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Introduction

A Geographic Information System (GIS) offers for students the opportunity to learn about complex geographical information. This knowledge is particularly beneficial for grasping the spatial relationships among different factors like land elevation, soil characteristics, and hydrological patterns, which are crucial for designing efficient and long-term hydraulic systems. Consequently, GIS serves as a multidisciplinary field that aids students in gaining a comprehensive insight into its real-world implications for addressing hydraulic challenges such as water resource allocation, flood vulnerability evaluation, and hydraulic simulation.

With this document, the author aims to offer an insight into the fundamental concepts of GIS and its actual applications in the field of water science. To achieve this goal, the document is organized as follows:

- Chapter one defined GIS, and traces a brief historical development of these systems.

- Chapter two examines the various methods and techniques used to represent data in GIS.

- Chapter three explores GIS analysis processes and the tools commonly utilized in softwares for these analyses.

- Chapter four focuses on remote sensing, which involves gathering information about objects or areas from a distance, primarily through sensors on satellites, aircraft, or ground-based stations.

- Finally, chapter five showcases the practical applications of GIS and remote sensing technologies in the field of water science, highlighting their significance in the study and management of water resources, ecosystems, and related environmental issues.

Chapter 1: Geographic information system (GIS)

1 GIS acronym

The term GIS stands for Geographic Information System (figure 1) is an effective tool that combines various maps to facilitate understanding and analysis of geographic data. This capability enables the resolution of issues and the enhancement of decision-making processes.

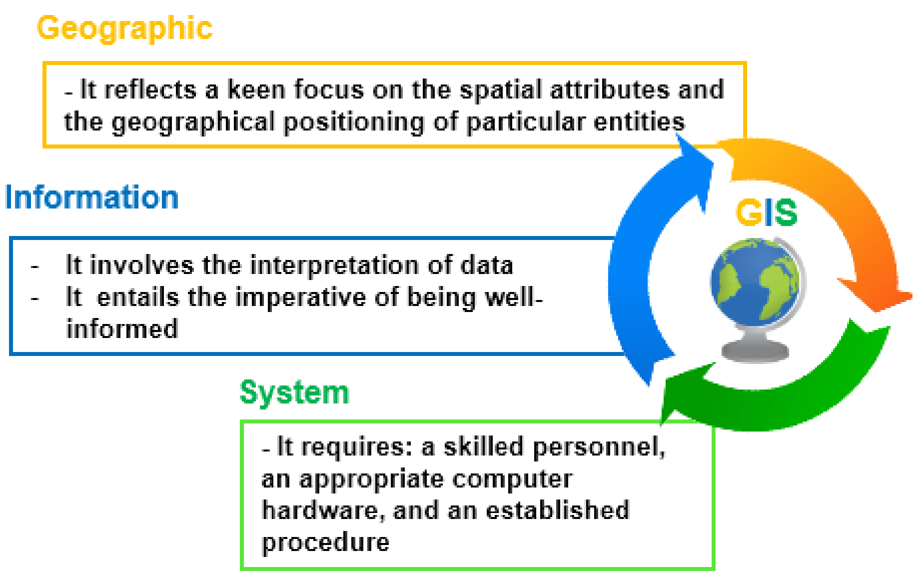


Figure 1: GIS acronym

2 Definitions

Many definitions of GIS have been proposed according to its functions and tasks.

- According to the online resource GIS Lounge, GIS is indeed, a technological field that integrates geographic features and tabular data to facilitate mapping, analysis, and assessment of real-world problems by combining location-based data with attributes,
- As defined by (Goodchild, 2002), GIS is a powerful tool for linking spatial locations to attributes or data about those locations. The tuple of "x,y" represents the spatial coordinates (longitude, latitude) that define a specific location on the Earth's surface.

These coordinates serve as fundamental elements for capturing and organizing spatial information within a GIS.

- According to the National Aeronautics and Space Administration (NASA), GIS is an integrated system comprising computer hardware, software, and skilled personnel. This system connects various types of geographically referenced data, including topographic, demographic, utility, facility, image, and other resource data.

From a technical perspective a GIS is a:

- Computer-based tool that is used for mapping and analyzing various elements and occurrences on Earth. GIS technology combines standard database functions, such as querying and statistical analysis, with the distinctive advantages of visualization and geographic analysis provided by maps. This integration of capabilities is often attributed to the Environmental Systems Research Institute (ESRI).
- Comprehensive digital tool comprising both hardware and software components specifically crafted for the spatial analysis and modelling of cartographic data. It facilitates a wide array of functions within a geospatial context, all aimed at the control and strategic planning of the socio-economic environment. (Longley & Batty, 1997)
- Computer system with the capability to gather, store, manipulate, and present geographically referenced information, which means data identified based on their specific locations. Practitioners also consider the entire GIS ecosystem to encompass the personnel operating the system and the data utilized within it, as defined by the United States Geological Survey (USGS).
- Part of a larger group of information technologies that have revolutionized the research methods and societal contributions of geographers. Over the last years, these technologies have had a profound impact on the specific research techniques used in the field, as well as how geographers communicate and work together. (First, Second, & Third, 1996)

- Versatile technology that finds applications in diverse industries and fields, making it a horizontal solution that spans various sectors and areas of knowledge. (Tomlinson, 2007)

GIS can be applied in many fields (see figure 2):

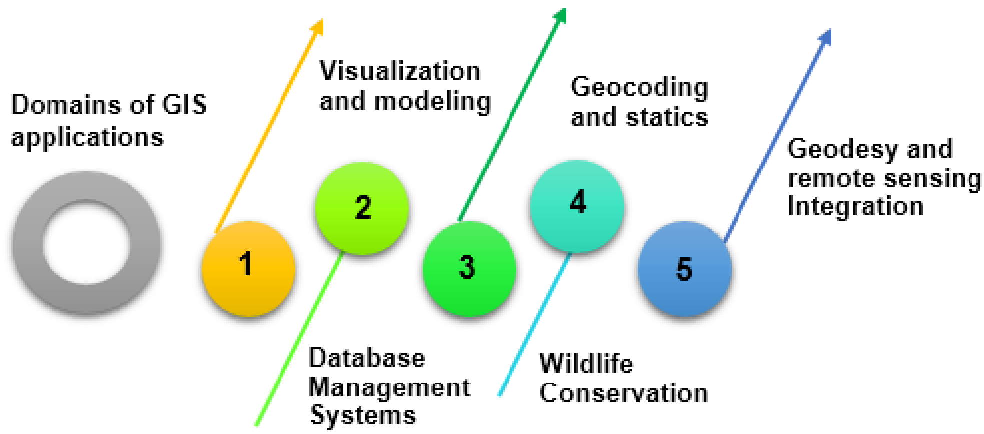


Figure 2: Field of application of GIS

3 *Remarkable history of GIS*

The history of GIS is characterized by significant stages of development, influenced by key individuals and advancements in technology. Below, we provide an outline of each stage in the history of GIS, highlighting its remarkable progression (figure 3).

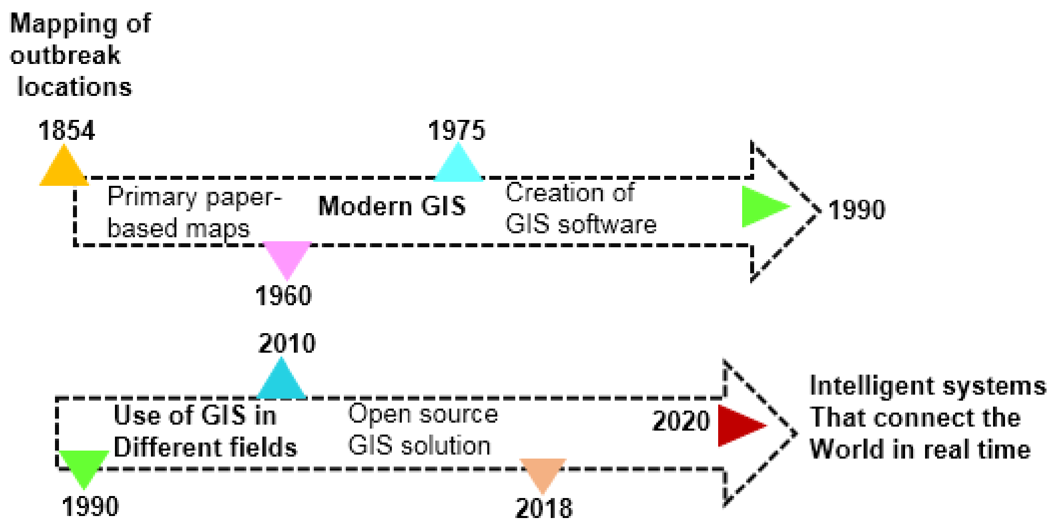


Figure 3: Evolution of GIS technology over time

- In 1854, during a cholera outbreak, Dr. John Snow challenged the prevailing belief that the disease spread through the air. He mapped outbreak locations, property boundaries, and water pumps, discovering a pattern that pointed to contaminated water from a specific pump as the source of the disease. This marked the beginning of spatial analysis and the field of epidemiology. Dr. Snow's work highlighted the power of GIS as a problem-solving tool, demonstrating how linking "what" with "where" on a map can lead to life-saving discoveries. (Biu, Nwasike, Tula, Ezeigweneme, & Gidiagba, 2024; Shiode, 2012)
- From 1854 to 1960, there was little advancement in GIS, which primarily relied on paper-based maps as computer mapping had not yet been developed. However, during the 1950s, maps started being used for purposes like: Vehicle routing, urban planning, and identifying points of interest, laying the foundation for the future development of GIS. These included the ability to output map graphics using line printers. improvements in data storage, and the increased processing power of mainframe computers, enabling the recording of coordinates as data inputs and computational operations on those coordinates. (Schulten, 2012)

- Between 1960 and 1975 modern GIS, several significant technological advancements paved the way for the birth of Key developments during this period (Taylor, 1991) included the creation of:
    - The Canadian Geographic Information System (CGIS) by Roger Tomlinson.
    - The adoption of GIS principles by the US Census Bureau.
    - The introduction of digital mapping in large-scale map production by the Ordnance Survey GB.

This era marked a critical phase in the development of GIS as a sophisticated tool for managing and analyzing geographic information.

- From 1975 to 1990, the era marked the creation of GIS software. Jack Dangermond, co-founder of Esri Inc, played a significant role in this development (Kumar, Singh, & Kaur, 2019). His background in environmental science and computer graphics led to the establishment of the first vector GIS, ODYSSEY GIS, in the mid-1970s. This period also witnessed advancements in computer memory and graphics, leading to the emergence of commercial GIS software. Esri, one of the key vendors, has since become the world's largest GIS software company and a leading expert in the field. This era was pivotal in shaping the modern GIS landscape. (EKLUND, 1977)
- Between 1990 and 2010, (GIS) experienced widespread adoption, becoming a mainstream tool. This growth was fueled by several key IT advancements, including:
    - More affordable and powerful computers.
    - A growing array of GIS software options.
    - Increased availability of digitized mapping data.
    - The launch of new Earth observation satellites and the integration of remote sensing technology further expanded GIS applications.

GIS became widely utilized in classrooms, businesses, and governments worldwide, solidifying its position as a fundamental tool in various sectors and applications.

- From 2010 to 2018, the growing use of GIS technology gave rise to open-source GIS solutions. GIS data, including resources like Landsat satellite imagery, became more accessible to a wider audience. GIS expanded its presence through online platforms, cloud-based services, and mobile applications, making it more user-friendly and widely available.

Chapter 2: Representation of data in GIS

1 GIS components

GIS is an exceptional tool with distinct functionalities, including the ability to process data linked to geographic references. It also offers spatial and attribute data entry/update capabilities, as well as conversion functions that aid in transforming information into useful formats. Moreover, it provides storage and organization for various types of spatial and attribute datasets while allowing manipulation through numerous operations. Besides this, GIS has presentation/display potentials suitable for diverse applications across industries/sectors worldwide; additionally, comes with several tools used together or independently depending on needs/preferences. There are five basic GIS components, needed for the mentioned functionalities (figure 4).

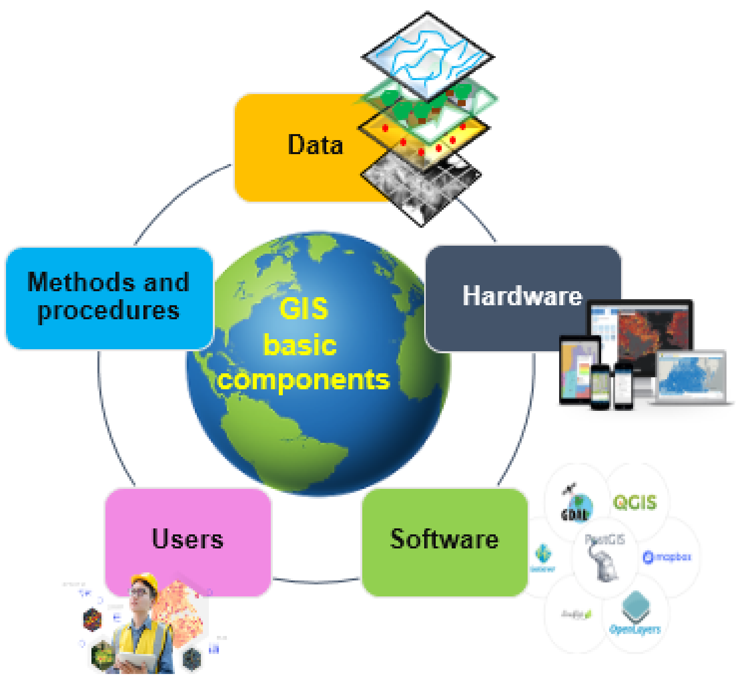


Figure 4: GIS basic components (Association, 2016)

1.1 Data

GIS are intended to integrate diverse data layers with a spatial component. This comprises not only traditional map data, but also images, features, base-maps, and non-spatial data.

Any data or information associated with geographic places is referred to as geospatial data. It contains both the geographic coordinates and any qualities or traits associated with that location. Satellite imaging, GPS devices, surveys, and remote sensing technologies can all be used to obtain geospatial data.

1.1.1 How GIS works?

Geographic Information Systems analyze and visualize information about the Earth's surface by combining spatial and attribute data. The procedure begins with data collection, in which various sources such as maps and satellite photos are georeferenced and entered into GIS software. This one, organizes and stores the data, making it available for examination via techniques such as overlaying layers and spatial querying. The analyzed data is then represented using maps and charts. It should be noted that GIS implementation can differ depending on software and user requirements. GIS data is classified into two types: raster and vector (figure 5).

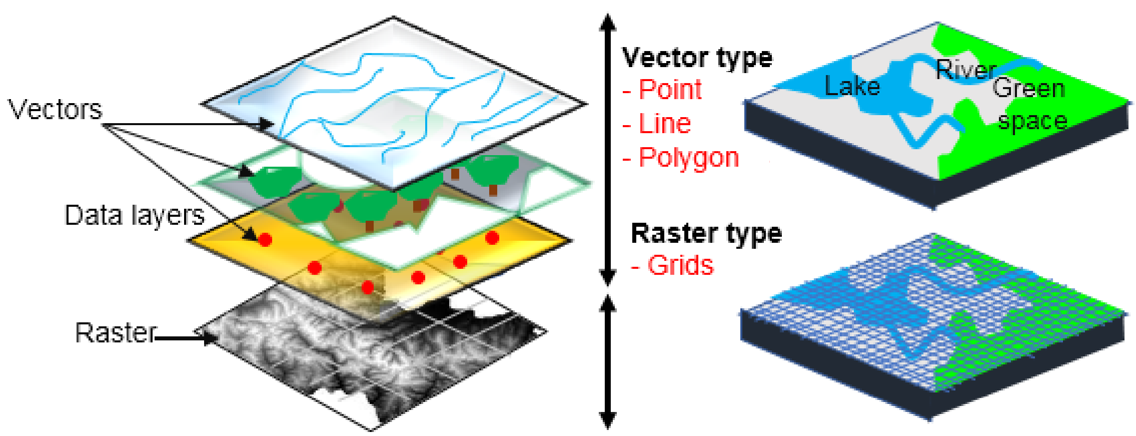


Figure 5: Data categories in GIS

1.1.2 Vector data

Vector data is a type of geospatial data that uses points, lines, and polygons to represent geographic elements (figure 6).

A: Points: the most basic type of vector data, points represent distinct locations on the Earth's surface. Their geographic coordinates define them, and they can be associated with attributes like as names, addresses, or other descriptive information. Cities, landmarks, and individual trees are all examples of point data.

B: Lines: they represent linear characteristics like roads, rivers, or boundaries. They are made up of a succession of connected points that each have their own set of properties (attributes). A road, for example, may contain properties such as road name, speed restriction, or road type.

C: Polygons: they are closed forms that have many sides that can be land parcels, administrative boundaries, or lakes built by linking a succession of points. A polygon representing a land parcel, and can be correlated with qualities for example, it may have attributes such as landowner, area, or land use category.

1.1.3 Raster data

A grid of cells or pixels is used to represent raster data. Each cell has a value that represents a different property. Here are a couple such examples:

- Elevation: A raster image depicting a terrain's elevation, with different colors denoting different heights.

- Satellite imagery: A detailed raster image of the Earth's surface acquired by satellites, including buildings, vegetation, and other characteristics (figure 6).

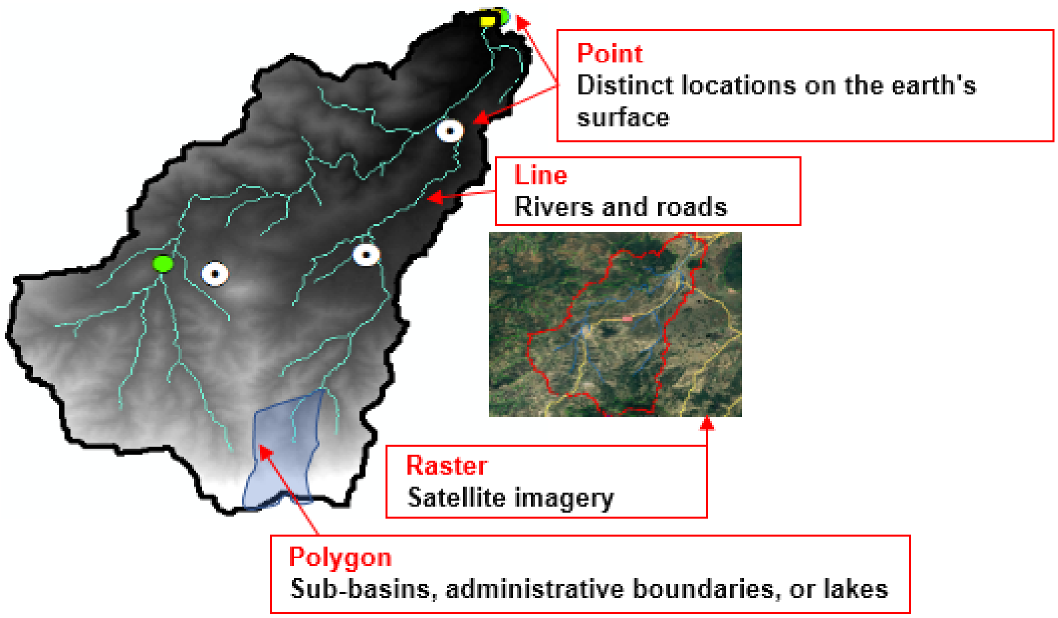


Figure 6: Example of vector and raster data

1.1.4 Sources of geographical data

Geographic data for GIS applications can be obtained from a variety of sources (table 1). Some typical sources include:

- Satellite imagery from NAS/ESA and private satellite companies.

- Aerial photographs acquired via airplanes, government agencies, survey businesses, and private corporations.

-GPS (Global Positioning System) data.

-Open data platforms, such as OpenStreetMap and data.gov.

-Data from censuses provided by government agencies.

-Data from remote sensing sources such as LiDAR, radar, and hyperspectral images.

-Maps and archives from the past.

-Social media and crowd-sourced data shared by Twitter and Instagram users.

Total station surveys and theodolite measurements are examples of land survey data.

Table 1: Satellite imagery/ topographic maps sources

Sources	Web site	Type of data
Government agencies	-US Geological Survey (USGS) -National Oceanic and Atmospheric Administration (NOAA) -Environmental Protection Agency (EPA	Free/low-cost spatial data.
Commercial data providers	-Esri -DigitalGlobe -Orbital Insight	-satellite imagery -maps - geographic information.
Open data sources	OpenStreetMap USGS Earth Explorer NASA's Earth data	free and publicly data.
Scientific research institutions	-Universities -research institutions -scientific organizations	data through research projects
Crowdsourcing platforms	-OpenAerialMap -Ushahidi -MapSwipe	Users data through volunteered geographic information (VGI).

1.2 Hardware

To make GIS operate, hardware in the form of computers is required (Powerful servers, mobile phones, or a personal GIS workstation might all be used), either freestanding or networked.

1.3 Software

GIS is essentially a piece of software that is used to store, analyze, and display information geographically. As a result, the following software components are required: tools for gathering input data, running desired queries and providing excellent visualization, system for managing databases. GUI stands for Graphical User Interface.

The selection of GIS software is determined by the specific needs, budget, and level of knowledge. Before making a decision, it's always a good idea to compare several software options. Bellow, in table 2, few examples of common GIS softwares and options:

Table 2: Common GIS softwares

GIS Software/Option	Definition
Esri's ArcGIS	A GIS program that analyzes geographic information by showing geographical statistics such as climate data or trade flows through layer building maps. It is used privately or openly on the internet by governments, academic organizations and private/commercial institutions around the world to produce and illustrate new research.
QGIS	QGIS (Quantum GIS) is well-known for its versatility and ease of use, making it suitable for users with varied degrees of GIS knowledge. Its open-source nature enables for customization and the creation of plugins to further expand its capabilities. This accessibility and adaptability have contributed to its popularity in a variety of industries
Google Earth Pro	A free desktop application with enhanced capabilities over the standard version, allowing professional users to explore and view satellite imagery, maps, terrain, and 3D buildings of the Earth, as well as a highly detailed and interactive virtual globe that can be navigated and explored using various tools and features.
GRASS GIS	GRASS GIS (Geographic Resources Analysis Support System) is a free and open-source software that offers a large range of tools for managing big and complicated spatial data sets, it includes a variety of capabilities for tasks such as spatial data manipulation, raster and vector analysis, image processing, mapping, and geostatistics.
MapInfo Pro	MapInfo Pro is a commercial GIS software with an easy-to-use interface and a plethora of capabilities for mapping, analysis, data management, and collaboration. Professionals in sectors such as urban planning, market research, environmental analysis, and location intelligence frequently use it.

Table 3: Common GIS softwares

GIS Software/Option	Definition
Global Mapper	Global Mapper is a robust an all-in-one solution for geospatial data storage and analysis for experts in cartography, environmental science, urban planning, and other sectors.
ENV	ENV, an abbreviation for ENVI, is a software package specializing in remote sensing and image analysis. It is commonly utilized in environmental science, agriculture, geology, and natural resource management. ENV offers an extensive collection of tools and methods for processing, analyzing, and displaying remotely sensed imagery.
SAGA GIS	AGA GIS (System for Automated Geoscientific Analyses) is a popular open-source GIS software for spatial data analysis and modelling. It offers a complete set of tools and algorithms for a variety of geospatial activities, making it an invaluable resource for researchers, analysts, and geoscientists.
Cadcorp SIS	Cadcorp SIS (Spatial Information System) is a fully comprehensive GIS software that includes a variety of tools for managing, analyzing, and exchanging spatial data. It is widely utilized across a variety of businesses, including government, utilities, transportation, and emergency services.
GeoDa	GeoDa is an easy-to-use software package that was created to help the free and open-source spatial analysis research infrastructure. Its sole purpose is to assist researchers and analysts in meeting the data-to-value problem. This difficulty entails converting data into insights.

1.4 Users

Individuals who interact with the GIS are referred to as users. They are the most valuable component in GIS since it is the people that design, implement, manage, and evolve the system in order to tackle real-world issues and find innovative solutions. Users can be GIS experts, decision-makers, scientists, urban planners, engineers, and so forth.

1.5 Methods and procedures

The principles and techniques used to acquire, handle, and analyze geographic data are represented by methods and procedures. They specify how information should be gathered, arranged, and integrated into GIS system, which may be applied in any field that deals with spatial data. The table 3 explains some common domains where GIS is widely used:

Table 4: GIS applications in different domains

Domain	GIS applications
Urban Planning	- Analysis and visualization of geographical data relating to: land use. zoning, pollution, transportation, and infrastructure. - Making well-informed judgments about: urban growth, city management, and long-term planning.
Environmental Management	- Analysis, visualization and collection of data about natural resources, ecosystems, and environmental factors. - GIS is utilized in environmental impact disaster management, and ecological system monitoring
Transportation and Logistics	- GIS is essential in Route planning, fleet management, vehicle tracking, and network analysis. It helps in effective transportation planning, logistics management, and traffic pattern monitoring.
Public Health	- Mapping and analysis of health-related data such as disease outbreak patterns, healthcare facility locations, and demographic information. - - Tracking and response to public health challenges, as well as resource planning and disease surveillance.
Agriculture and Forestry	- Management and monitoring of agricultural land, crop production, soil conditions, forestry resources, crop planning, precision farming, land classification, and forest management decisions. - Assessment and management of natural resources such as water, minerals, and energy sources. - Monitoring of resource availability, extraction activities, and the assessment of environmental effect.
Emergency Management	- Emergency preparation, response, and recovery. during natural catastrophes, crisis situations, or humanitarian emergencies. - Mapping dangers, identifying susceptible areas, calculating damages, and organizing assistance.
Archaeology and Cultural Heritage	- Geographic information systems can catalog, assess, and protect archaeological sites, heritage constructions, and cultural landscapes. They are useful for geographical analysis, site management, and mapping cultural heritage.

2 Comparison between raster and vector mode

Both raster and vector data have advantages and disadvantages, and the choice between them is frequently determined by the unique requirements and goals of a GIS project.

Advantages of adopting raster mode:

- Raster data is less complicated, faster processing speeds and easier to grasp than vector data. This facilitates data processing and analysis.

- Raster data enables for the representation of continuous elements and phenomena that fluctuate gradually throughout a region.

-Because raster data is a widely established data format, it is relatively easier to trade and share across different GIS tools and platforms. This compatibility facilitates collaboration among businesses and researchers.

The vector mode has various advantages: the main one is: Data storage efficiency due to the fact that vector mode displays data as a single vector, allowing numerous operations to be executed at the same time, resulting in faster execution times, better performance, and reduced overall memory access while consuming less energy.

3 How to perform a geographic database?

A geographical database for every research region is organized as maps. Each database element is referred to as a "coverage" in vector mode and a "layer" in raster mode.

Coverage is a single type of spatial object that can be assigned a number of attributes. Layers are the continuous spatial variation of a single phenomenon or variable like altitude displayed in a digital elevation model (DEM). An attribute table can be used to relate spatial objects in layers.

Chapter 3: Analysis in GIS and softwares

In this chapter, a comprehensive exploration of the key techniques and methodologies that underpin the analysis of geographic information will be embarked. Where, diverse array of tools and concepts which are important for acquiring insights from geographic data will be uncovered.

The fundamental principles of GIS analysis, including: measurements and modelling over vector and raster types will be subsequently discussed, and equipped with skills to conduct sophistical spatial analyses and derive valuable conclusions from geographic data.

1 GIS and spatial analysis

Some fields like the geoinformatics encompasses GIS and spatial analysis, which are dedicated to the management and analysis of geographic information. Spatial analysis, an integral component of geoinformatics, plays a crucial role in understanding the distribution and interconnections among geographic entities and occurrences. By employing mathematical, statistical, and computational techniques, spatial analysis facilitates the examination of spatial data to identify patterns and trends. This discipline finds practical applications in other domains such as public health, environmental studies, urban planning, and criminology, among numerous others (M. Viana, 2023).

Spatial analysis involves a range of methodologies, including spatial interpolation, regression, grouping, smoothing, and so on. These methods are used to examine many types of spatial data. As technology advanced, new approaches for solving difficult geographical problems developed, including machine learning and deep learning (M. Viana, 2023).

2 *Spatial data modelling*

Spatial analysis incorporates a variety of computational models, analytical techniques, and algorithmic approaches to assimilate geographic information and define its suitability for a target system. Shapefiles (.shp) are used to store the data (figure 7).

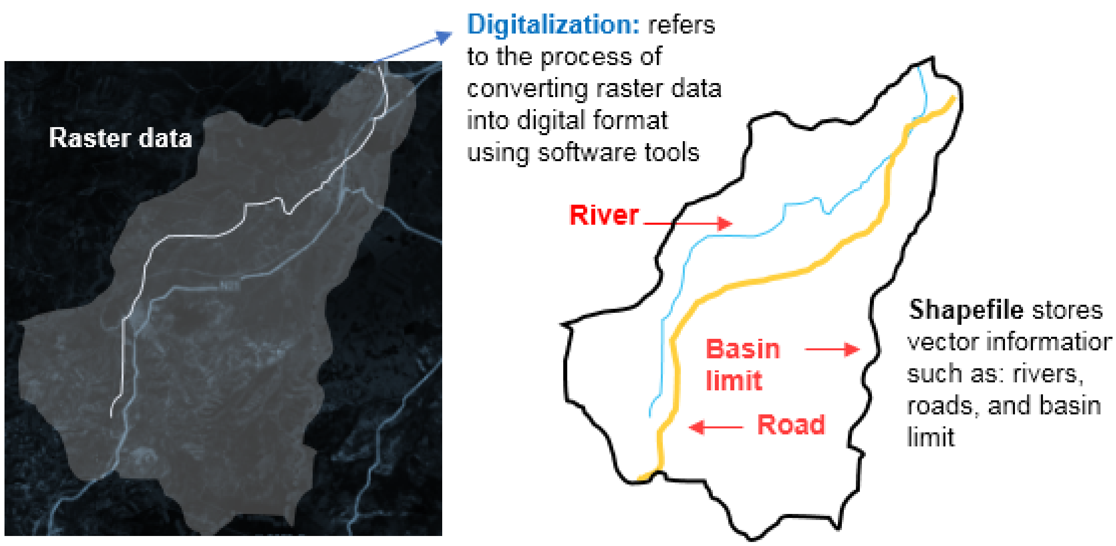


Figure 7: Shapefile for GIS use

Data are stored in different ways in GIS according to the used file format. As an example, ArcGIS can handle several file formats by default from Arc/Info coverages and ArcView shapefiles, or by "import" when we deal with special extensions like: dxf or JPEG. The shapefile format must contain at least three files (*.shp, *.shx, *.dbf) to open layers or copy their data from a computer to another or even between drivers and servers.

By conducting spatial analysis, users can derive a new set of information after combining data from many independent. This procedure is done with a large, and sophisticated operators /geo-processing tools

The well called spatial modelling allows to derive and predict new future data which describes what might happen in the real world. Two types of models are involved for modelling spatial problems (figure 8)

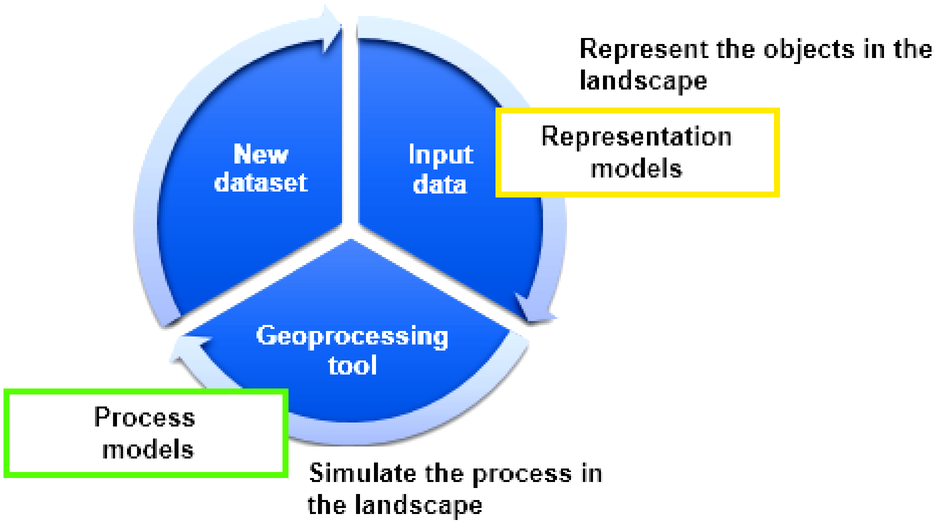


Figure 8: Types of models for spatial modelling in GIS

3 *Georeferencing*

The technique of giving positions to geographical objects (aerial photographs/satellite images) within a geographic frame of reference is known as georeferencing. It is fundamental to geospatial technology in general, and to GIS in particular. Georeferencing processes can be divided into two types based on the spatial resolution in use: metric georeferencing and indirect georeferencing. Metric georeferencing, also known as continuous georeferencing, is based on coordinates (Rana, Patel, & Vakharia, 2024) . A coordinate system can specify every position on the Earth's surface by a collection of values (coordinate). GIS databases, which contain collections of geographic features referred by coordinates, rely on metric georeferencing. Indirect georeferencing approaches use attribute data to get metrically georeferenced locations from existing GIS databases.

The characteristic could, for example, be the name or index linked with a location.(Kobayashi, 2019)

This handout covers some fundamental concepts, such as:

- Configuring the projection for precise scale recording.

- Generating a georeferenced section of an image via exportation.

- Adjusting the transparency of an image.

4 Spatial analysis procedure

The geographical analysis process can be broken down into multiple steps:

- To start the analysis, it is necessary to outline the problem. This helps in identifying all required operations needed to obtain significant results.
- Preparing all maps and adding attributes as needed is subsequently essential to ensure that spatial data is ready to use.
- Running various spatial procedure according to the fixed objective such as: manipulating features, combining coverages or creating buffer zones around objects among others.
- Preparing attribute tables and derived material.
- Executing tabular analysis by using the defined models.
- Assessing outcomes carefully all outcomes utilizing reports and maps.

5 Spatial analysis types

Usually GIS applications integrate spatial analysis tools for accounting how many vertices make up each polyline and for other feature statistics. Choosing the type of spatial analysis (figure 9) depends on the subject areas. In hydraulics, people working on hydrological modelling will most likely be interested in analyzing terrain and flow water moves across watersheds. In this topic examples of a useful vector/ raster spatial analysis are discussed in the following section.

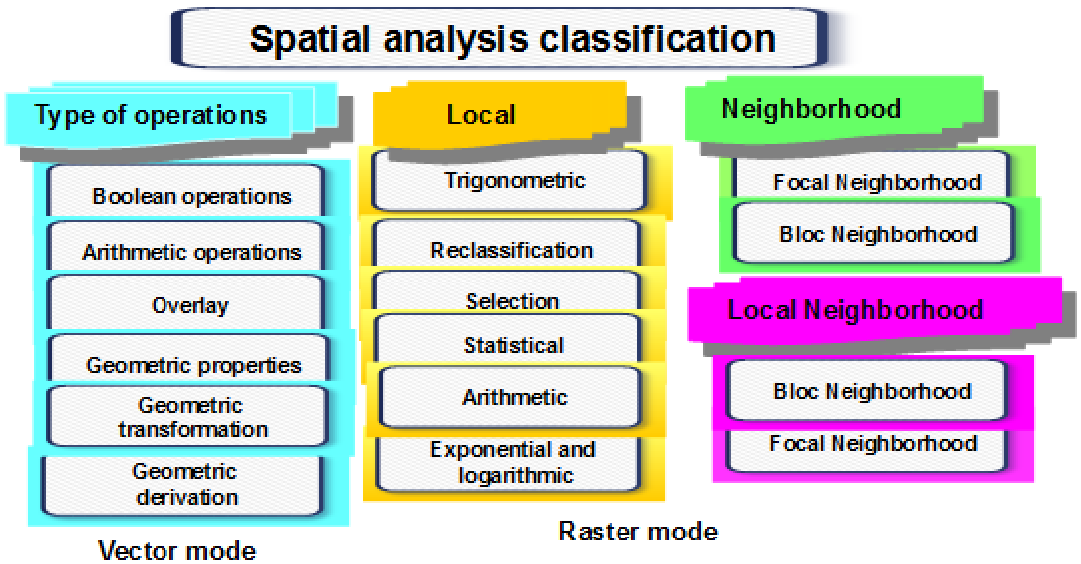


Figure 9: Classification of spatial analysis types

5.1 Vector spatial analysis

In GIS, the provided geoprocessing tools allow the user to automate many tasks associated with manipulating individual or multi-features datasets. It usually involves a spatially explicit analysis, and resulting in an output feature dataset.

5.1.1 Single layer vector analysis (individual feature dataset)

The primary tool utilized for vector spatial analysis is known as Buffer. It designates all of the area encompassing a particular distance from a feature (point, line, polygon). These buffers are subsequently superimposed onto other layers in order to identify which areas fall within that same range. Buffers are common easy and quick tools, used to address questions of proximity for solving problems and determining areas (J. Campbell & Shin, 2019) (figure 10).

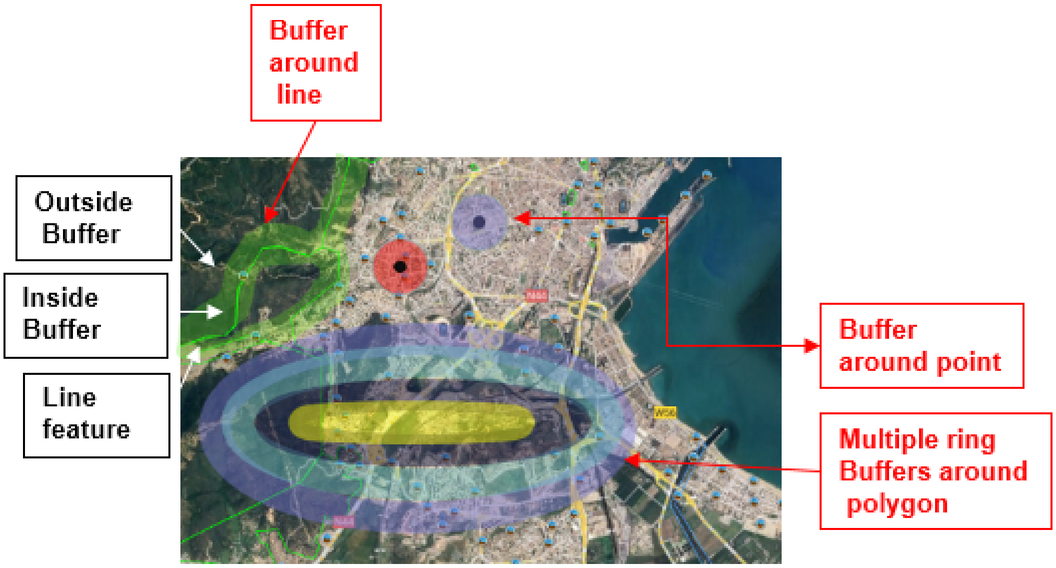


Figure 10: Buffer around features

Some geoprocessing tools include: select, dissolve, append, and merge are commonly used in junction with multilayer methods (figure 11).

- Select: The select operation generates an output layer by filtering out specific features from the input layer based on a query defined by the user. The resulting output layer exclusively contains those selected features as per the query criteria.
- Dissolve: by using a predetermined attribute, the dissolve operation merges neighboring polygon features into one dataset. The function produces an output layer that eliminates extraneous line segments while maintaining its original extent. This processed layer is more accessible for visual interpretation if classified according to the field used during dissolving process.
- Append: The act of appending creates a polygon layer by merging the spatial extent of two or more layers. The output layer will be identical to the feature type found within each input layer, which must possess matching features as well.

Unlike the dissolve function, append does not eliminate border lines between appended layers for line and polygon datasets.

- Merge: when using the merge operation, features are brought together to create one feature with matching attribute information. Sometimes, there may be varying values for an attribute in the original features. If this is the case, only the first encountered value will appear on the new merged table while other attributes will no longer exist. Merge can become quite helpful when polygons overlap unintentionally by combining them into a single entity effortlessly.

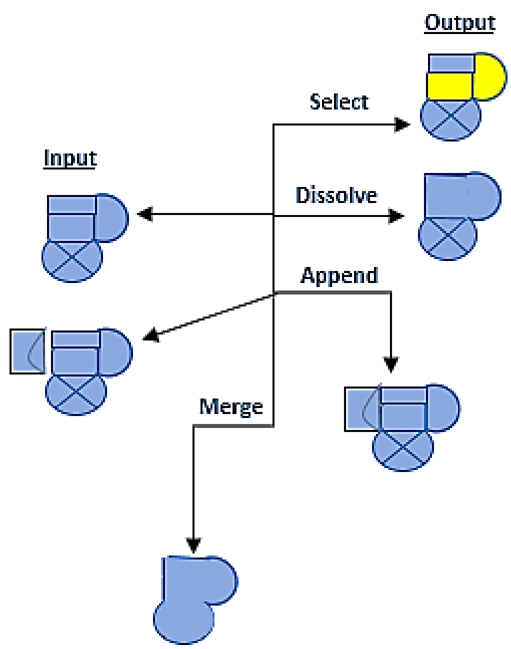


Figure 11: Geoprocessing functions for single layer

5.1.2 Multilayer vector analysis

The overlay of cartographic information system is a powerful function that superposes two or many spatial dataset features from different maps to create a new one. In a GIS, this process ensures not only combination of datasets but, also the attribute information as well.

Point-in-polygon, polygon-on-point, line-on-line, line-in-polygon, polygon-on-line, and polygon-on-polygon are the available basic overlay for vector datasets in GIS (figure 12). one of the overlay datasets must always be a line or polygon layer, while the second may be point, line, or polygon. The new layer produced following the overlay operation is termed the output layer (J. E. Campbell & Shin, 2011).

1: Point-in-polygon: this overlay requires as inputs two layers: a point and a polygon. When performing this operation, a new output point layer is returned that includes all the points that occur within the spatial extent of the overlay, as well as the attribute information. Clipping is a tool used to limit the functions within one layer strictly within the confines of another. Shapefiles of all kinds (point, polyline, polygon) are regarded as clipped.

2: Polygon-on-point: in this operation, and as its name suggests, the polygon layer is the input, while the point layer is the overlay. The polygon features that overlay these points are selected and subsequently preserved in the output layer.

3: Line-on-line: Line features are required as input and overlay layer for the line-on-line operation. The output from this operation is a point located precisely at the intersection of the two linear datasets.

4: Line-in-polygon: the concept of overlaying a line onto a polygon is similar to this of a point in a polygon. The only obvious difference being in using lines as input in this scenario. Essentially, any line within the boundaries of an overlayed polygon will be incorporated into the output layer.

5: Polygon-on-line: the operation of overlaying polygons on lines is contrary to the process of embedding lines within polygons. In this scenario, the input layer consists of polygon features, while the overlay comprises line features. The outcome involves selecting and retaining only those polygon shapes which overlap with the designated lines in a resultant output layer.

6: Polygon-on-polygon: The process of overlaying polygons onto lines requires choosing and preserving solely those polygon forms that intersect with specified lines. To accomplish this end, the line characteristics serve as the overlay ingredient, while polygon features make up the input layer.

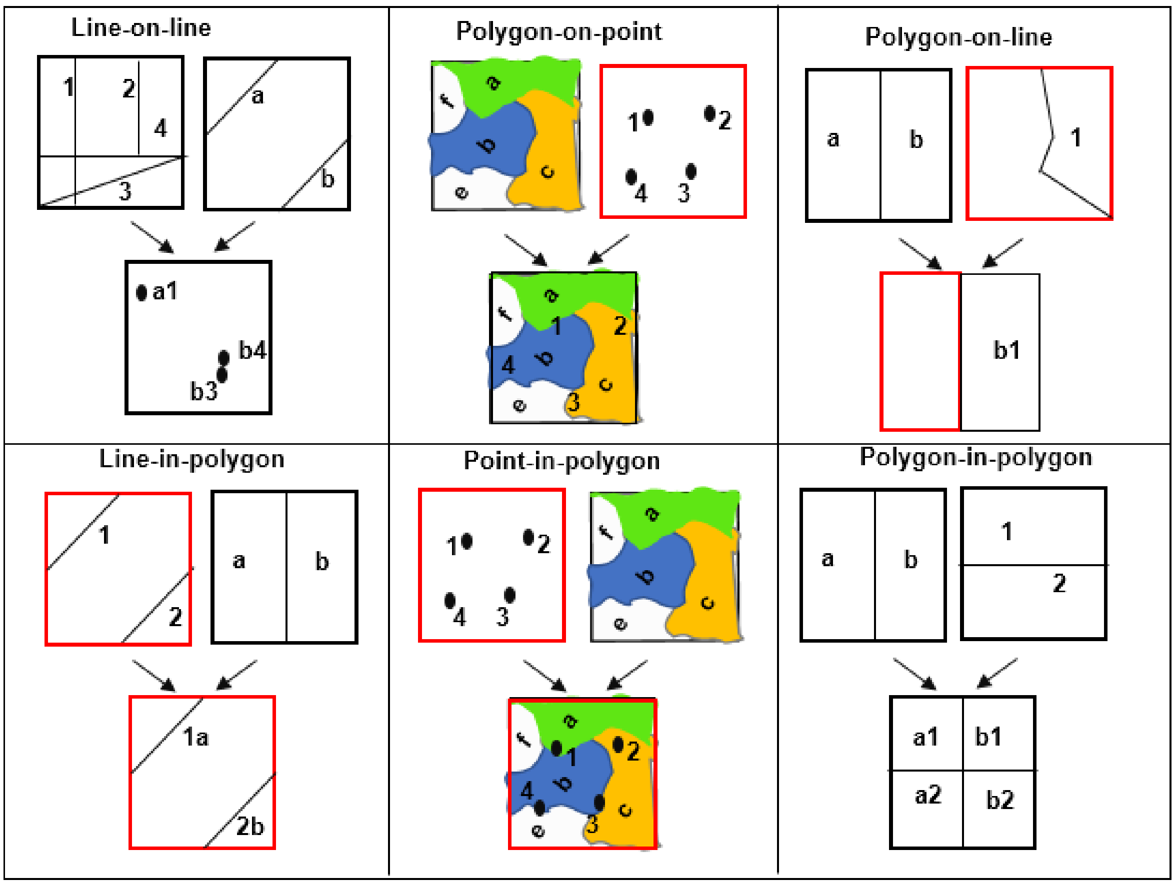


Figure 12: Overlay types for multilayers.

Intersection, symmetrical difference, union, and split are typical process examples that are often used to determine what falls in or anywhere between two different vector forms (figure 13). The table below gives their definitions.

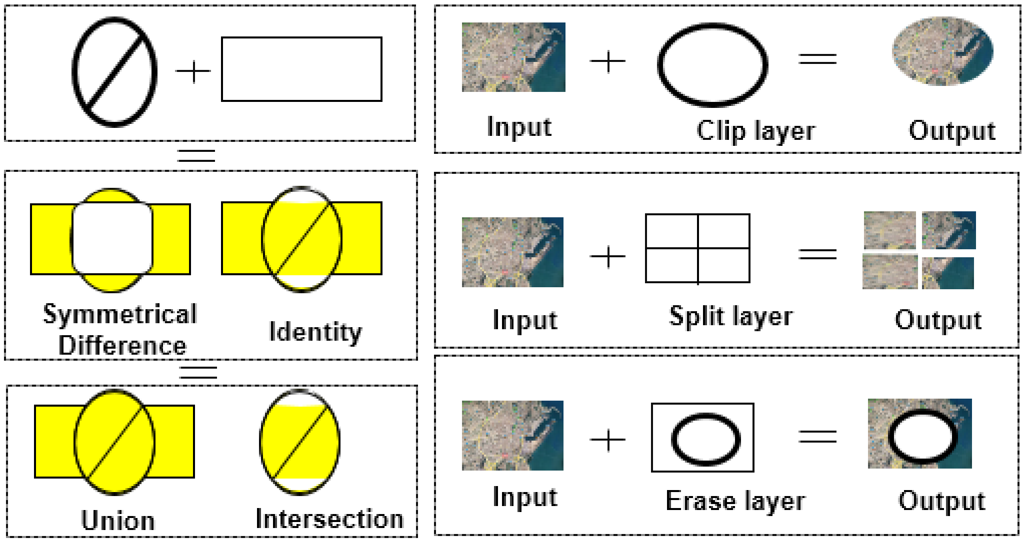


Figure 13: Spatial overlay operations with two vectors in GIS

Table 5: Definition of overlay operations in GIS (vector type)

Intersection	The output layer comprises the regions where both layers intersect.
Union	The output layer of the union operation comprises all sections obtained by merging the two input layers.
Symmetric difference	The result of symmetrical difference operation is the output layer comprising every section from input layers, except for regions where they intersect.
Identity	Computes intersection and identity of the input features.

5.2 Raster spatial analysis

The raster data models are useful for continuous data. As an example, the Digital Elevation Model (DEM) is the most used raster data that changes across topographic surfaces. Where a regular array of Z-values is referenced to a common datum to represent terrain relief.

The geoprocessing tools available for use on raster datasets include both single and multiple layer analysis. The classification of both analyses may base on two types: 1) the type of operation. 2) based on local, neighborhood, and local neighborhood operation.

5.2.1 Single layer raster analysis

When conducting single raster analysis, reclassifying a dataset is commonly one of the initial steps (J. E. Campbell & Shin, 2011). There are typically two actions taken during this process: first, new values are assigned to pixels based on their original classes; secondly, these newly classified values can then be utilized as simplified inputs for subsequent analyses. (Figure 14)

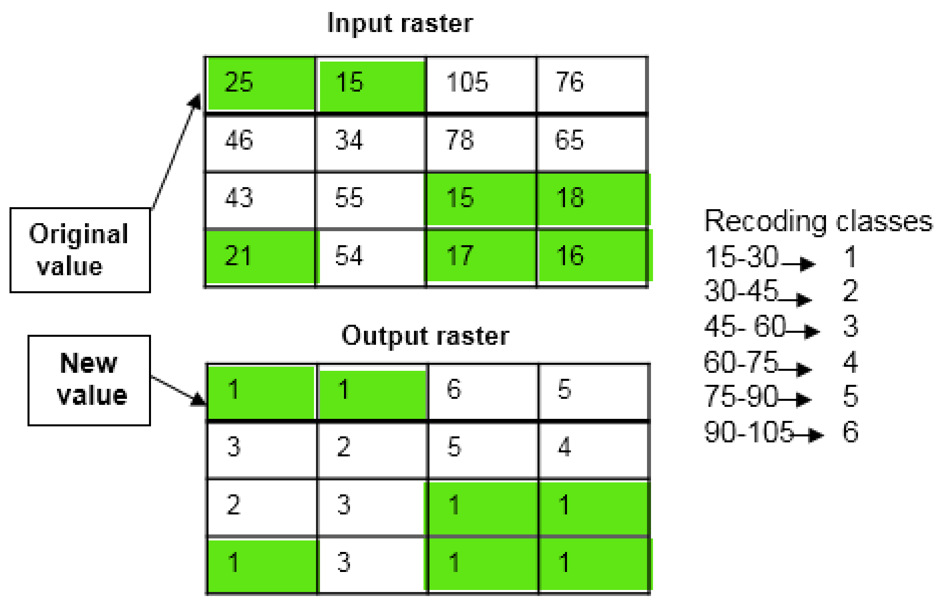


Figure 14: Process of reclassification for raster dataset

In figure 14, the green color represents the process of buffering a raster, it is defined as the creation of an output dataset that encompasses one or multiple zones of specified width around an input feature. For raster datasets, this entails grid cells with uniform values.

5.2.2 Multiple layer raster analysis

Any raster dataset can be clipped like vector dataset. To do this, first overlay the input raster with a vector polygon clip layer. Once you perform the raster clipping process using this technique, you'll end up with a single new raster file that is exactly like your original one but now has the same boundaries as defined by the polygon clip layer used during processing (figure 15).

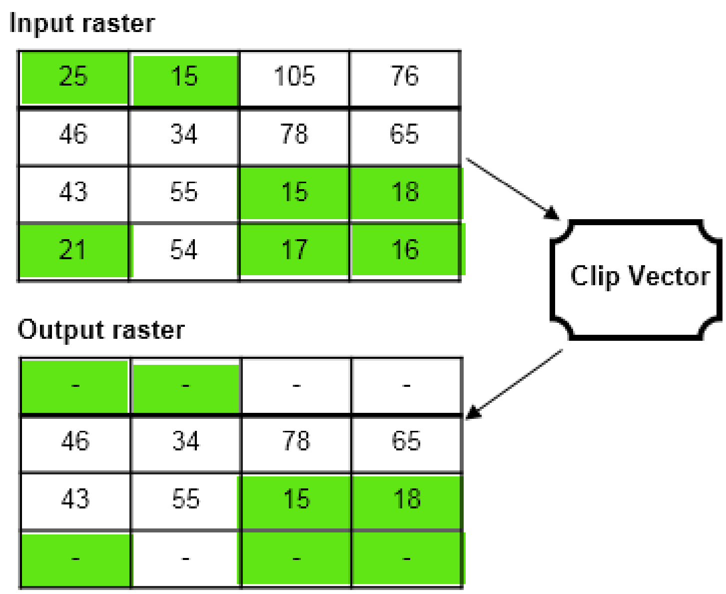


Figure 15: Clipping a raster to a form of vector layer

The raster overlay requires combination of layers using mathematical methods and functionalities, where, the input grids are transformed into a new raster that contains resulted values for each cell (figure 16).

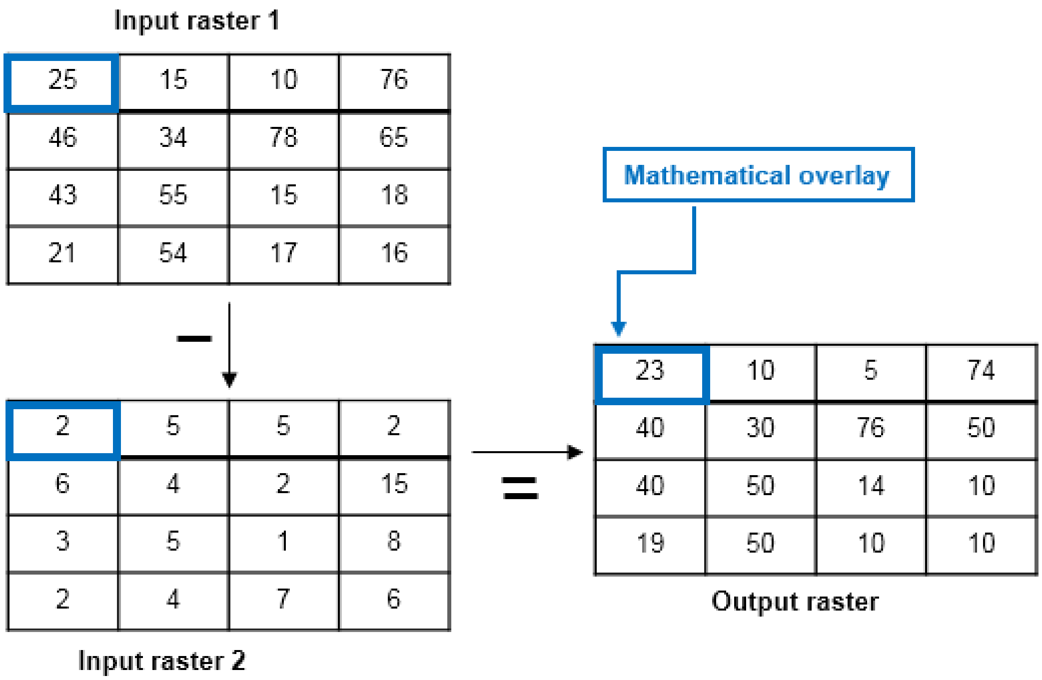


Figure 16: Production of output raster using mathematical overlay of two input rasters.

Another raster overlay method named the Boolean approach can also be employed to compare the information of two overlying input raster datasets and combine them into a single coded output raster. Relational operators (<, <=, =, <>, >, and =>) to evaluate conditions of the input raster datasets.

The simplicity of this approach offers an advantage, as it only requires two input raster datasets. For instance, if one dataset displays the presence of rivers using a binary system (“0” indicates no river and “1” signals its existence), and another shows rural areas (with “0” representing non-rural and “1” indicating rural), adding these datasets together, leads easily to identify pixels that contain both rivers and rural areas (by locating those with a value of "2").

6 Scale of operations

The consideration of scale is of utmost importance in GIS analysis. It encompasses the spatial extent and level of detail at which geographic data is examined and interpreted. Understanding the scale at which GIS analysis is conducted is crucial for ensuring accurate and relevant findings. This concept is integral to effectively managing geographic data and making informed decisions based on the selection of appropriate data sources, the resolution of spatial datasets, and the choice of analytical methods.

Geographic phenomena can exhibit different patterns and relationships at different scales, which can significantly impact the interpretation and analysis of spatial data. An analysis conducted at a local scale may provide different insights compared to the same analysis performed at a regional or global scale. Therefore, recognizing the scale of operations is essential for contextualizing the results and understanding their implications within the broader geographical context (Goodchild, 1990).

6.1 Local operations for single/multiple raster

The execution of local operations on either a single or multiple rasters can differ. When used with single raster, this type of operation usually involves applying mathematical transformations to each cell in the grid. If applied to several rasters, it enables various analyses such as temporal changes over time. For example, if two separate rainfall depth information rasters for a particular watershed are accessible at Year 2022 and Year 2023 respectively; their values can be subtracted from each other easily using these techniques - resulting in an output raster that reveals the variations in precipitation levels across those years (figure 17).

Input raster

25	15	105	76
46	34	78	65
43	55	15	18
21	54	17	16

Input raster/10

2,5	1,5	10,5	7,6
4,6	3,4	7,8	6,5
4,3	5,5	1,5	1,8
2,1	5,4	1,7	1,6

Output raster

Figure 17: Local operation on a raster input

6.2 Neighborhood operations

The neighborhood operations produce a simplified raster dataset as the result, where each cell's value depends statistically on its input value and its neighboring cells within a specified distance. The operation treats the neighborhood around every processed cell as if it is a moving window that moves with it. Depending on how big and what shape (geometric/irregular) of this zone are used specifically determines which surrounding cells will be included in calculating an output value for each processing cell. Typically, the most widely used is 3 by 3 configuration containing both central and eight other nearest neighbors to calculate values for outputs.

Spatial Analyst has two fundamental types of neighborhood operations. The first type involves overlapping neighborhoods around the processing locations, while the second type utilizes non-overlapping neighborhoods. The input dataset undergoes processing using overlapping neighborhoods with the Focal Statistics tool. On the other hand, non-overlapping neighborhoods are considered by the Block Statistics tool while processing data. (figure 18)

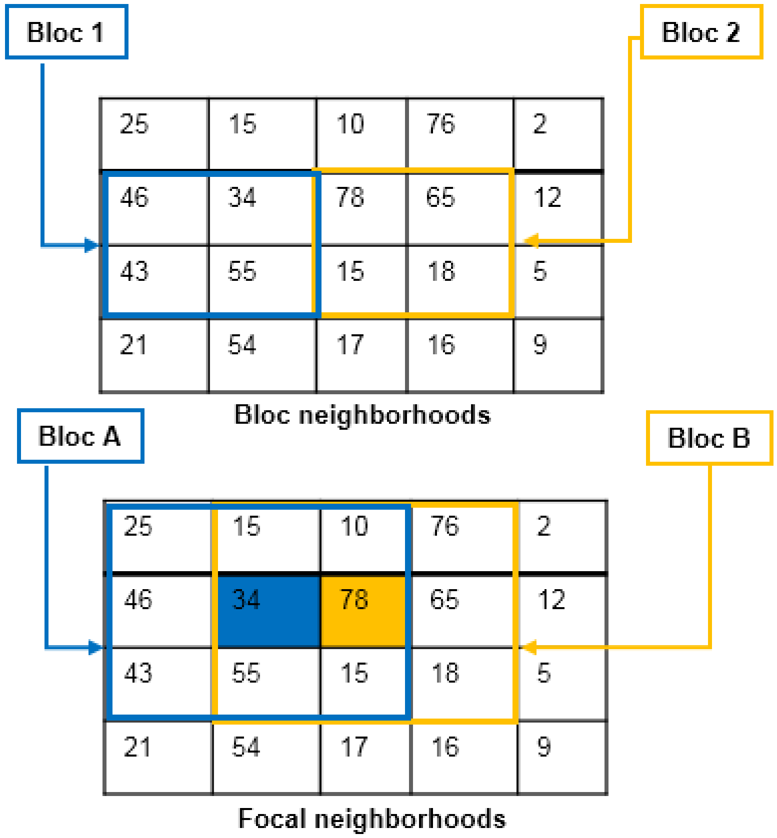


Figure 18: Neighborhood process types

6.3 Zonal/global operations

The output of zonal operations calculates the value at each location based on the cell value and its association with a map zone. Unlike focal operations, where neighborhood shapes are predetermined, in zonal operations, zones' configuration determines it. Furthermore, these configurations may comprise disconnected areas or arbitrary sizes/shapes defined as feature/raster data.

Global operations, also referred to as raster-based operations, generate an output raster dataset wherein the value at each cell location may depend on all cells from different input raster datasets. Two major categories of global operations include Euclidean distance and weighted distance.

The global distance operations in Euclidean space's involve assigning the distance between every cell in the output raster dataset and its closest source cell. The starting point for a new route can serve as that source cell, while each location of a given cell may be assigned with an indication of its nearest source direction value.

The Weighted global operations (non-Euclidean distance) calculate the expense of traveling between a destination cell and its closest source cell on a surface, taking into account an extra cost beyond Euclidean distance. In cases where the terrain is challenging, like in steep or marshy areas, constructing a route from point A to point B might incur higher costs than utilizing the shortest and most direct path.

Chapter 4: Remote sensing

Remote sensing refers to the use of various techniques and knowledge to observe and analyze the physical and biological attributes of objects from a distance, without any direct physical interaction. Essentially, it is a means of acquiring information about an object, including its inherent characteristics and properties, by measuring and processing the electromagnetic radiation emitted or reflected by the object.

The purpose of this chapter is two-fold:

- Firstly, it aims to showcase the role and techniques of remote sensing in studying territories to gain valuable insights into the geographical features of different regions.
- Secondly, the chapter aims to provide the necessary theoretical foundations for understanding the information derived from satellite remote sensing images.

1 History of remote sensing

The first pictures of the Earth were captured since 1946 by cameras on rockets. These early highlighted the significance of establishing observation bases in outer space Color images of the Earth and weather obtained during Gemini flights in the 1960s demonstrated that both geological and man-made landmarks, as well as storms in the Earth's atmosphere, could be viewed from orbit (Giardino, 2011). Subsequently, valuable information about sea conditions and surface roughness could be derived by analyzing the specular reflection of sunlight. However, it was not until the 1970s that oceanographers were able to obtain usable data on sea surface temperature and water turbidity. Scientific investigations conducted along with the remarkable demonstrations of human capabilities in space revealed previously unknown knowledge. The first total eclipse of the Sun was viewed from space, with photographs of the airglow and zodiacal light. In 1978, the first satellite Seasat dedicated to ocean studies (e.g. providing data on: surface temperature/ roughness) was launched to mark a significant milestone. To overcome the challenge of cloud cover, most sensors operated in the microwave part of the electromagnetic spectrum, where clouds are transparent. In the same year, NASA's experimental Nimbus 7 satellite significantly designed for a water color observation, which provided improved numerous synoptic views of ocean color at a resolution of approximately one kilometer. Additionally, passive microwave sensors on the same satellite measured ocean surface temperatures. Since then, various oceanographic satellites such as Geosat, and the Russian Meteor series satellites have been launched and revolutionized in many fields of, geophysics, physics, biology, and chemistry.

2 Why remote sensing is interesting?

The Earth's surface observation plays a crucial role in various sectors, providing valuable information. One such sector is remote sensing. The interest of spatial remote sensing lies in its ability to:

- Allow for coverage of hostile zones and fast data collecting by sampling geography and time on a regular basis.

- Provide images from satellites that offer diverse insights into acquisition methods, radiation properties, and resolution levels.

- Observe phenomena that occur on the Earth's surface.

3 What does remote sensing measure?

Remote sensing measures a variety of Earth system variables, including snow cover, vegetation, sea, electromagnetic radiation, land cover, temperature, precipitation, atmospheric components, and terrain, depending on the individual objectives. Some frequent measures include the following cases:

- The object can be identified directly or discovered indirectly.

- The object cannot be seen directly, but it is detected by the presence of another visible object.

4 remote sensing types

Remote sensing measures energy responses using sensors deployed on various platforms (e.g. spaceborne and airborne). Sensors can be either active or passive (figure 19).

- Active sensor is a device which is subject to the electrochemical principle. It illuminates a target with a known energy source and then measure the time, requiring for this process. The transmitter element is assembled by the sensor and emits a signal, light wavelength or electrons that are reflected to target.

- Passive sensors are designed to monitor natural energy (sunlight) that is reflected from an object. These sensors encompass various types of radiometers and spectrometers. In the field of remote sensing, passive systems are commonly utilized within specific regions of the electromagnetic spectrum, namely the visible, infrared, thermal infrared, and microwave portions.

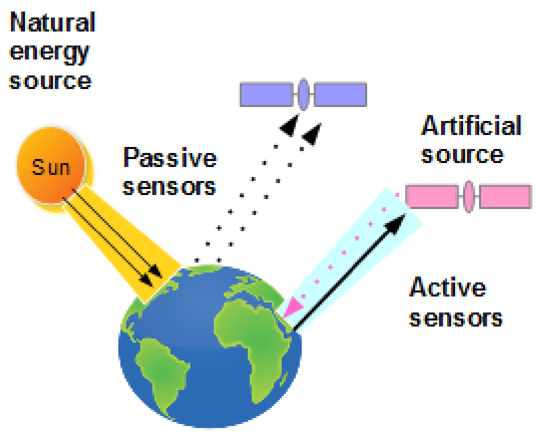


Figure 19: Difference between active and passive sensor types

According to (Zhu et al., 2018), the remote sensing sensors can be classified, depending on their characteristics into: imaging and non-imaging sensors. The imagine type includes: optical, thermal, and radar sensors. while non-imaging sensors can be: spectrometers, radiometers, and altimeters (figure 20)

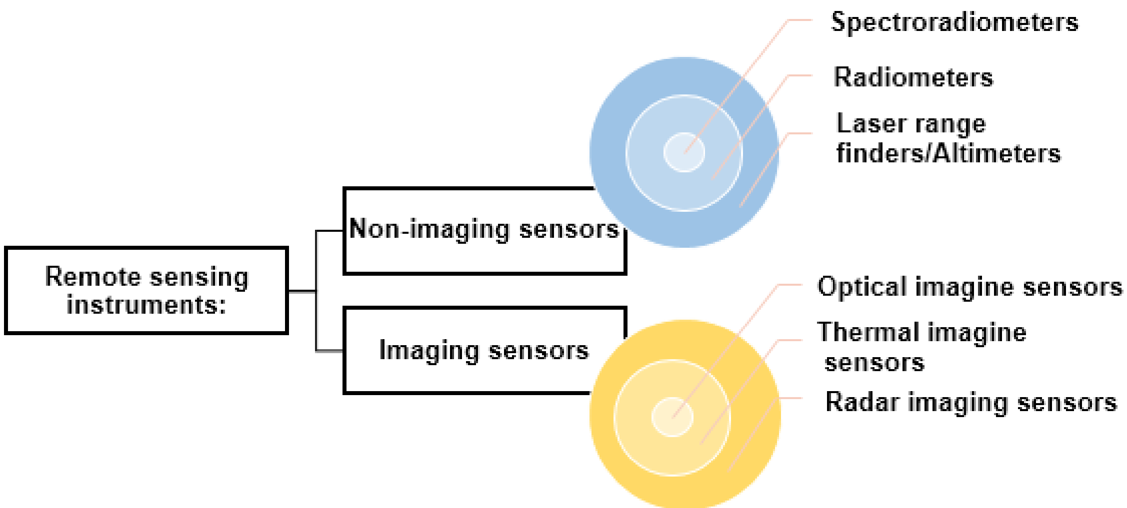


Figure 20: Remote sensing instruments

5 Vectors

Vectors can be classified into different categories based on their proximity to the Earth's surface:

1. Vectors operating within a few meters from the ground: This group encompasses equipment such as cranes, vehicles equipped with radiometers, and aerial photography devices. These vectors are primarily utilized for tasks that require close proximity to the ground.

2. Vectors operating between several meters and several kilometers: This category includes aircraft such as airplanes, helicopters, and balloons. These vectors are capable of operating at moderate altitudes and are commonly employed for various purposes such as transportation, aerial surveys, and atmospheric research.

3. Vectors operating between several kilometers and a hundred kilometers: This particular category refers specifically to stratospheric balloons. These balloons are designed to operate within the stratosphere, which is situated between the troposphere (where most weather phenomena occur) and the mesosphere. They are frequently employed for scientific experiments, weather observations, and telecommunications purposes.

4. Vectors operating between 200 kilometers and 40,000 kilometers: This category primarily comprises satellites, both manned and unmanned. Satellites are launched into space and can orbit the Earth at different distances. They serve a multitude of functions including communication, weather monitoring, navigation, remote sensing, and scientific research.

Each of these types of vectors serves distinct purposes and operates at specific distances from the ground in order to fulfill their respective missions.

6 Satellite orbits

An orbit refers to a consistent and repetitive trajectory followed by an object around another. The celestial body that is in orbit is commonly referred to as a satellite. Satellites can occur naturally, such as the Earth or the Moon. As the Earth revolves around the Sun, it is presently in orbit. Numerous planets, including Earth, possess moons that revolve around them. Additionally, satellites can be artificially created, like the International Space Station. Planets, comets, asteroids, and various other objects within the solar system also revolve around the Sun. There are two types of satellite orbits (figure 21):

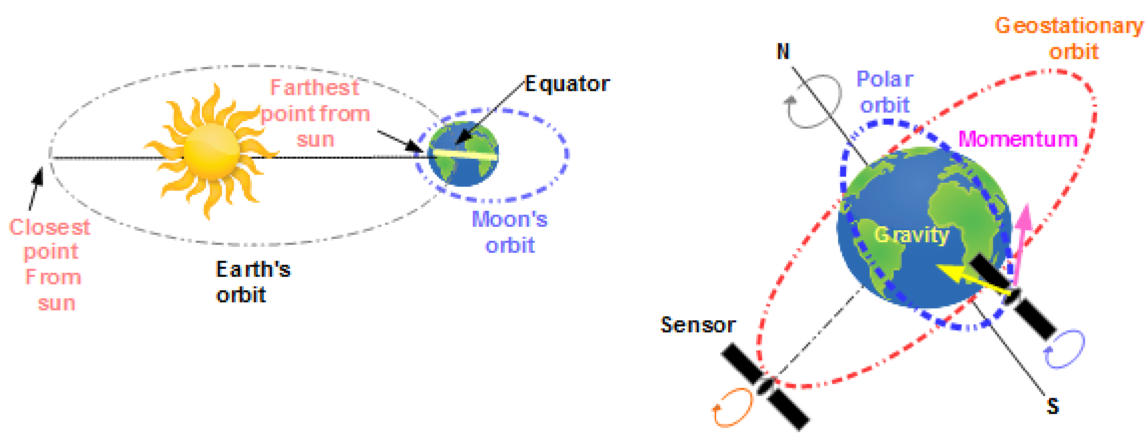


Figure 21: Concept and types of satellite orbits

6.1 Polar orbits

Instead of traveling east to west, polar orbiting satellites usually go north to south across the surface of the planet. It should be noted that these satellites do not always cross the North and South Poles exactly; a degree variation is nevertheless regarded as falling inside the bounds of a polar orbit. These orbits, which are located above the surface of the Earth, are classified as low Earth orbits.

6.2 Geostationary

The orbital path of GEO satellites around the Earth is fixed at a distance of 35,786 kilometers. This specific distance allows the satellite to synchronize its speed with the Earth's rotation, resulting in the satellite remaining stationary over a particular location on the planet. Currently, the majority of communication satellites are positioned in geostationary orbit, and this arrangement is expected to continue for the foreseeable future. Geostationary satellites primarily cater to a specific geographical area and enable the provision of voice, data, and video services.

In the United States, many long-distance phone providers rely on geostationary satellites as a backup source for phone service. An example of a GEO satellite system is INTELSAT.(Peterson, 2003)

7 Difference between satellite and sensors

- Satellites play a crucial role in remote sensing as they serve as platforms or spacecraft equipped with sensors and various instruments. These tools allow satellites to observe and collect data on the Earth's surface, atmosphere, and other environmental characteristics. The significance of satellites lies in their ability to provide a unique perspective, allowing for the collection of extensive data and photographs across large areas. Major satellite types include: astronomical, communications, navigations, reconnaissance, Earth observation, space station, and scientific (Welti, 2012) .

- Sensors are the instruments utilized by satellites to acquire information about the Earth's surface and atmosphere. These sensors encompass a range of equipment such as lidar (light detection and ranging), radar systems, optical cameras, multispectral and hyperspectral imagers, and other specialized devices designed to record specific types of data.

8 Why remote sensing data need to be analyzed?

Geospatial data must be thoroughly processed and analyzed in order to provide relevant insights. While an image can carry a lot of information, it takes several stages to convert that sight into a language we can understand. Practical objectives of remote sensing are shown in the following representation (figure 22).

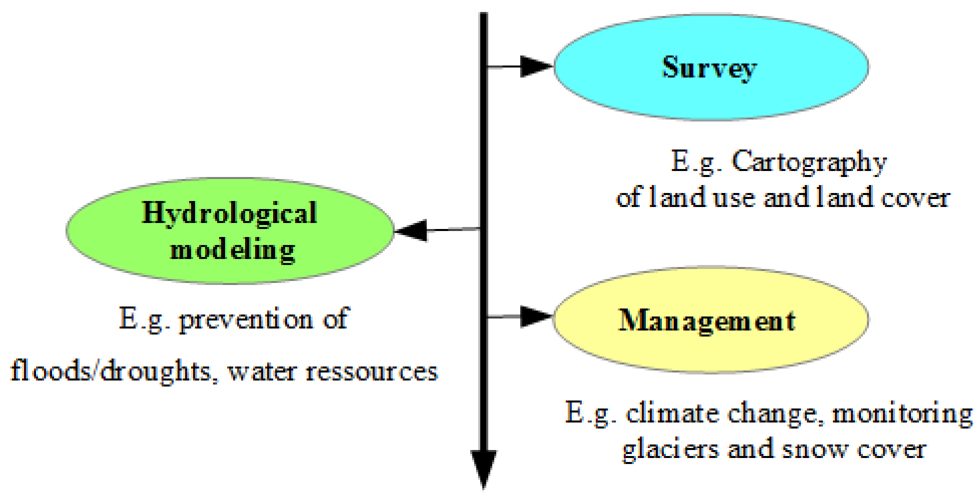


Figure 22: Some practical objectives of remote sensing

9 Steps in remote sensing

- **Energy source/illumination:** Remote sensing necessitates an energy source that supplies electromagnetic recording of energy by the sensor

- **Radiation and the atmosphere:** as energy flows from source to target, it interacts with the surrounding atmosphere. This interaction may occur a second time as energy passes from the target to the sensor.

- Interaction with the target: energy travels through the atmosphere and reacts with the target based on its qualities and radiation.

- Recording of Energy by the Sensor: after the target scatters or emits energy, a distant sensor collects and records the electromagnetic radiation.

- Transmission, reception, and processing: sensors record energy and send it electronically to a receiving station where it is processed into a picture, which can be printed or digital.

- **Interpretation and Analysis:** the processed image is evaluated visually, digitally, or electronically to derive information about the lit target.

- **Application:** the remote sensing method concludes with applying the information extracted from imagery to better comprehend the target, provide new information, or solve a specific problem. See (figure 23) for more details.

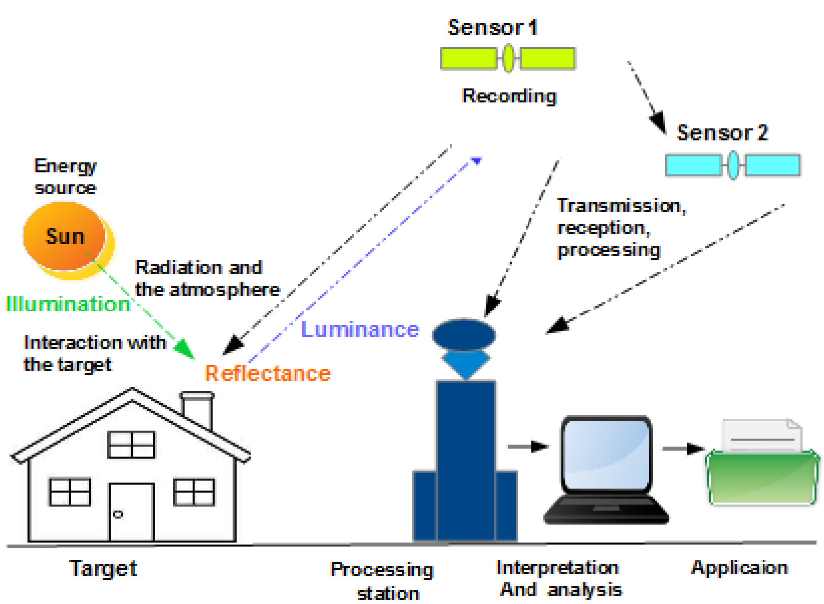


Figure 23: Remote sensing steps

* **Illumination**: it indicates the intensity of light captured by an optical or radar sensor and emitted or reflected by a surface. In remote sensing, this is a crucial factor as it reveals the reflectance characteristics of the surface, enabling the identification of various land cover categories and facilitating long-term change monitoring. Its significance stems from its capacity to assess the degree of brightness in the surroundings, which is affected by a variety of elements such as the sun's location, nearby light sources, time of day and year, air conditions, and the surface's reflecting characteristics.

* **Reflectance:** Reflectance pertains to the extent of light being reflected by a surface or optical apparatus. It is measured by the proportion of reflected power to the incident power when light is directed onto a surface.

* **Luminance:** it is the light that is produced and projected per area (in cd/m²), which stands for candela per square meter. However, it is often mistakenly used interchangeably with the term "brightness".

10 Sun and atmosphere

The utilization of passive optical remote sensing heavily relies on the sun as the primary source of electromagnetic radiation. It is commonly assumed that the sun behaves as a blackbody with a surface temperature of approximately 6000Ko. The sun's radiation encompasses various regions, including ultraviolet, visible, infrared, and radio frequency. Notably, the highest intensity of radiation occurs at around 0.55 µm, which falls within the visible range. However, when solar radiation reaches the Earth's surface, it undergoes modifications due to atmospheric radiation at different wavelengths, following Planck's Law. Consequently, during daylight hours, the observation of the Earth involves the reflection of solar radiation by the Earth's surface and the emission from the surface itself. Prior to interacting with the Earth's surface, solar radiation must traverse the atmosphere, where it is subject to scattering and absorption by gases and particulates.(Joseph, 2005)

11 Electromagnetic radiation

Electromagnetic radiation, upon reaching a surface, undergoes various interactions such as reflectance, or transmission. These interactions are determined by the characteristics of the object and the wavelength (length of an individual wave in m) of the incident radiation. By studying these interactions, one can gain insights into the properties of the observed objects. (Joseph, 2005)

In the field of remote sensing, the identification of objects is facilitated by a fundamental property known as the signature. It is assumed that each object possesses a unique signature. Discrimination among different targets is achieved through four major characteristics: spectral, spatial, temporal, and polarization variations. (Joseph, 2005)

Spectral variations refer to the changes in the reflectance of objects as a function of wavelength. For instance, the color of objects in the visible region is a result of spectral variation in reflectance. Spatial variations, on the other hand, pertain to the arrangement of terrain features, which provide attributes such as shape, size, and texture. These attributes aid in the identification of objects. (Joseph, 2005)

Temporal variations involve changes in reflectivity or emissivity over time. These variations can be diurnal or seasonal. For example, the reflectivity of crops during their growing cycle can help differentiate between crops with similar spectral reflectance's but different growth patterns. (Joseph, 2005)

According to the theory of waves, the electromagnetic radiation consists of an electric field (varies in strength and is positioned at a right angle to the direction in which the radiation travels) and a magnetic field perpendicular to the electric field, travels at the speed of light (V) equals to: the frequency (description of how many waves per second a wavelength produces). (figure 24)

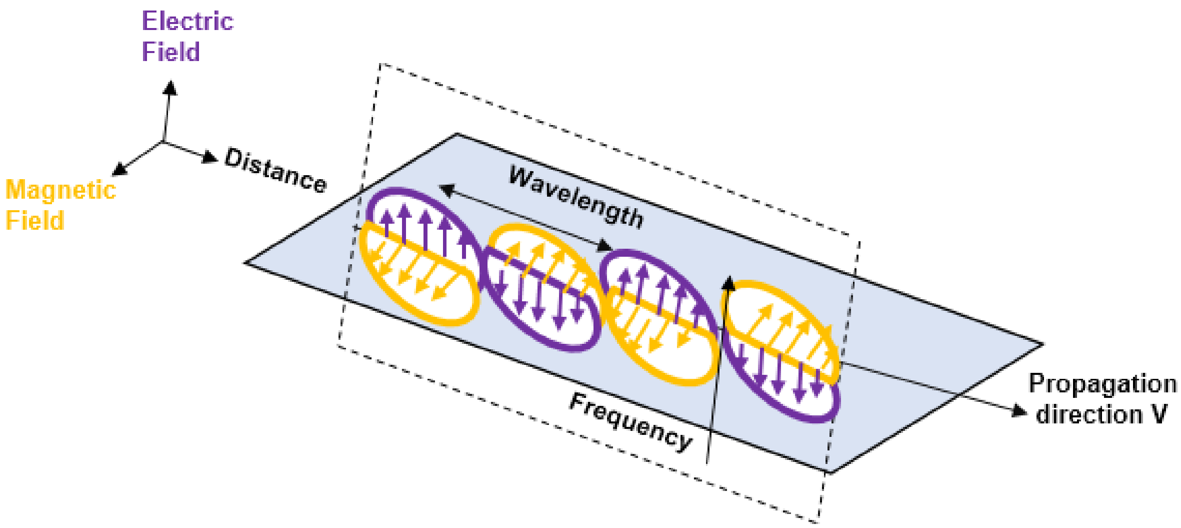


Figure 24: Electromagnetic radiation

11.1 Reactions of the electromagnetic radiation

When incident radiation interacts with the target, some outcomes can occur (Bonn & Rochon, 1992):

- Absorption: This process involves the conversion of incident radiation into heat, thereby influencing the internal energy of the object.

- Reflection, refers to the proportion of energy that is reflected compared to the energy received. In the case where the sun is the source of the incident energy, the reflectance is commonly referred to as albedo.

- Transmission: This is determined by the ratio of energy that is transmitted through the object compared to the energy received. (figure 25)

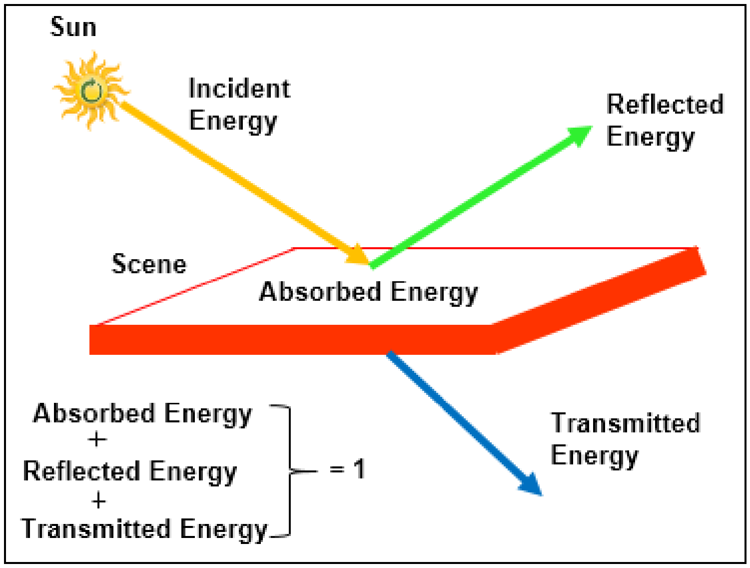


Figure 25: Absorption, reflex ion and transmission (Bonn & Rochon, 1992)

12 Electromagnetic spectrum

The electromagnetic spectrum (figure 26) includes a variety of traveling waves, including those emitted by the Sun. It is represented by a long line, with one end composed of radio waves with the longest wavelengths and lowest frequencies in the spectrum. A single radio wave covers the length of a football field.

- Following the radio waves come microwaves, which generate more energy because to their shorter wavelengths and higher frequency. Infrared light follows suit.

- Visible light is a short section of the electromagnetic spectrum that lies between infrared and ultraviolet light.

- Within the visible light spectrum, red wavelengths have the lowest frequencies and longest wavelengths. As one proceeds from red to orange, yellow, green, blue, and violet, the wavelengths shorten and the frequencies increase.

- Beyond visible violet light, we enter the region of UV frequencies.

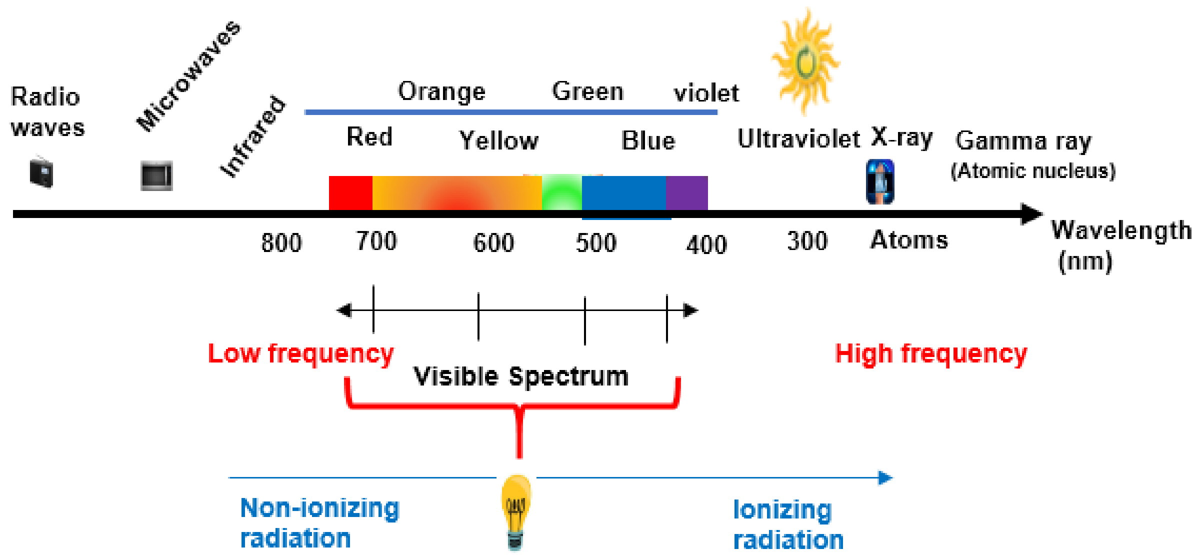


Figure 26:Electromagnetic spectrum

13 Characteristics of remote sensing imagery

Electromagnetic energy can be detected using photography or electronics. Photography and electronic processes acquire electromagnetic energy in different ways. The first process uses a chemical reaction on a light-sensitive surface, whereas electronic operations use sensors to capture and store energy changes.

Sensors act similarly to the human eye in that they can capture visible light wavelengths, which are subsequently interpreted by the brain as different colors. This information is then digitally saved in a file, representing the complete wavelength range and allowing numerical data to be integrated using the primary colors red, green, and blue. Thus, most photos share the attribute of being constructions of grey or color tones. There are significant disparities between photographic imagery on the one hand and images obtained by non-photographic sensors on the other.(Schmit, Maire, & Humbert J., 2001)

13.1 Spatial resolution

Spatial resolution is a key consideration in remote sensing, as it directly impacts the level of detail in an image. When the pixels in a satellite image are larger, the resulting image provides a more generalized representation of objects, lacking in finer details. Conversely, when the image resolution is low, the level of detail is insufficient. The ultimate objective in remote sensing is to obtain a highly detailed image with the best possible resolution, which requires minimizing the distance between two adjacent objects that can be distinguished by the sensor.

The distance between the observed target and the platform plays a crucial role in determining the image size captured by certain sensors. For instance, the spatial resolution of an image captured by a passive sensor is determined by its instantaneous field of view. This field of view represents the visible surface at a specific altitude and time. (figure 27)

In order to differentiate elements on the observed surface, the distance from the sensor to the surface, known as the resolution cell, is of utmost importance. For an element to be detected, it must be equal to or larger in size than the resolution cell. This parameter is critical in achieving higher image resolution and capturing finer details in various remote sensing applications.

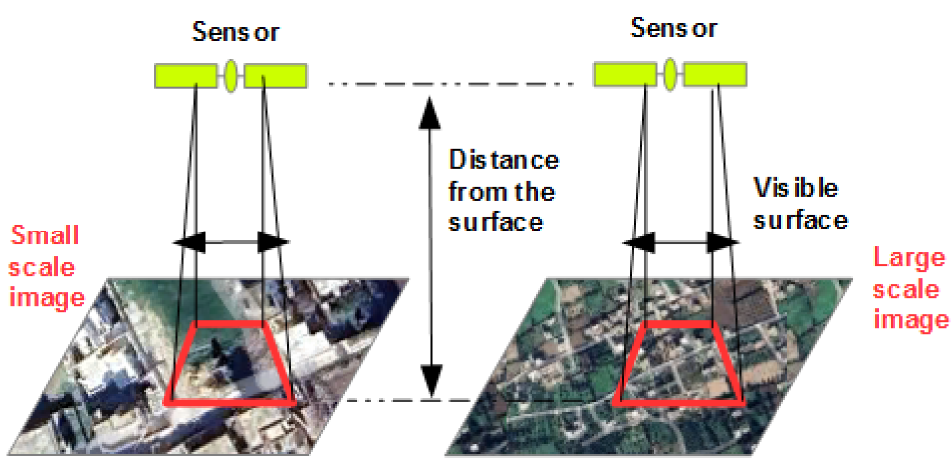


Figure 27:Impact of spatial resolution on elements detection.

13.2 Radiometric resolution

The radiometric properties of a captured image define the data it contains. These properties determine the detector's sensitivity to the intensity of electromagnetic energy, which in turn affects the level of detail that can be discerned. A higher radiometric resolution indicates a greater sensitivity of the detector to subtle changes in energy intensity. On the other hand, the dynamic range refers to the range of wavelengths to which the detector can respond.

In the binary-encoded image data, the intensity levels are represented. These levels are usually displayed in grayscale, where black represents a numerical value of "0," and white represents the maximum numerical value.(Ose, Corpetti, & Demagistri, 2016)

To produce a colored image, many images can be captured by a same sensor, in many different bands (for instance, in three different wavelength ranges) , and then combined, where, each band is assigned a color (red, green, or blue). (figure 28)

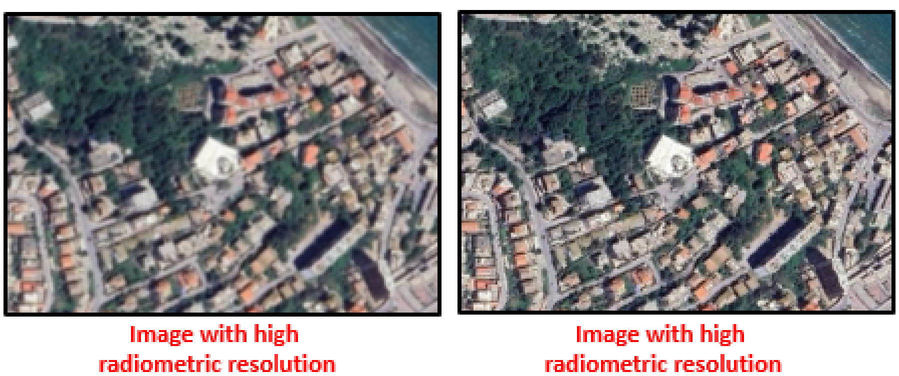


Figure 28: Sensitivity of detectors in representing images with high/low resolution

13.3 Temporal resolution

Temporal resolution is the frequency or repeat rate with which a sensor revisits a given area on the Earth's surface. The resolution is governed by the sensor's unique properties and the satellite's orbit pattern. It is also valuable in time series analysis, particularly in applications such as deforestation monitoring, where the ability to collect repeated coverage allows for the detection of changes in infrastructure, troop movements, or the introduction/modification of equipment. The presence of cloud cover over a specific place might also influence the feasibility of capturing repeated photographs. To characterize temporal resolution, the time interval between successive photographs of the same ground location acquired by the sensor is measured. The actual temporal resolution varies according on the platform employed, with satellites often sticking to fixed return periods based on their orbital features, whereas unmanned aircraft systems and aircraft provide multiple return times. (Kotawadekar, 2021)

14 Image processing chain

Remote sensing produces flat territory representations, what means that the obtained information in form of images require processing and interpretation to be extracted. The image processing chain is a fundamental sequence of procedures that extracts meaningful information from images. While the specific steps may differ based on the sensor or project, they often include:

1) Preprocessing: transforming raw data into precise spatial and radiometric values.
2) Processing: using the data to answer questions about material composition, surface roughness, and object height.
3) Postprocessing: removing errors and preparing the results for further study.

There are two types of adjustments that can be performed during the preprocessing step: radiometric and geometric. Radiometric corrections assist us in correcting issues such as sensor irregularities or atmospheric noise that may affect the accuracy of the data we collect with sensors; they also allow us to convert the data into an accurate representation of the reflected or emitted radiation measured by the sensor. Geometric corrections rectify distortions caused by changes in the Earth's location relative to the sensor, allowing us to convert the data into actual coordinates on the Earth's surface, such as latitude and longitude.

When digitalized, remote sensing data can be effectively processed and analyzed through computer systems. This processing can serve to improve the quality of the data before it is visually interpreted. Additionally, automated processing and analysis techniques can be employed to identify specific targets and extract valuable information without the need for human intervention. Nevertheless, it is important to note that digital processing and analysis methods are typically utilized in conjunction with human interpretation, serving as a supportive and complementary tool.

The step of assigning labels to various elements within an image is known as image classification. it aims to generate detailed maps of land use/cover resulted from adding many spectral bands in this process. Ultimately, Advanced remote sensing tools, such as softwares, are often utilized in accurately categorizing a range of features.

15 Elements of visual interpretation

When evaluating disparities between targets and their backgrounds, interpretations are generated using a variety of variables. These features include tone, shape, size, pattern, texture, shadow, and connection. The table below describes each characteristic of interpretation:

Table 6: Description of variables used for visual interpretation of images

Characteristics	Description
Tone	It refers to the lightness/darkness of an of an object/area.
Shape	The shape refers to the outline of an object/area.
Size	Size is the dimensions of an object/area.
Pattern	Pattern are the arrangement of features within an object/area.
Texture	It is the surface characteristics of an object/area.
Shadow	It denotes the shaded regions created by an object as it obstructs light from reaching the ground or a surface.
Association	Association pertains to the spatial connections existing between objects/regions.

Chapter 5: Application of GIS and remote sensing in the water sector

Overview

The visualization and analysis of data gathered through remote sensing methods within GIS are two functionalities employed in hydrology to oversee and understand the dynamics of water resources for strategic planning over extended periods. This can lead to the development of effective water distribution systems, the pinpointing of water contamination origins, and the assessment of potential hazards like droughts/floods and water pollution occurrences. Consequently, GIS and remote sensing have pivotal roles in ensuring the sustainable utilization and preservation of precious water reserves.

To help students in familiarizing themselves with the ArcGIS software for the first time, fundamental principles and clear-cut guidelines are presented as a basic overview on how to visualize and analyze data.

1 Georeferencing

Georeferencing involves the assignment of geographic coordinates, specifically latitude and longitude, to digital photographs, maps, and other spatial data. This process enables the examination and editing of such data within a geographical context, facilitating their integration into Geographic Information Systems (GIS) and other geospatial applications.

The integration of disparate data sets into a unified geographic framework is made possible through georeferencing. As a result, this technique finds utility in various fields of study, including urban planning, agriculture, environmental science, and archaeology.

Georeferencing can be accomplished through different methods, namely manual digitizing, automatic registration, and ground control point procedures. The accuracy of georeferencing is influenced by the technology employed, the quality of the data, and the level of detail required for the intended application.

In this particular section of the course, a comprehensive example will be provided to illustrate the process of conducting georeferencing for a Google Earth image.

2 Preparation of the image and the target coordinate system

To initiate the ArcGIS program on your computer, you can either access it through the start menu or by clicking on its desktop icon. Once the program is open, proceed by selecting the desired coordinate system for your image. Afterward, it is recommended to disable the auto adjust feature located in the Georeferencing bar. In the event that this option is not visible or accessible, you can alternatively find it in the geoprocessing toolbar or the drop-down menu. By deselecting the Auto Adjust Bottom option, you gain greater control over the georeferencing process and minimize the risk of image distortion or misalignment. This allows the user to manually adjust the bottom of the image to align with the bottom of the target coordinate system's extent (figure 29).

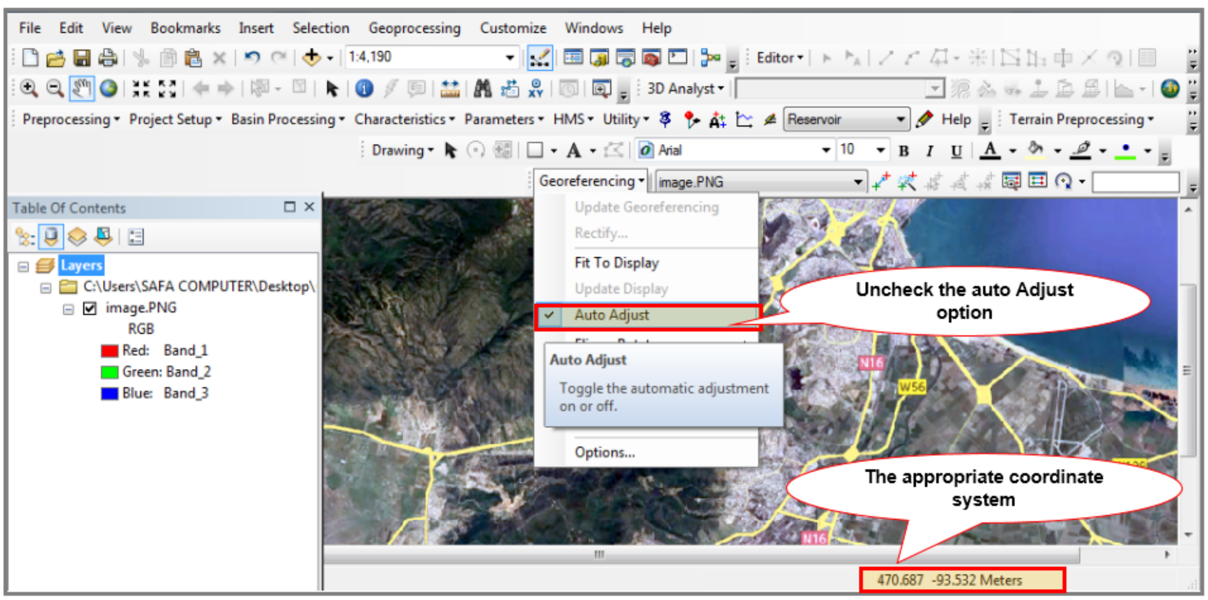


Figure 29: Selection of the appropriate coordinate system for the image

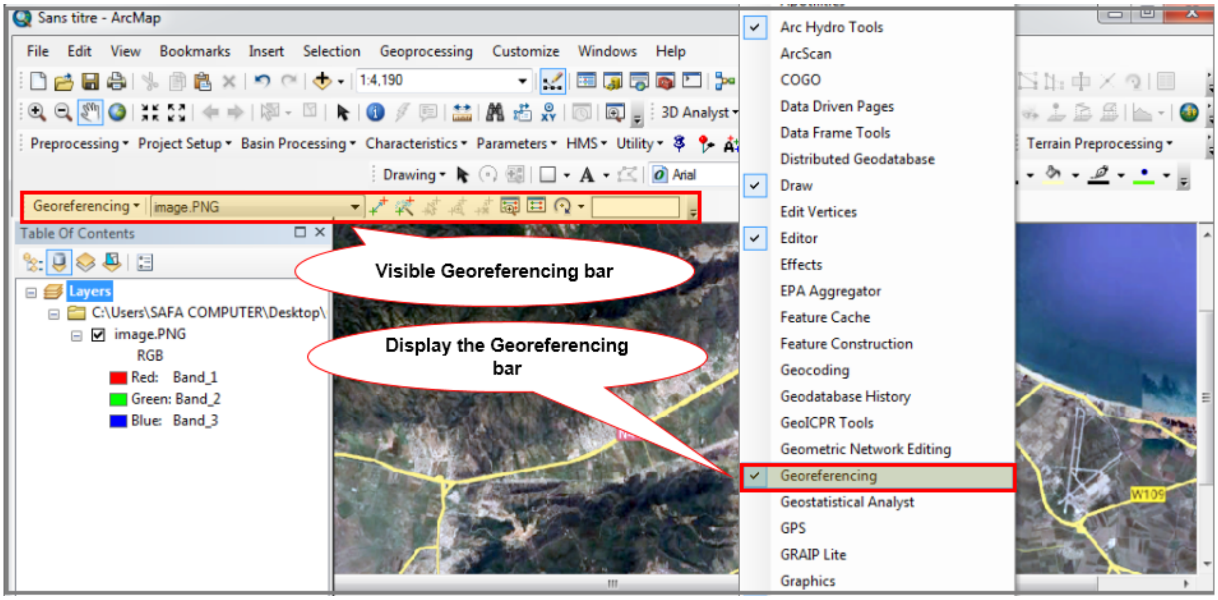


Figure 29: Selection of the appropriate coordinate system for the image

- Select the raster image in PNG file format to be incorporated in ArcMap program, then lunch the program and proceed to create a new map (figure 30).

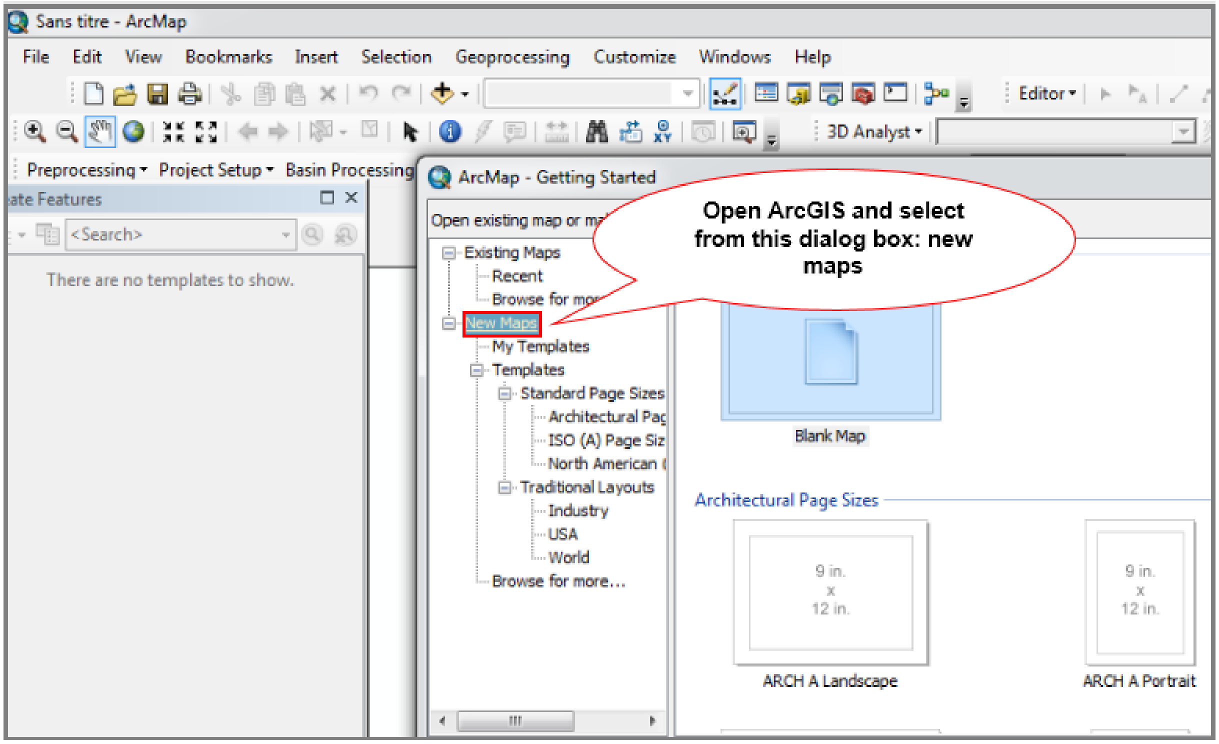


Figure 30: Opening of a new ArcMap

- To retrieve data, choose the option "select data bottom" or alternatively, navigate to "file/add data/add data". Next, locate the desired image within its designated folder. Once selected, the image will be displayed and a suggestion to georeference it will be presented (figure 31).

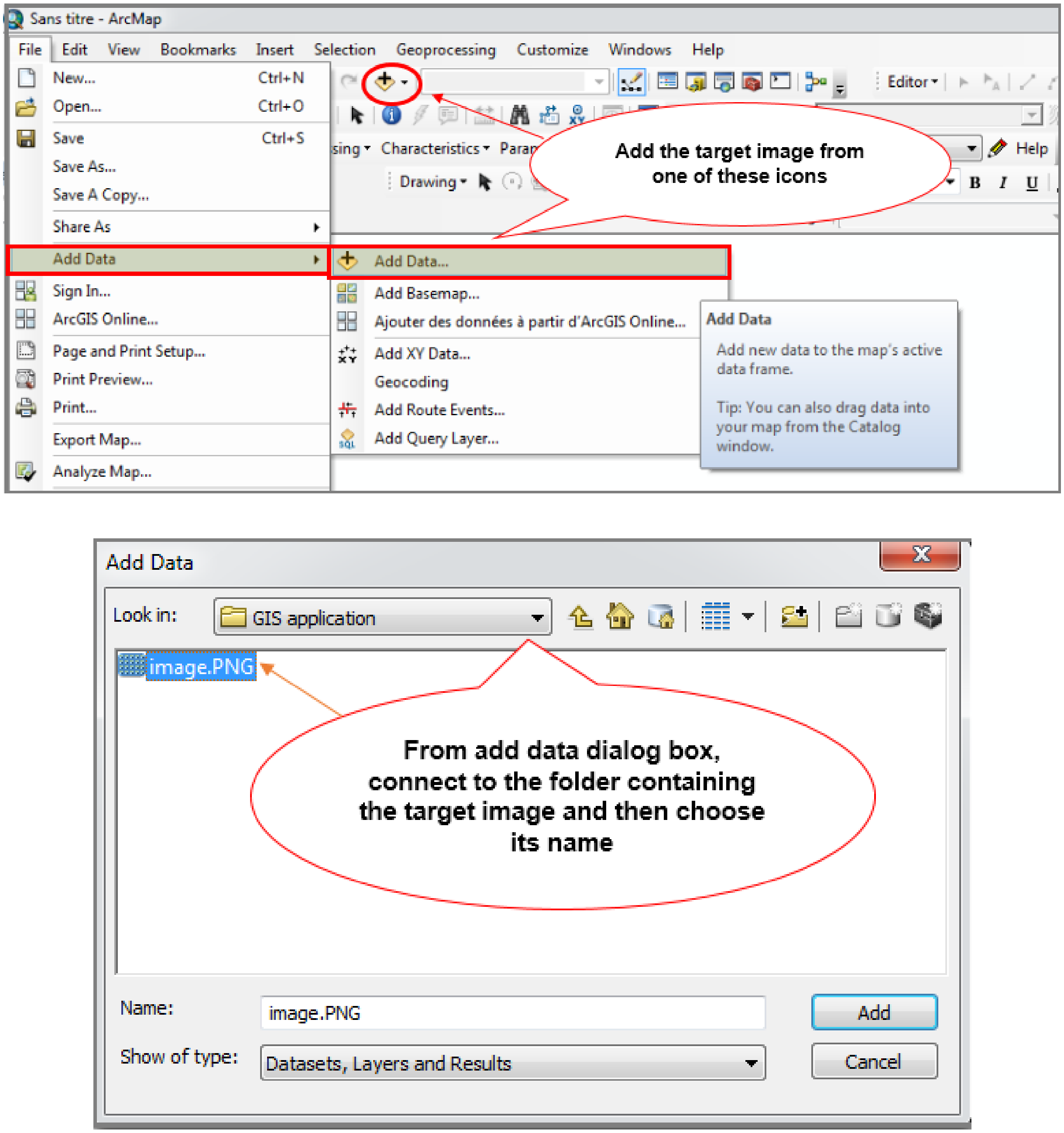


Figure 31: Visualization of the image in ArcMap software

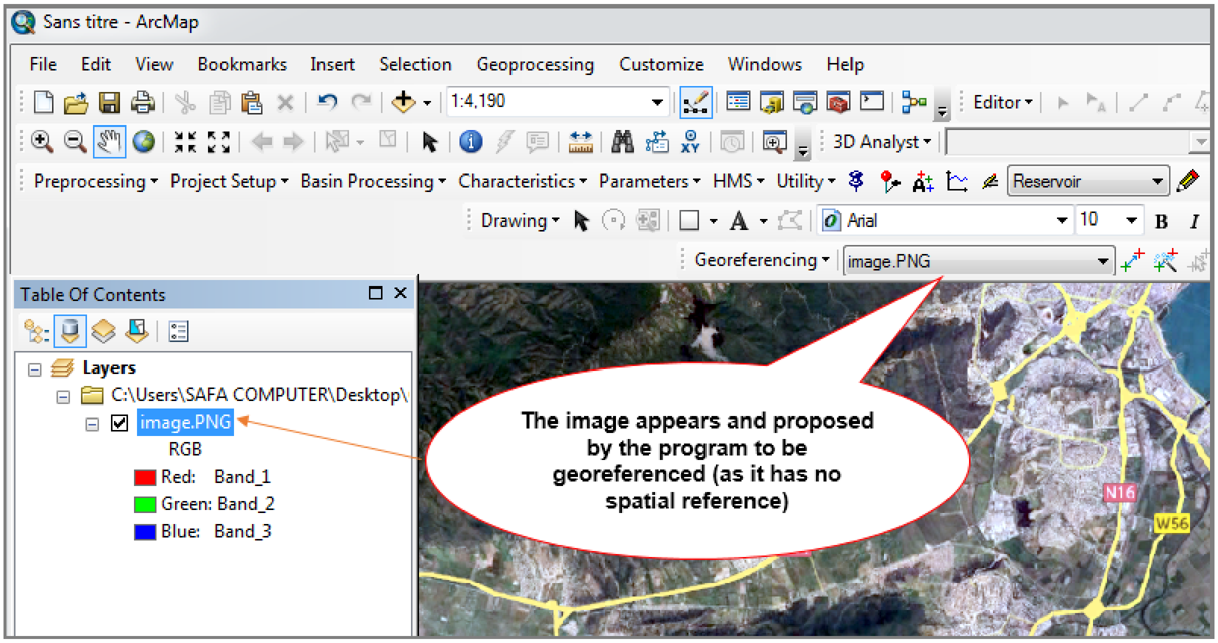


Figure 31: Visualization of the image in ArcMap software

To verify whether the loaded image possesses any reference or not, you have to: 1) Ensure that the image layer is visible within the Table of Contents. 2) Right-click on the image layer and choose "Properties" option. 3) navigate to the source context the "spatial coordinate" Within the "Properties" dialog box.

- If the "georeferencing" section displays "undefined" or "unknown" under the "Geocoordinate system" category (figure 32), it signifies that the image lacks any reference. Conversely, if it exhibits "Yes" or any other georeferencing type, it indicates the presence of a reference for the image.

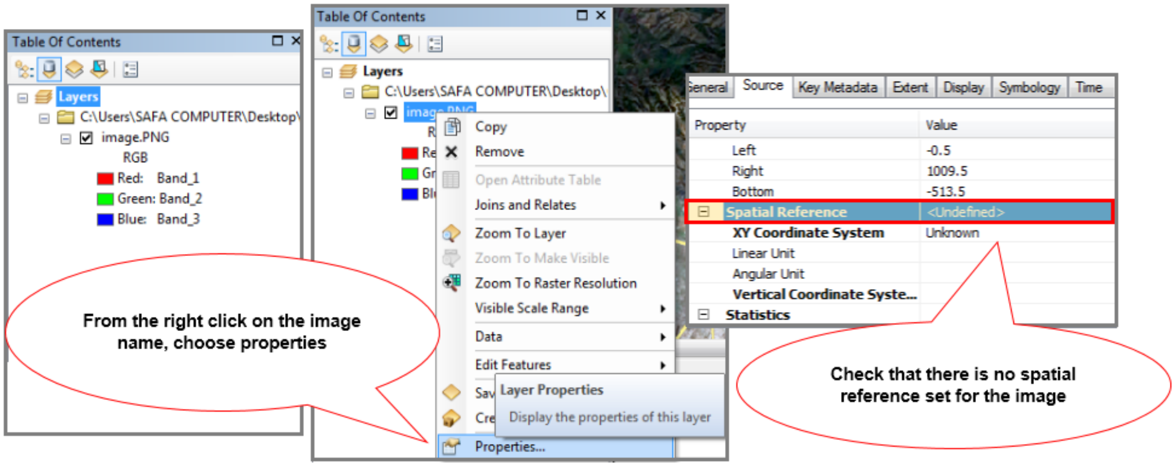


Figure 32: Spatial reference check

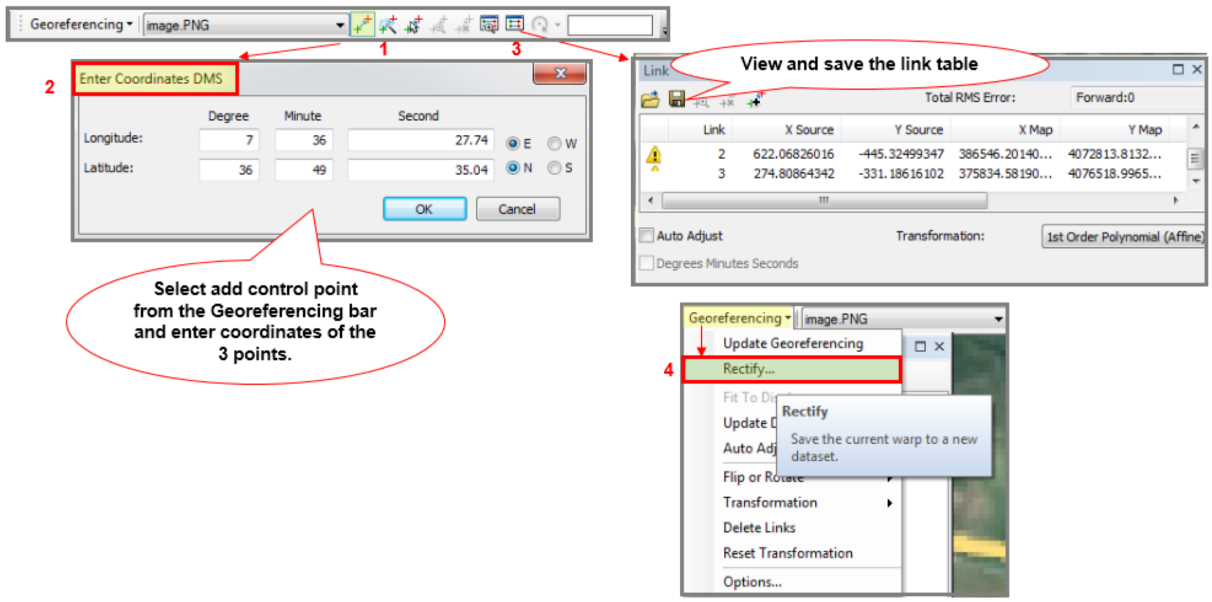
To identify the location where an image was captured, one of the simplest approaches is to utilize Google Earth. To ensure accurate alignment between the coordinate system in ArcMap and Google Earth, the user must select a minimum of three control points with known coordinates. These control points serve as reference points to align the locations on the raster image with the corresponding real-world locations in the referenced images.

In this particular example, road intersections were chosen as control points. The selection of these points was facilitated by utilizing the zoom functionality. Following this, the subsequent steps were carried out:

1. Access the georeferencing bar and select the "Add Control Point" option. Choose one of the road crossings within the image.

2. Right-click on the selected point and input the longitude and latitude in the Degree Minute Second (DMS) format.

3. Click on the "Rectify" option in the georeferencing bar to proceed with the alignment process. Save the georeferenced image in the (.tiff) file format (figure 33).



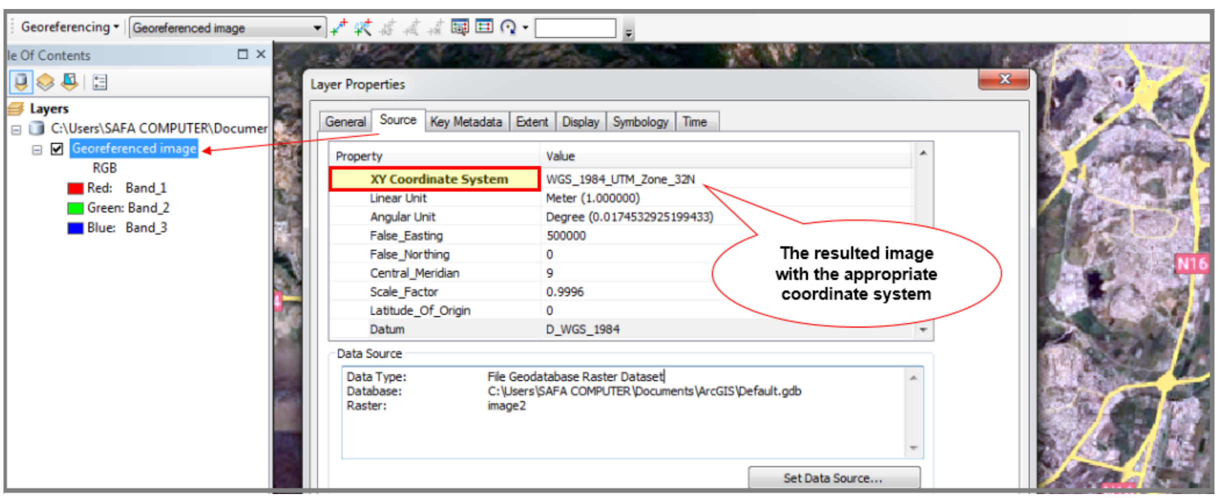


Figure 33: Georeferencing steps using Google Earth

3 *Creation of geodatabase and features dataset for data*

The process of creating geodatabases and features datasets in ArcMap can be accomplished through a series of straightforward steps.

Firstly, in Step 1, a geodatabase file needs to be created in Arc Catalog. To do this, one must open ArcMap and either create a new folder or connect to an existing folder where the database will be stored. Then, by right-clicking on the file in the ArcMap menu, a new geodatabase can be selected (figure 34).

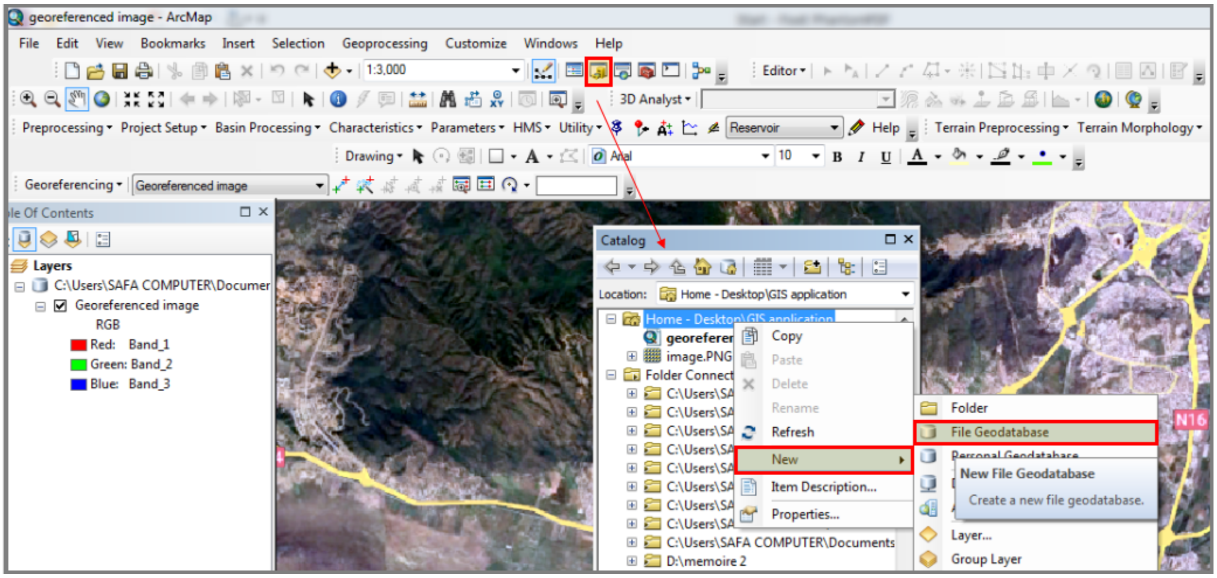


Figure 34: Creation of new file geodatabase

Moving on to Step 2, the creation of a feature dataset is required. This can be done by selecting "new" and then choosing either "feature dataset" or "feature class" within the new geodatabase (figure 35).

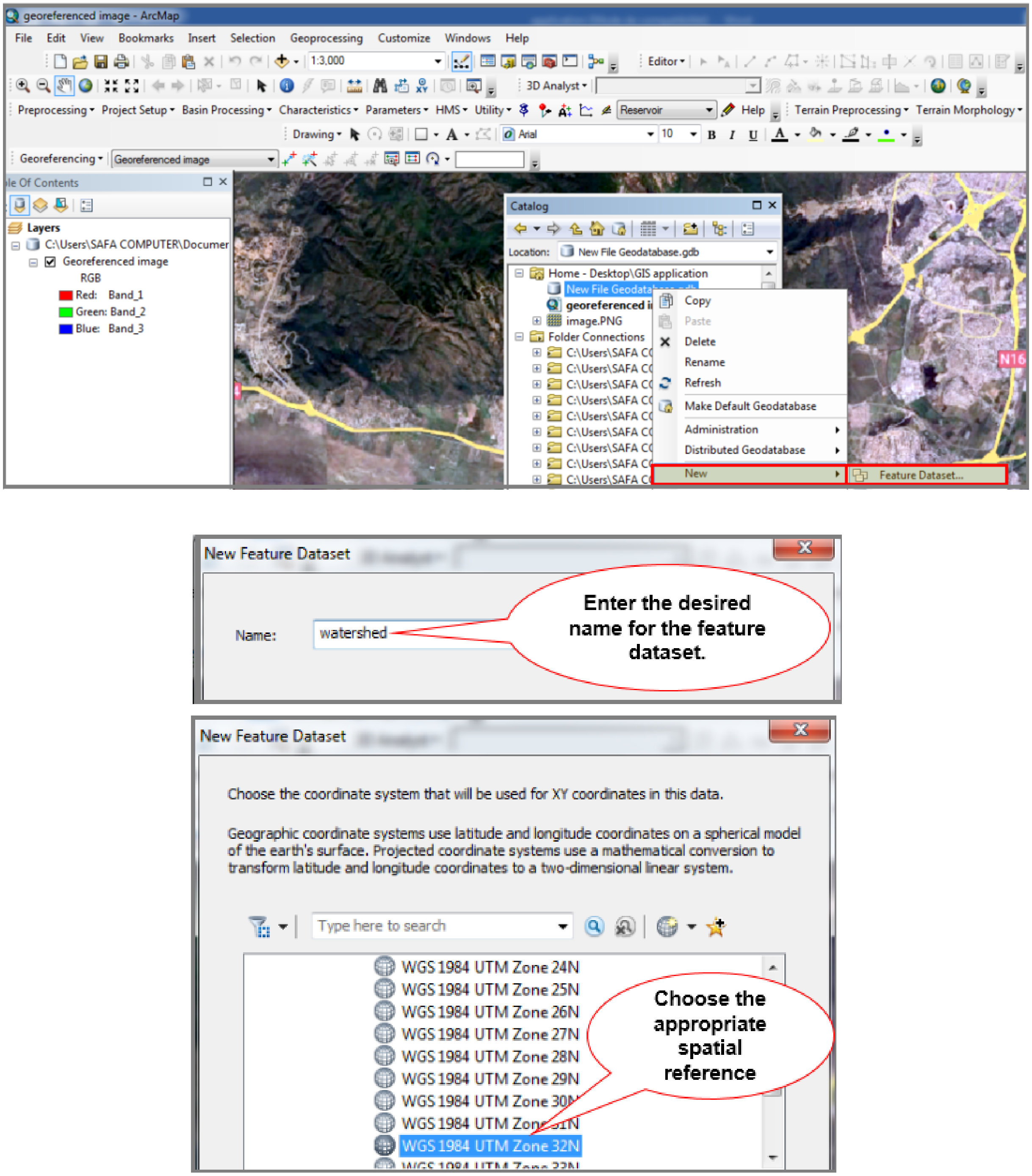


Figure 35: Creation of a new feature dataset

Finally, in Step 3, data can be added to both the geodatabase and the feature dataset. Once the geodatabase and feature dataset are set up in ArcMap, data can be added through three steps. Firstly, the shapefile can be dropped into the geodatabase. If the shapefile has a different format than the geodatabase, the data layer must be converted (figure 36) by right-clicking on its name, selecting "data," then "export data," and finally clicking "ok."

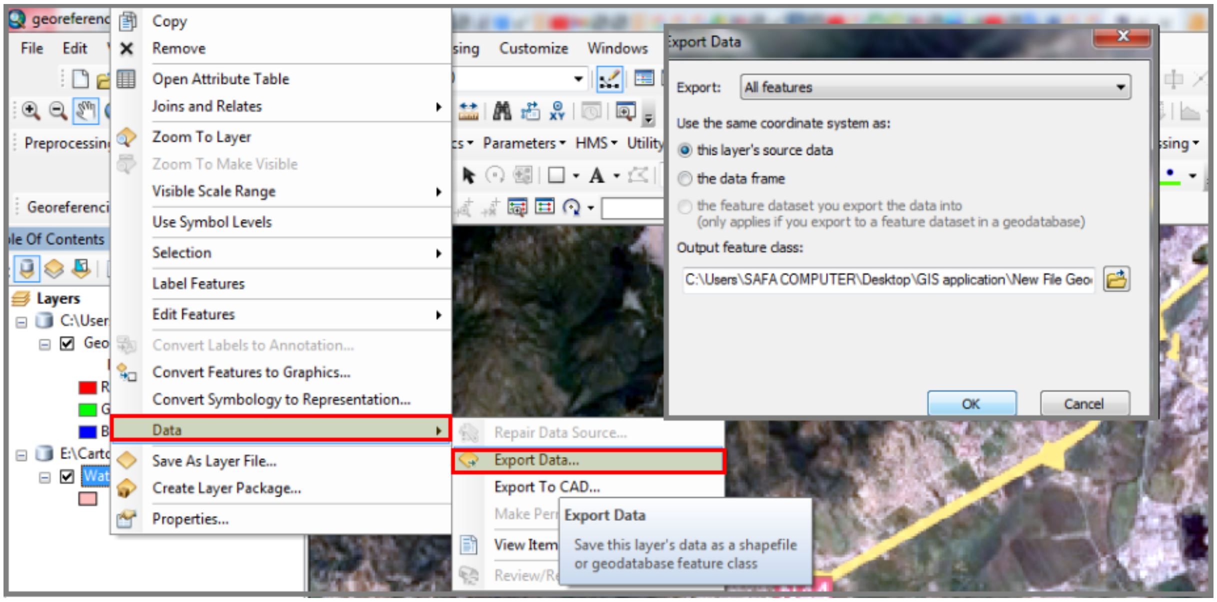


Figure 36: Conversion processes of a shapefile to a geodatabase

Initiating a new feature and incorporating its attribute table, or conducting spatial analysis, can be achieved by choosing a fresh feature class within the geodatabase (figure 37).

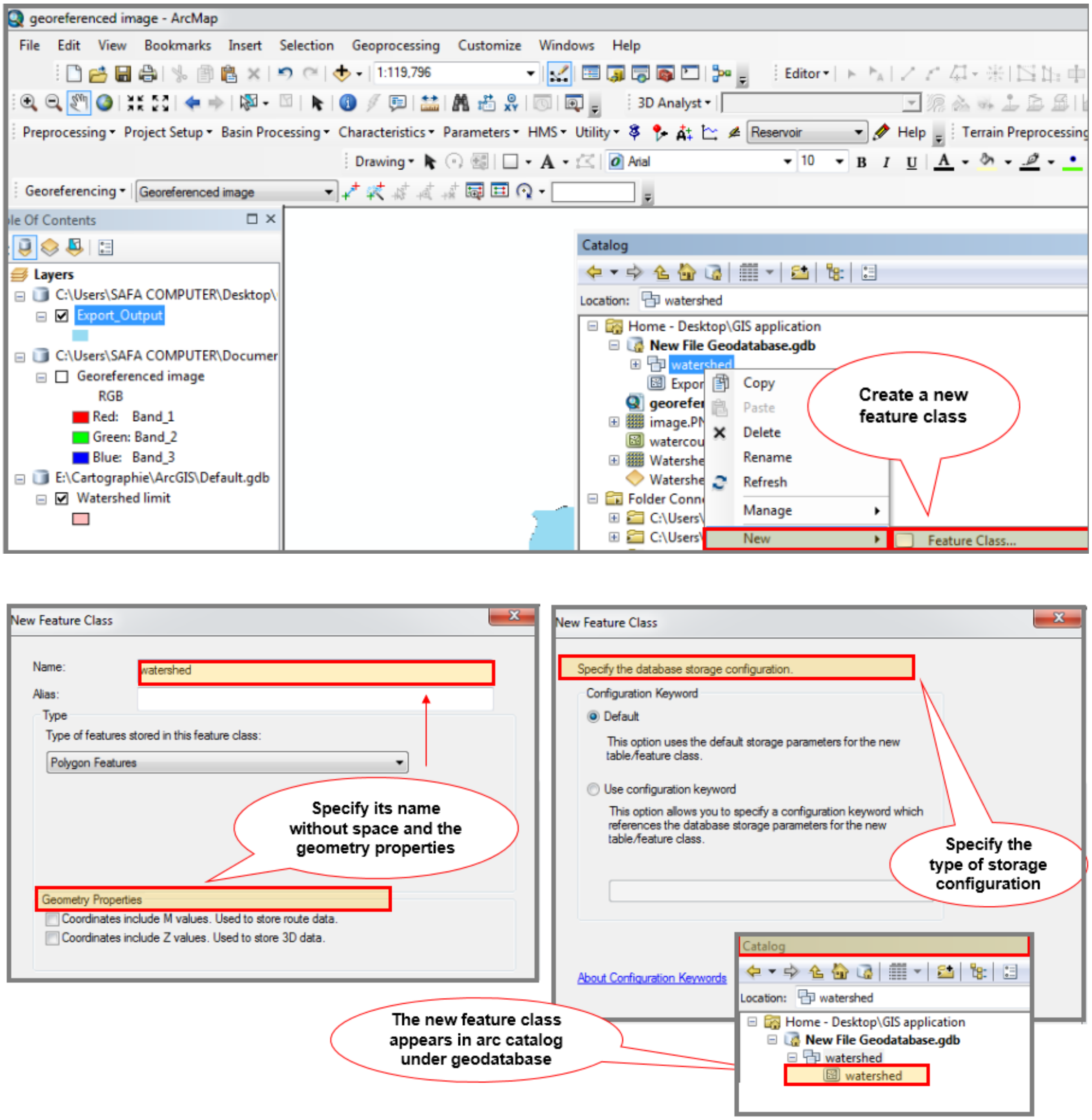


Figure 37: Creation of a new feature class

4 Watershed delineation

The process of delineating a watershed in ArcMap can be accomplished through two methods: utilizing the ArcToolbox or employing the Arc Hydro Tools package. In this particular instance, we will focus on using ArcToolbox to delineate the watershed, following these steps:

1. Prior to commencing the delineation process, it is essential to add the available Digital Elevation Model (DEM) file in ArcMap.

2. Within the main interface of ArcMap, access the "ArcToolbox" window.

3. From the options presented, select "spatial analysis tools" and subsequently choose "hydrology" (figure 38).

4. Proceed with the delineation process using the selected tools and functionalities within the ArcToolbox.

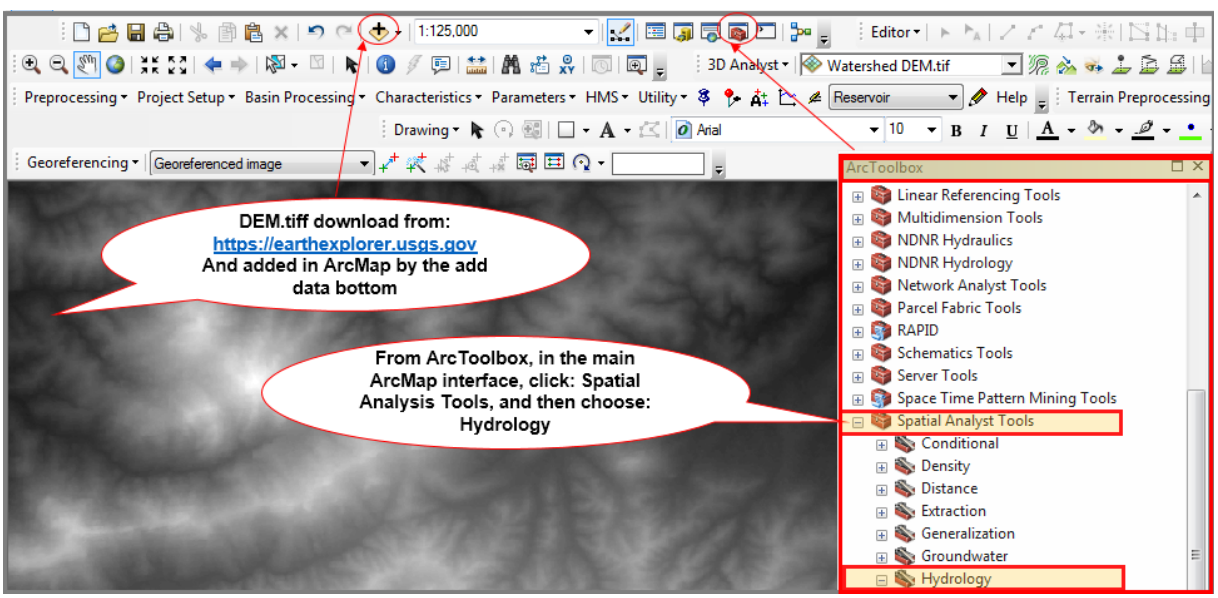


Figure 38: Adding the DEM file

- Remove small imperfections in the surface DEM and create a depression less raster by filling sinks.

- Generate a flow direction grid using the refined fill map as the surface raster input.

- Calculate flow accumulation by utilizing the designated flow direction.

- Develop an outlet shapefile in point format and define its coordinate system.

- Delimit the watershed area and convert it from raster to polygon format for information extraction purposes (figure 39).

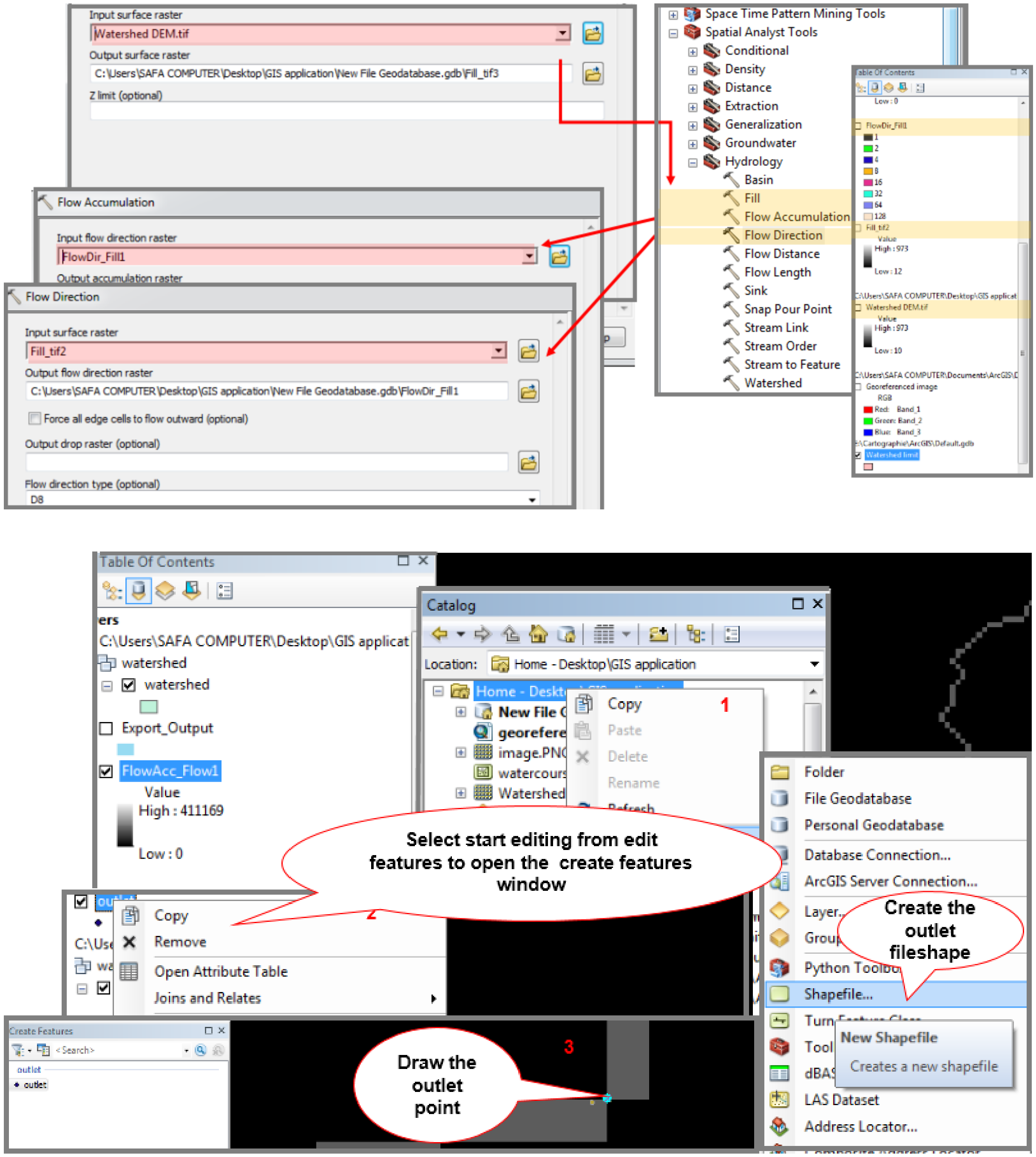


Figure 39: Steps for watershed delineation in ArcMap

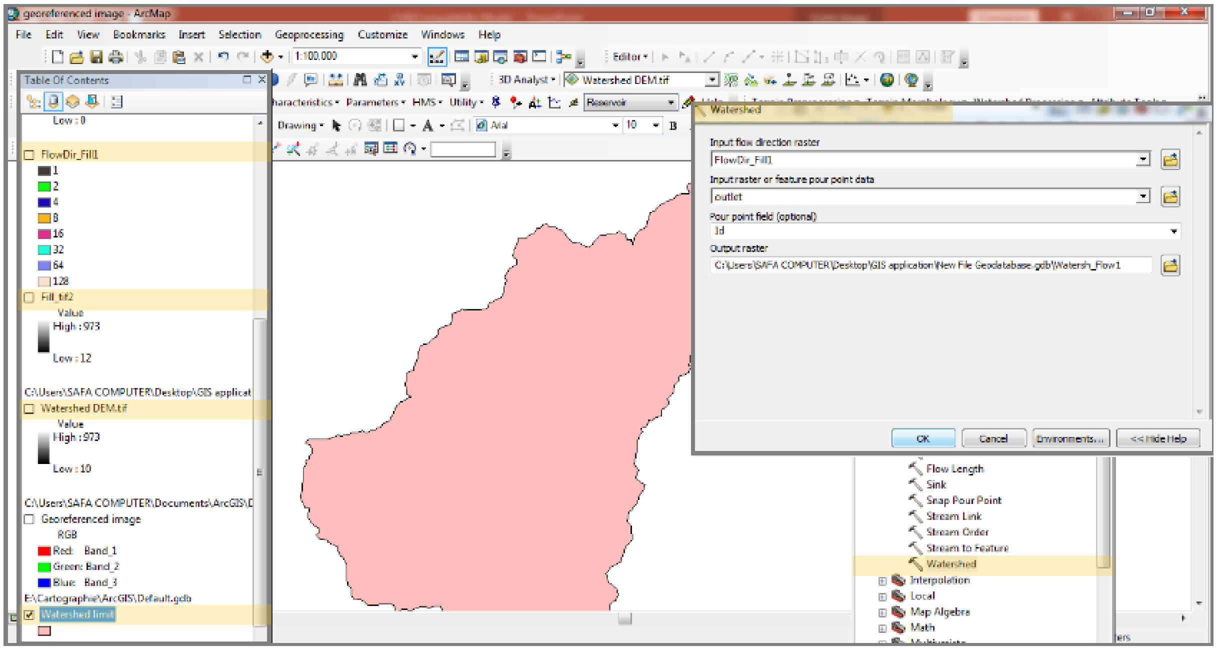


Figure 39: Steps for watershed delineation in ArcMap

Conclusion

The objectives of this course for undergraduate hydraulic students were diverse and significant. Initially, the course sought to acquaint students with fundamental concepts in cartography, data management, and spatial analysis. Subsequently, it aimed to instruct them on the utilization of GIS tools and techniques to address issues pertaining to water and hydraulic resource management. Students were educated on the significance of integrating GIS data within the realm of hydraulic engineering and the environment. Lastly, the course aimed to cultivate students' spatial analysis and data visualization skills, which will be indispensable for their future professional endeavors.

The importance of these objectives lies in their ability to empower hydraulics students to fully comprehend and harness the capabilities of GIS. By acquiring knowledge and skills in this domain, students are better equipped to confront the challenges of their field and effectively work with spatial data. Furthermore, their proficiency in utilizing visualization tools allows them to make informed decisions and contribute to the promotion of environmental sustainability.

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