1): Overlay various data layers in GIS.

Functionalities of GIS

- GIS Data input, storage and retrieval
- Data manipulation and analysis
- Data output/display or visualization
- Database management

GIS Components

Five essential components make up a GIS as an integrated system:

1) **Hardware** (computers, scanners, and servers).
2) **Software** (GIS application, operating system).
3) **Users** (Users with varying privileges who provide service, coordinate operations, define final products, and analyze data, in addition to end consumers).
4) **Supported data types** (any spatial data of raster and vector types).
5) **Procedures** (such as data management, input/capture, modeling, and geographical analysis).

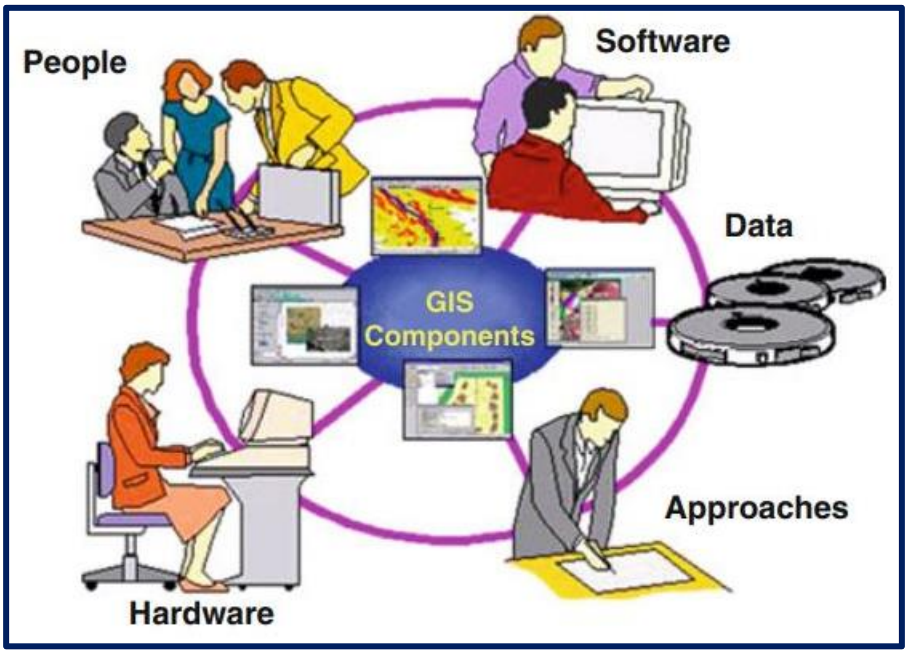


Figure (2): GIS basic components (Kolios et al., 2017).

GIS Software

GIS software offers the features and resources required to store, process, and present geographic data. The following are regarded as essential GIS software components (Kolios et al., 2017):

- ❖ Tools and menus for managing and importing geospatial information.
- ❖ A database management system (DBMS) for organizing and storing geographic data.
- ❖ Tools for spatial analysis, visualization, and geographic inquiries.
- ❖ A graphical user interface (GUI) that allows users to access tools with ease.

Supported Types of Data

All kinds of data can be gathered and analyzed using a GIS. which falls into two broad categories: vector data and raster data (Kolios et al., 2017).

A. Vector data type: The data are saved as points, lines, and polygons in the vector data type. Compared to the raster format, less computer memory is required and more location accuracy is offered. Data with distinct spatial boundaries, such as street boundaries, land parcels, and country borders, can be stored using the vector data type. The vector data type accurately measures and displays object coordinates when compared to ground measurements.

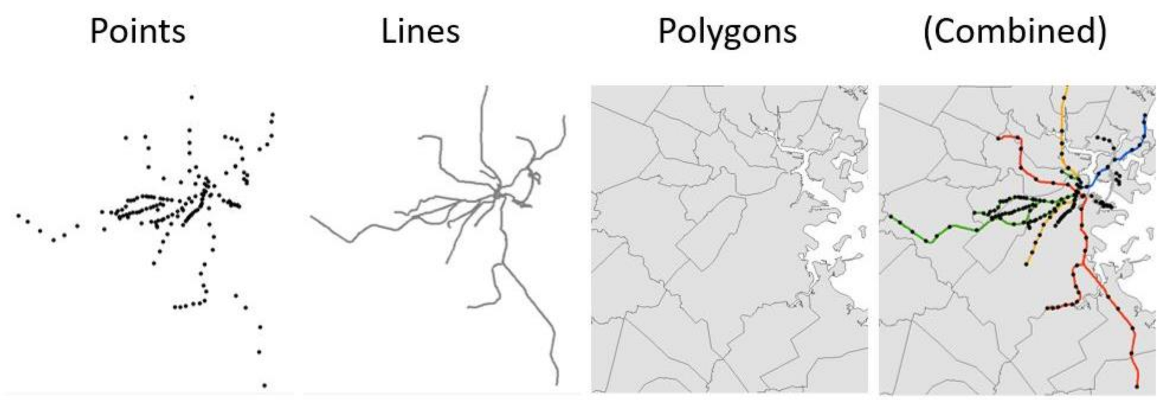


Figure (3): Object types portrayed by the vector data type.

B. Raster data type: Raster data types allow for certain types of operations that the vector data types did not provide since the data is represented by pixels with values, forming a grid. Raster data can be used to store continuously changing data, such as that seen in aerial photos, satellite images, chemical concentration surfaces, and elevation surfaces. A regular two-dimensional (2D) grid of cells makes up raster data (pixels). It is also possible to arrange raster data in three dimensions. In this instance, the 3D cell gets transformed into a cube (a voxel). Raster data's geometric correctness is constrained by its pixel resolution. A realistic depiction of the world can be produced by combining raster and vector data types.

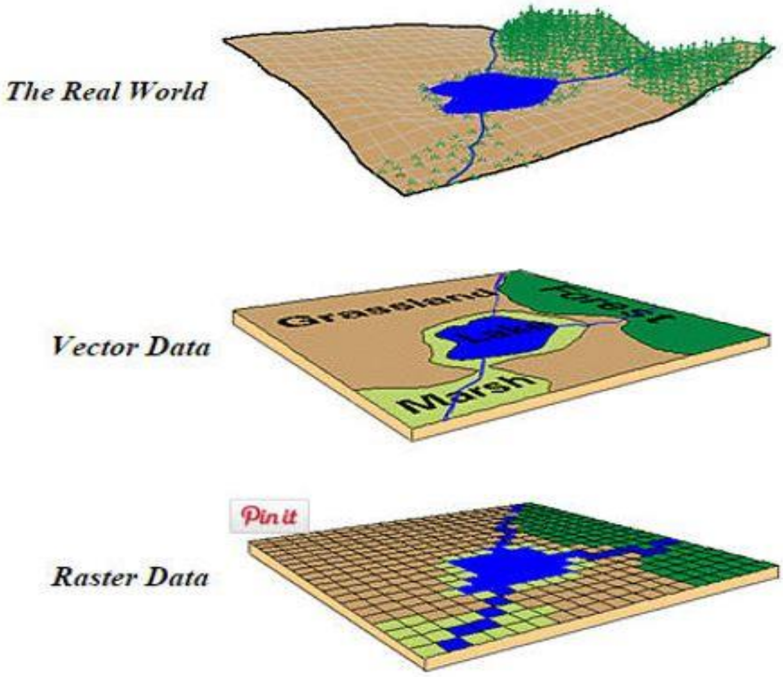


Figure (4): Vector and Raster data type.

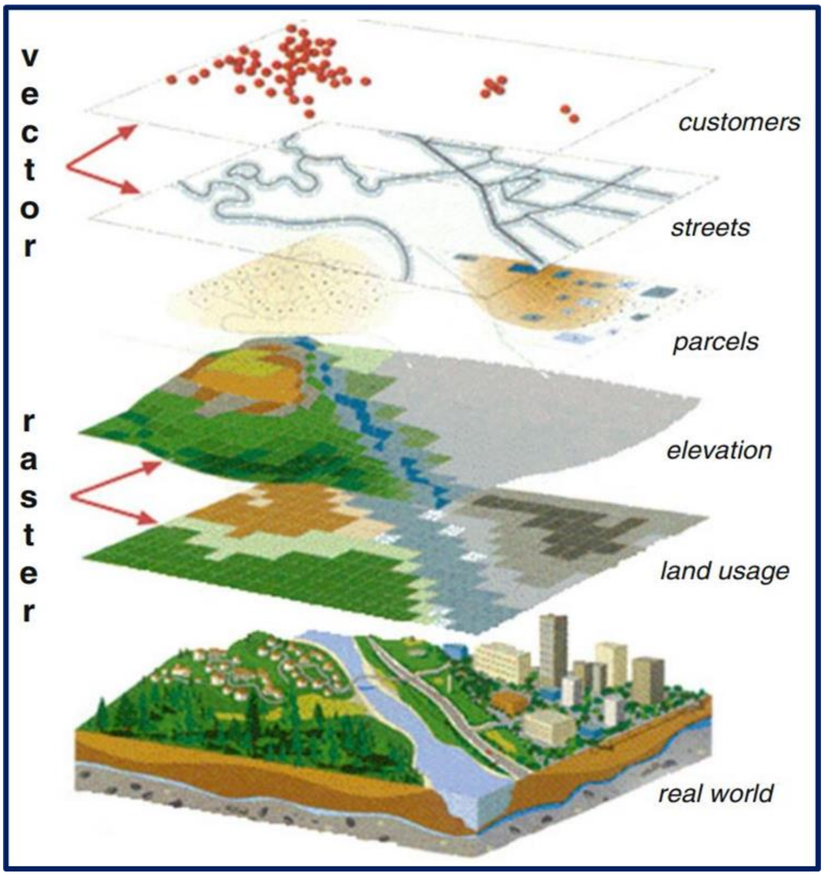


Figure (5): Combine vector and raster data sets to represent the real world.

GIS Capabilities and Procedures

- The main characteristics of a GIS are **the geographic dimensions and labels** that are given to all the different kinds of data that are handled by these systems.
- **Latitude**, **longitude**, and **elevation** are the geographic coordinates that define the physical objects in space (geolocation), giving the data representation accurate dimensions.
- In addition to the GIS's capability to provide geographical dimensions for any spatial information, such systems can perform a broad variety of operations and procedures such as **Spatial Interpolation**.

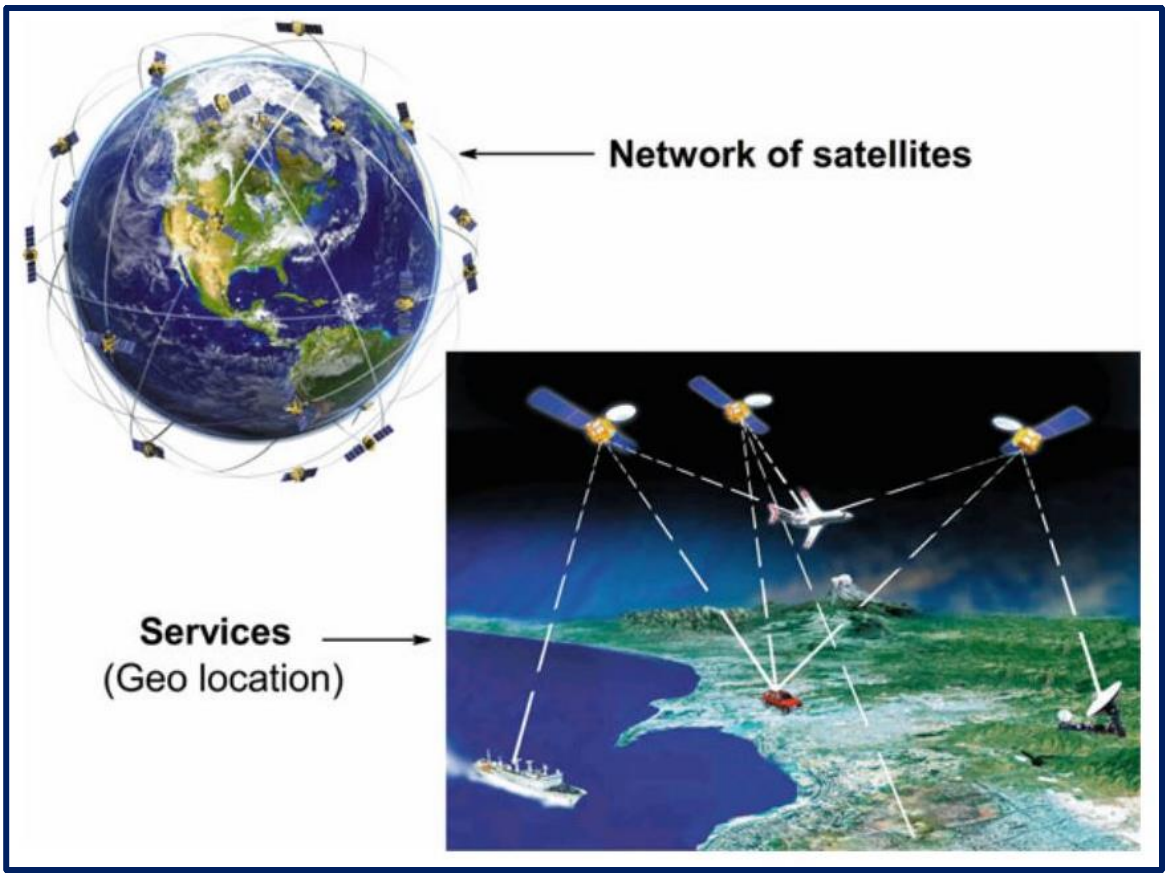


Figure (6): Utilization of satellite networks for the global provision of precise geolocation services (Kolios et al., 2017).

Spatial Interpolation

Spatial Interpolation is the technique of estimating unknown values of points using points with known values. It calculates the unknown values of any geographic point dataset, including elevation, precipitation, atmospheric chemical component concentrations, noise levels, etc. There are numerous interpolation techniques, which can be categorized into deterministic and geostatistical categories.

1. **Deterministic**

The mathematical functions that are employed in the deterministic technique to generate the values at unknown places are based either on the level of similarity or the level of smoothing for surrounding data points. The Inverse Distance Weighting (IDW) approach and Radial Basis Functions (RBF) are representative instances of deterministic methods.

The Inverse Distance Weighting (IDW) Method.

Unidentified data at one selected point can be estimated using IDW. Greater influence on the projected values will come from points nearer the forecast site than those from points more distant. The IDW method has irreplaceable advantages for modeling the water quality of rivers because the IDW has high accuracy compared with other methods. The IDW has adopted the following equation:

$$\mathbf{P_o} = \frac{\sum_{i=1}^{m} \mathbf{P_i} \, \frac{1}{\mathbf{D_i^S}}}{\sum_{i=1}^{m} \frac{1}{\mathbf{D_i^S}}}$$

Where; P_o is the required projected value, P_i is the defined value entered to calculate P_o, D_i is the distance between p_i and p_o, m is the number of defined values employed in estimation, and S is the given power (more than 1).

2. Geostatistical

To predict values at every location within a region of interest, geostatistical methods combine statistical and mathematical methods. These methods not only produce spatial estimation but also probability output maps. One of the most well-known and often applied geostatistical techniques is the Kriging method.

The Kriging Method.

One of the most used geostatistical techniques. The sampled data are interpreted as the outcome of a random process. In general, points closer to the location of interest are given greater weight than points further away and applied using the following formula:

$$\mathbf{Z_o = \sum_{i=1}^{n} \lambda_i \, Z_i}$$

Where; Z_o is the estimated value of an unknown point, Z_i is the Z value of known point i, λ_i is the weight for point i, and n is the number of known points used in estimation.

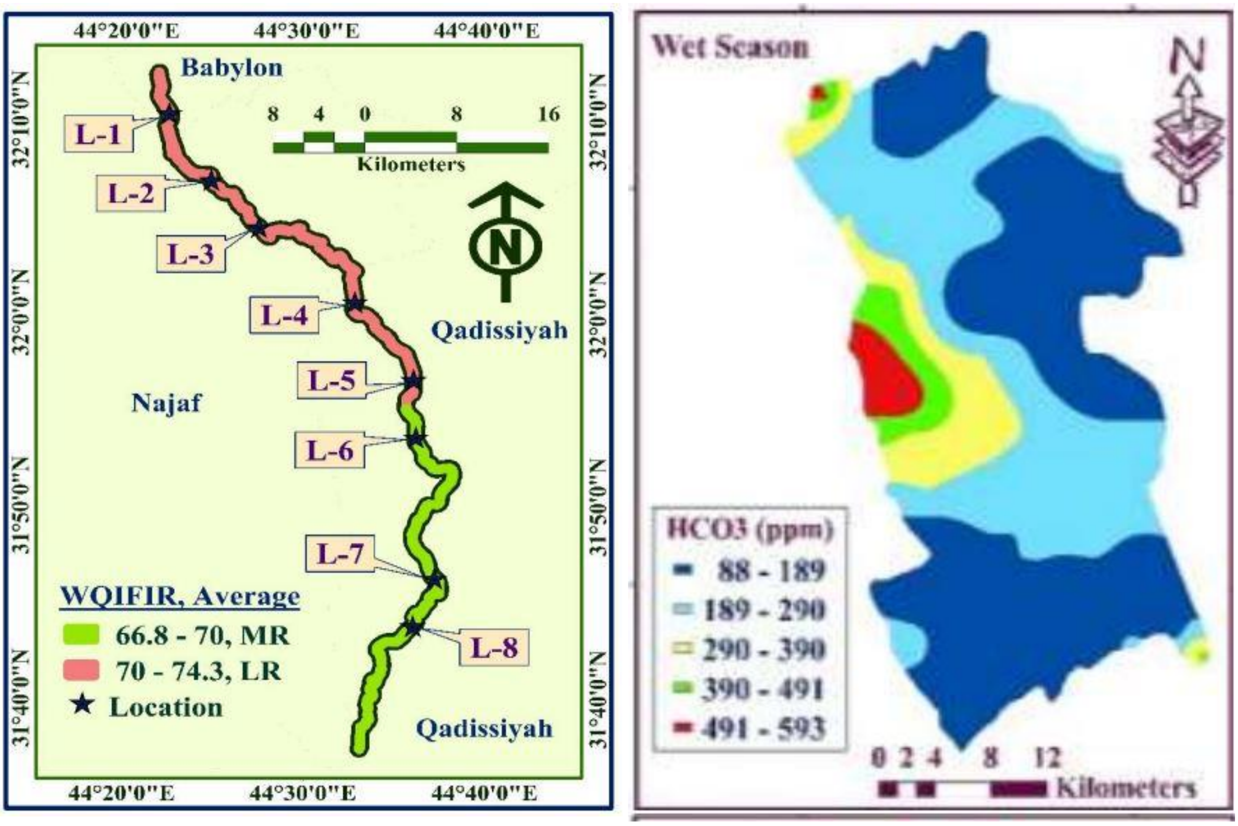


Figure (7): Using spatial interpolation techniques to produce spatial distribution maps using GIS.

GIS Applications in the Environmental Monitoring

GIS plays role in environmental monitoring, modeling, and evaluation because it provides potent computer mapping and analyses capable of integrating massive quantities of spatial data. Mathematical models can be connected with GIS to provide significant outputs relevant to many scientific and environmental domains. For instance, the water quality index (WQI) and geographic information system (GIS) can be used to indicate the water's state, such as excellent, good, or bad. Due to its high level of accuracy in water quality modeling, spatial interpolation techniques like inverse distance weighted (IDW) have good benefits for the assessment of data in rivers.

Examples of applications:

1. Water Resources Management:

- Use GIS to monitor water quality in rivers and groundwater.
- Analyze floods and their risks using topographic maps and hydrological data.

2. Environmental Pollution Monitoring:

- Create air and water pollution distribution maps using remote sensing data.
- Assess soil pollution using GIS techniques and analyze laboratory samples.

3. Climate Change and Desertification Assessment:

- Analyze climate change data and its impacts on agricultural lands.
- Monitor desertification in arid regions using satellite imagery.

4. Solid Waste and Waste Management:

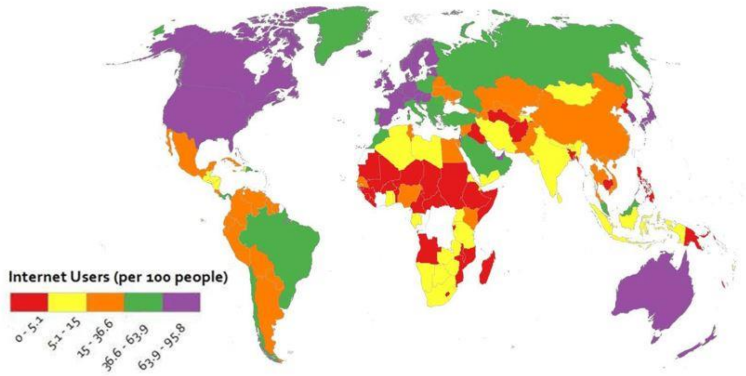
- Identify the best locations for waste treatment plants according to environmental standards using GIS.

5. Environmental Planning and Land Management:

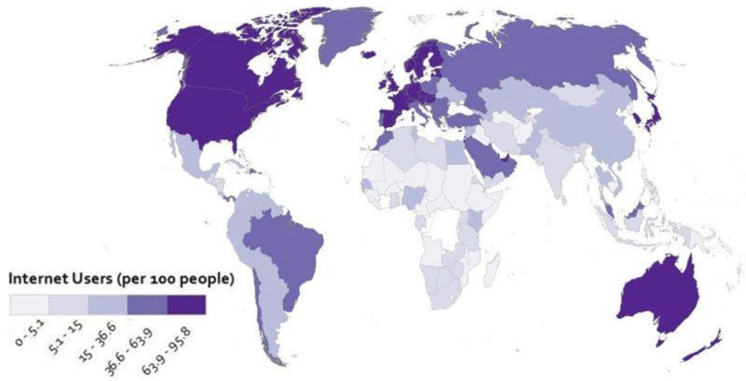
- Analyze land uses and identify environmentally sensitive areas to protect them from degradation.

Choosing Color

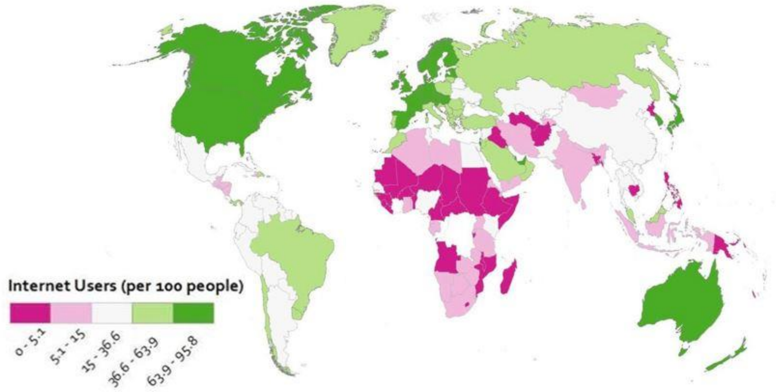
Qualitative Color Example



Sequential Color Example



Diverging Color Example



Remote Sensing

It is the process of obtaining information about objects and phenomena on the surface of the Earth by collecting data and information without the need for a direct presence on the site. This is done by using sensors and tools such as satellites and drones.

It is used in applications such as environmental monitoring, natural resource management, weather forecasting, climate change monitoring, natural disaster monitoring, agricultural activity monitoring, land analysis, aerial photography, military reconnaissance, and others.

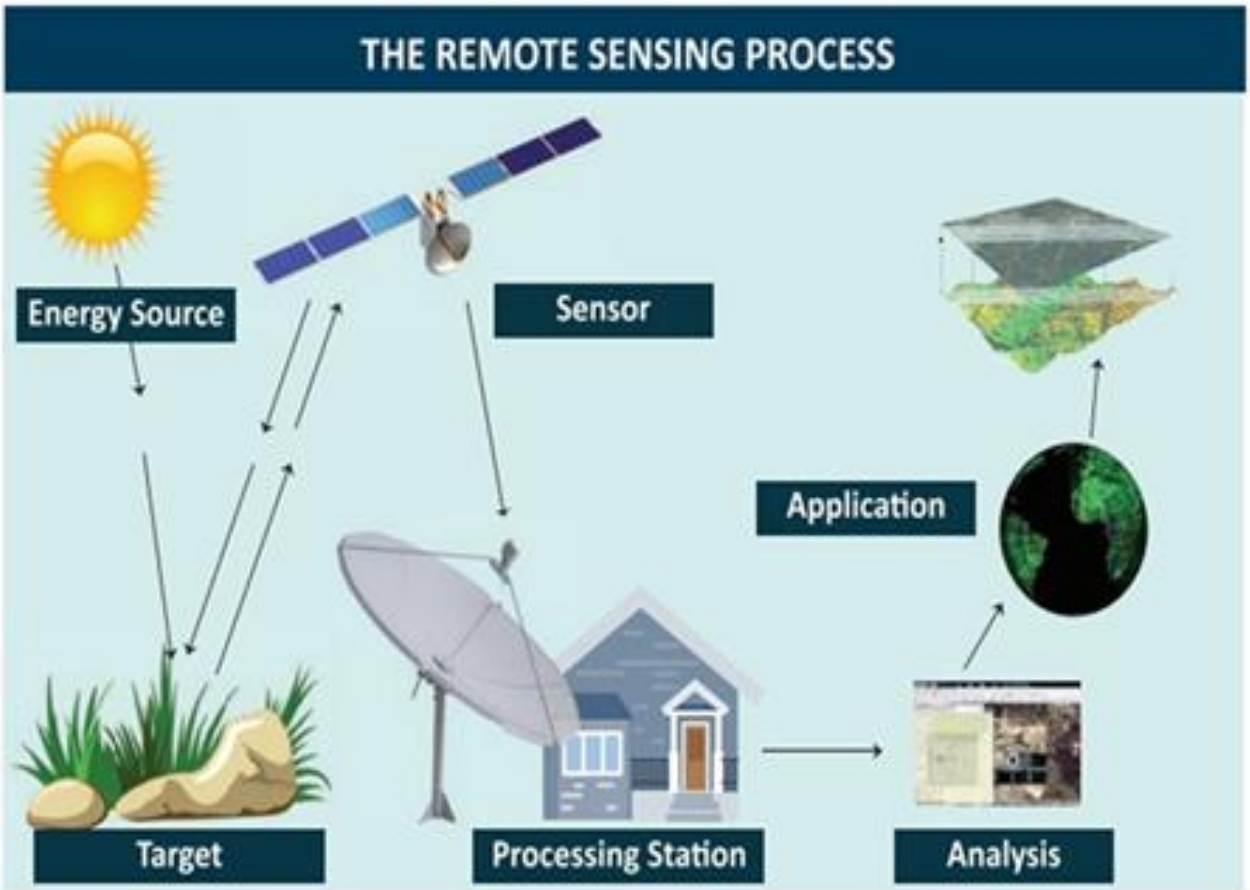


Figure (8): The Remote Sensing process.

Data collection techniques

1. **Aerial photography**: Using cameras installed on airplanes or drones to take aerial photos.

2. **Television and video sensing**: Cameras and television devices are used to record images and video. They can be used in urban monitoring, agriculture, geography, environment and other applications.

3. **Radar**: Using radio waves to determine distances, speeds, and other information about targets.

4. **Satellites**: They are used to collect various information such as photography, surveying, climate measurements, etc.

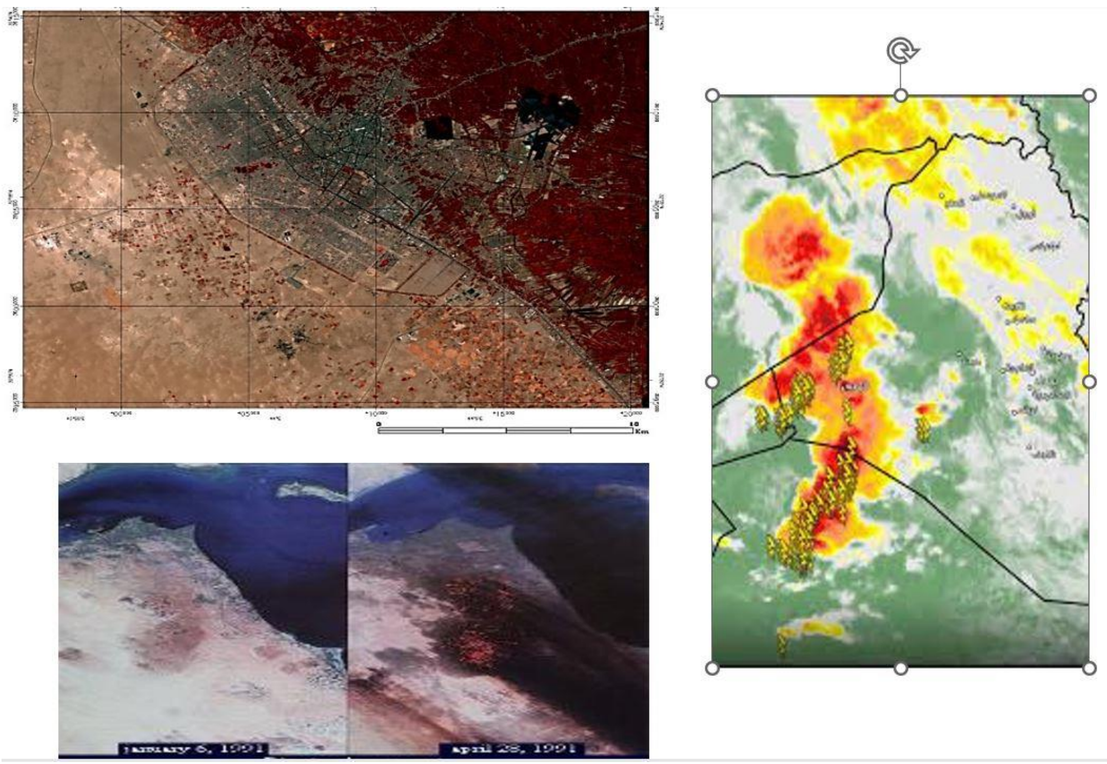


Figure (9): Data collection techniques

Data processing and analysis

1. Calibration

Adjusting and adjusting measured values from sensors to ensure data accuracy by comparing sensor signals to previously known metrics to obtain correct calibration values such as noise caused by light, heat, and temporal variations in performance.

2. Geometric Correction

It aims to correct geometric and spatial aberrations in the sensed data, as well as fix geometric distortions that occur due to factors such as the curvature of the Earth's surface and lens aberrations. Mathematical models and image processing are used to identify and correct these aberrations and ensure that the sensed information matches geographic reality

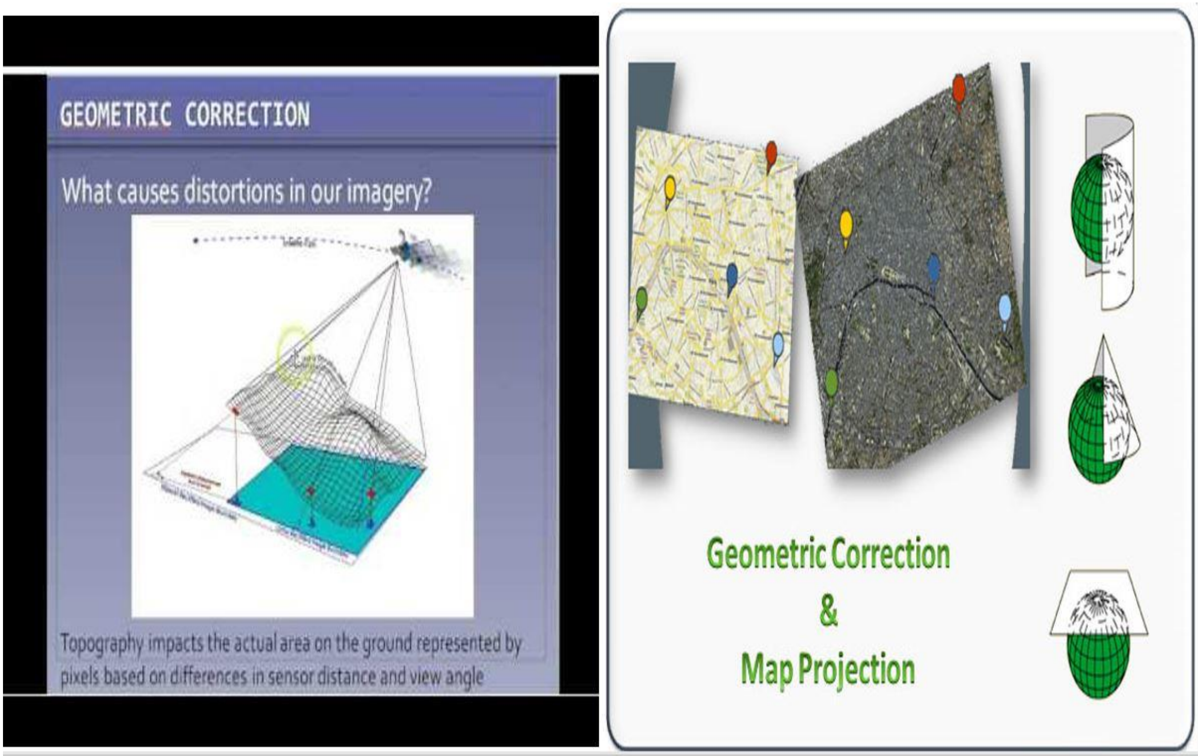


Figure (10): Geometric Correction.

Remote sensing applications

1. Land cover change detection and land use mapping
2. Monitoring climate change and air quality
3. Monitoring oceans and coasts
4. Water quality monitoring
5. Forest fire monitoring
6. Crop mapping and monitoring
7. Forecasting the yield of agricultural fields
8. Monitoring volcanic activity
9. Flood monitoring
10. Drought monitoring and forecasting
11. Urban planning and urban growth monitoring