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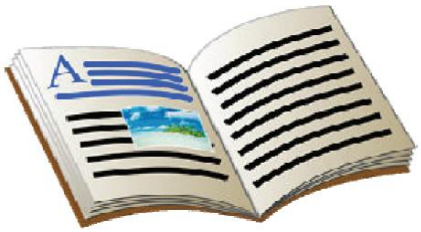
Faculté des Sciences et des Sciences Appliquées

وزارة التعليم العالي والبحث العلمي
جامعة أكلي محند أولحاج
- البويرة -
كلية العلوم والعلوم التطبيقية

Civil Engineering Department

Course handout



Option: Hydraulic Engineering

Degree: License

Geographic Information Systems (GIS)

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2023-2024

People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
Akli Mohand Oulhadj University of Bouira

Civil Engineering Department
License 3, Option: Hydraulic Engineering

COURSE HANDOUT

Geographic Information Systems

Dr. Lyes TAIB
2023/2024

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Introduction

Geographic Information Systems (GIS) represent a vital component of modern technology in the field of geomatics and spatial data management. By combining geographic data with advanced computing capabilities, GIS provide powerful tools for the collection, management, analysis, and visualization of spatial information.

This course module aims to provide students with a comprehensive understanding of the fundamental principles of GIS, as well as practical skills for effectively manipulating geographic data and utilizing advanced functionalities of GIS software.

Throughout this module, we will explore key GIS concepts, including types of geographic data, methods for data collection and processing, spatial analysis techniques, cartography and visualization, as well as practical applications in various domains such as land use planning, environmental management, urban planning, natural resource management, and many others.

By combining theory and practice, this course will equip students with the necessary skills to address complex challenges related to spatial data management and analysis, and prepare them to effectively utilize GIS in their future professional careers.

We are confident that this module will be a rewarding experience, providing students with the knowledge and skills needed to become competent practitioners in the field of Geographic Information Systems.

Chapter I

Geographic Information System (GIS)

Introduction

The first chapter of the theoretical part is essentially devoted to a brief presentation of geographic information in the first place, as it is the "raw material" of a GIS, where we will define it and explain its essential components.

Secondly, we will focus on Geographic Information Systems (GIS). This requires developing some basic elements such as definitions of GIS, historical overview, their components, application domains, etc.

Although this work will not cover all elements of a GIS, such as technical and computer elements, it provides an overall overview of this indispensable tool in the fields of urban management and, of course, heritage management.

I.1. Geographic Information

I.1.1. Definitions

Geographic information refers to any information related to a point or set of points spatially referenced on the surface of the earth. It is of paramount importance for those involved in managing a space or objects dispersed within a given space, ranging from the distribution of natural resources (soils, water, vegetation) to the location of infrastructure (roads, buildings, networks of various facilities), as well as administrative and political boundaries. Even statistical data relating to population, employment, or crime fall within this definition, as long as they have a spatial extent.

The definition of each of the components, information system, and geographic information, helps to clarify its scope:

- ***Information system***

A set of interconnected components that gather information, process it, store it, and disseminate it to support decision-making and control within the organization.

An information system is a technical process of information processing and management, empowered to: collect and encode, store and extract, combine and analyze, visualize and represent information.

➢ *Geographic information*

Information is considered geographic when it relates to one or more locations on the surface of the Earth. This information has the characteristic of being localized, identified, or geocoded.

Geographic information is a value with a dual nature, both spatial and thematic. It is a value that relates to an object that is both physical, demographic, social, political, and economic, on one hand, and spatial, corresponding to a localized object (point, line, and area), on the other hand.

I.1.2. Components of Geographic Information [1]

Geographic data consists of two (02) components: spatial data and attribute data.

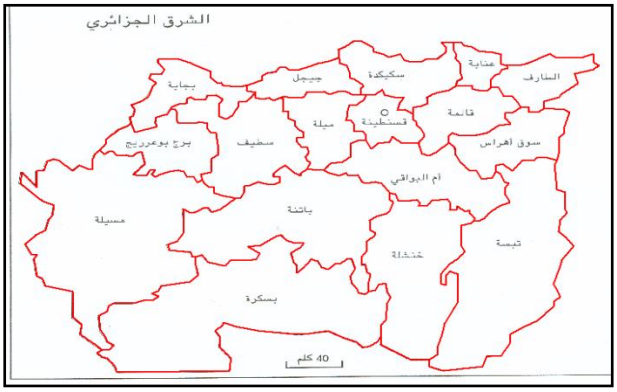
a. Spatial data: represent geographic objects associated with their location in the real world (localized data). Geographic objects are represented on maps by points, lines, and polygons.

b. Attribute data: describe specific properties of geographic objects such as parcel number, bridge width, or vegetation type.

Here are some examples illustrating the relationship between space and attribute:

- A parcel and its number;
- The position of a bridge and its width;
- The location of a natural surface and its vegetation type.

Figure 06 : Spatial data



Source : Auteur, février, 2024.

Figure 07 : Attribute data

ID	Wilaya	Densité_Pop_2008	Nbre_Commerce_2009
1	Béjaia	279,25	44 706
2	BBA	152,73	26 406
3	Msila	39,00	33 146
4	Biskra	34,89	20 213
5	Sétif	229,09	61 144
6	OEB	81,38	25 121
7	CNE	429,12	46 845
8	Taref	122,32	15 908
9	Jijel	247,17	26 218
10	Skikda	223,22	33 194
11	Annaba	423,56	31 018
12	Guelma	117,64	18 234
13	SoukAhras	96,48	14 762
14	Tebassa	45,60	20 208
15	Mila	43,95	26 908
16	Khenchela	39,41	11 900
17	Batna	62,90	37 507

Source : Auteur, février, 2024.

[1] H. HAMMOUM, R. BOUZIDA, « Pratique des systèmes d'information géographiques (S.I.G)», Op.cit. P21 et 22.

I.2. Geographic Information Systems (GIS)

I.2.1. Definitions

A GIS (Geographic Information System) is a Geographic Information System. Numerous definitions appear in the literature for GIS, but they are often incomplete, as they only present one aspect of GIS. According to the definitions from Le Petit Larousse:

A system is a "combination of elements brought together to form a whole."
Information is an "element of knowledge capable of being coded for preservation, processing, or communication."

Geographic is "related to geography, with the object of describing the surface of the Earth." The term "system" here generally implies a computer system.
Computing is "the science of automatic and rational processing of information as a medium for knowledge and communication, implementing hardware and software."

Several aspects are therefore inherent in the concept of GIS. Information is the data, geographic qualifies this information by assuming it is located in space, and system implies that this information is organized within a computer system. However, this purely structural description does not clearly delineate the notion of GIS, particularly compared to automatic mapping systems. Indeed, a map is the conventional representation of the spatial distribution of concrete or abstract phenomena.

Cartography is the set of operations for the development, drawing, and editing of maps.

Automated cartography, or computer-assisted cartography, involves the use of computer techniques in cartography.

A Geographic Information System (GIS) is a collection of computer hardware, software, and geographic data with which users interact to integrate, analyze, and visualize data, identify relationships, patterns, and trends, and find solutions to problems. The system is designed to capture, store, update, manipulate, analyze, and display geographic information.
A GIS allows maps to be represented as layers of data that users can study and use for analysis (ESRI, 2008). It is an automated system that operates using computer technology and follows its tools, mechanisms, and logic.

A GIS is a geographic information management system, comprising spatial databases associated with thematic and relational attribute databases.

A Geographic Information System is a set of digital data, geographically located and structured within a computer processing system, including functional modules that allow for

the construction, modification, querying, and cartographic representation of the database according to semantic and spatial criteria.

I.2.2. Historical Overview[2]

The first operational GIS systems emerged in the 1960s, primarily in Canada and the United States. The undisputed pioneer is the Canadian Geographic Information System (1964), which compiled information regarding land use and environmental data across a large portion of Canadian territory. The software was developed for these specific needs. Two other early achievements deserve mention: the New York Land Use Information System (1967) and the Minnesota Land Management Information System (1969).

Since that time, costs and technical difficulties have significantly decreased, and numerous commercial software options are now available, offering good performance at reasonable prices.

I.2.3. Components of a GIS[3]

A GIS mainly comprises five (05) components:

I.2.3.1. The computer hardware

GIS systems today operate on a wide range of computers, from data servers to networked desktop computers or standalone units. Data processing is carried out using software on a computer. Client-server systems on intranet, extranet, or even via the Internet subsequently facilitate the dissemination of results more and more effectively.

I.2.3.2. The GIS software

GIS software provides the tools and functions to store, analyze, and display all information.

I.2.3.2.1. Typology of GIS software

This software can be categorized into three main families:

a. Desktop General-Purpose GIS

Their primary purpose is the import of external data and their analysis to produce maps for insertion into reports or presentations. They allow for the modification of geometric or

[2] H. HAMMOUM, R. BOUZIDA, « Pratique des systèmes d'information géographiques (S.I.G)», Op.cit. P24.

[3] LAKHDAR. A, Extensions périurbaines de Constantine diagnostic et évaluation, cas de la zone Zouaghi Ain El Bey, Application d'un SIG (MapInfo), Mémoire de magister, Faculté des sciences de la terre, géographie et aménagement du territoire, université Mentouri Constantine, 2011, P15 et 16.

descriptive data, but they do not have sophisticated quality assurance tools for entering complete databases. They have development tools to adapt to any type of application.

b. Management-oriented General-Purpose GIS

They have the same capabilities as desktop GIS software, but are often less user-friendly, yet they have much more powerful modelling tools, which impose constraints on data entry and thus ensure a certain data quality. These GIS also have client/server capabilities, allowing multiple people to work on the same database from remote computer stations. They have development tools to adapt to any type of application.

c. Industry-specific GIS

These software programs are highly specialized from the outset, intended for specific professions. Their scope of application is limited, but they are often the only ones or the best in their field. Nevertheless, they are still GIS because they possess the five functionalities that define GIS: Display, Acquisition, Abstraction, Analysis, and Archiving. Frequently, software vendors market additional modules that transform general-purpose GIS into specialized GIS for specific industries.

I.2.3.2.2. Presentation of some GIS

The following list is not exhaustive but includes some of the most widely used general-purpose GIS software in France, limited to those available on PC:

- MapInfo: A typical general-purpose desktop GIS. It allows for easy creation of various thematic analyses. It enables users to seamlessly open Excel files, open and modify Access files, work with Oracle data, etc. However, its modeling capabilities are limited, it does not support client-server data processing, and working with large databases can be challenging.
- ArcView: Also a general-purpose desktop GIS, although integrating external data can be more complex. It is user-friendly but has limited structuring capabilities and requires additional components for database sharing.
- GéoConcept: Positioned at the boundary between desktop GIS and management GIS. It offers the openness and user-friendliness of desktop GIS and, like management GIS, can work in client-server mode with reasonably sized databases.
- ArcInfo: Its latest version, V8, seems to fall between the first two categories.
- APIC: This is clearly a management system. Integrating external data is cumbersome; however, the software has extensive modeling and group work capabilities.

Source : http://georezo.net/forum/viewtopic.php?id=53501 + traitement, Auteur, février, 2024

I.2.3.3. Data organized into databases

Data are certainly the most important components of GIS. They form the foundation of GIS. Geographic data and associated tabular data can either be internally generated (imported from files) or acquired from data producers (entered by an operator).

I.2.3.4. Methods

The implementation and operation of a GIS cannot be considered without adhering to certain rules and procedures specific to each organization. GIS requires technical knowledge and various skills, and thus involves various professions that can be performed by one or more individuals.

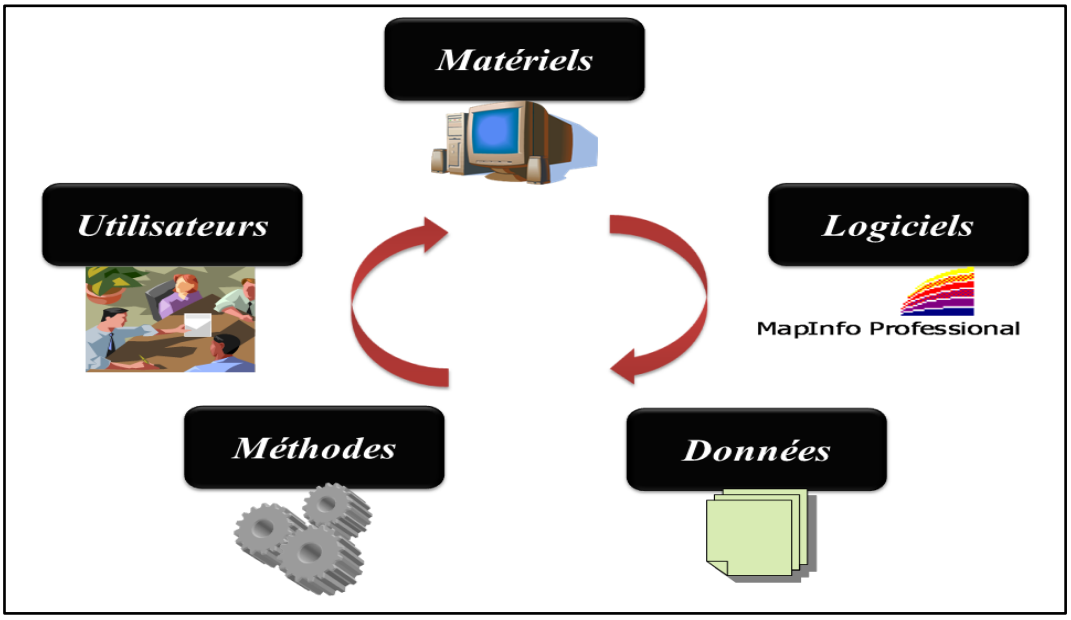
A "GIS professional" must mobilize skills in geodesy (understanding of reference system and projection system concepts), data analysis, modeling processes (such as Merise analysis, UML language), statistical processing, graphic and cartographic semiotics, and graphic processing. They must be able to translate questions into computer queries.

I.2.3.5. Human resources (users)

As a tool, the exploitation of a GIS relies on its usage, which involves one or more users. GIS caters to a large community of users, ranging from those who create and maintain the systems to individuals who incorporate geographic dimensions into their daily work. With the emergence of GIS on the Internet, the user community has significantly expanded.

Since not all GIS users are necessarily specialists, a GIS provides a series of toolsets that users assemble to accomplish their projects. However, becoming a geomatician is not something that happens overnight: a good understanding of the manipulated data and the nature of the processes performed by the software is essential to properly interpret the quality of the results obtained.

Figure 09 : Components of a GIS

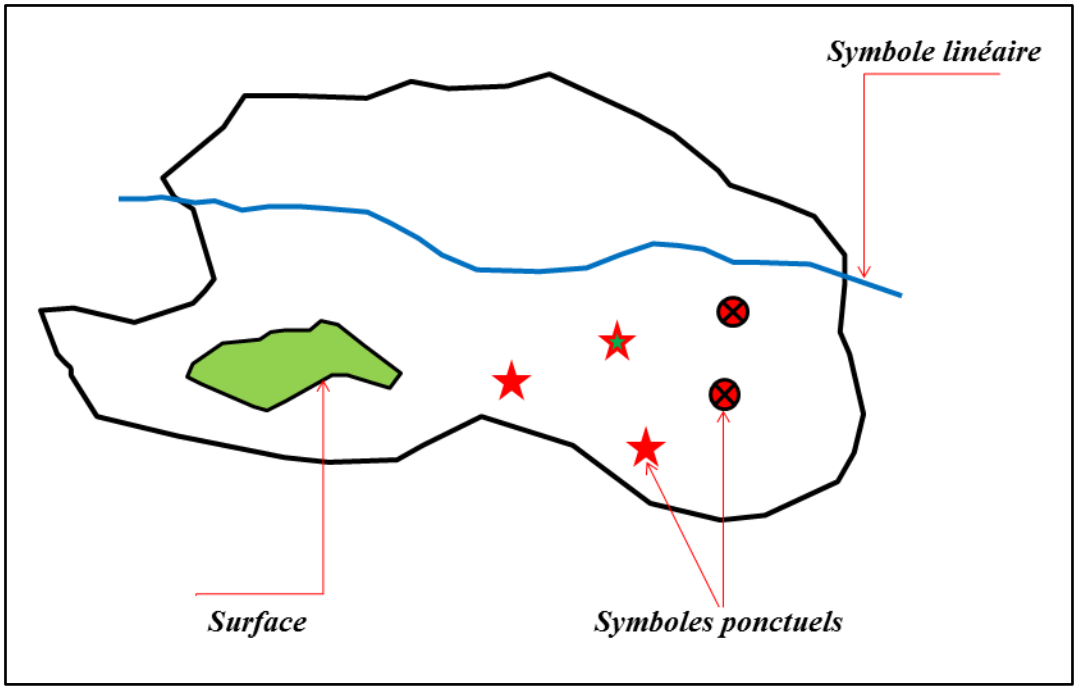


Source : Auteur, février, 2024.

I.2.4. The geographic entities of a GIS

The spatial data in a GIS are modeled from three (03) types of entities: points, lines, or polygons.

Figure 10 : Geographical entities of a GIS

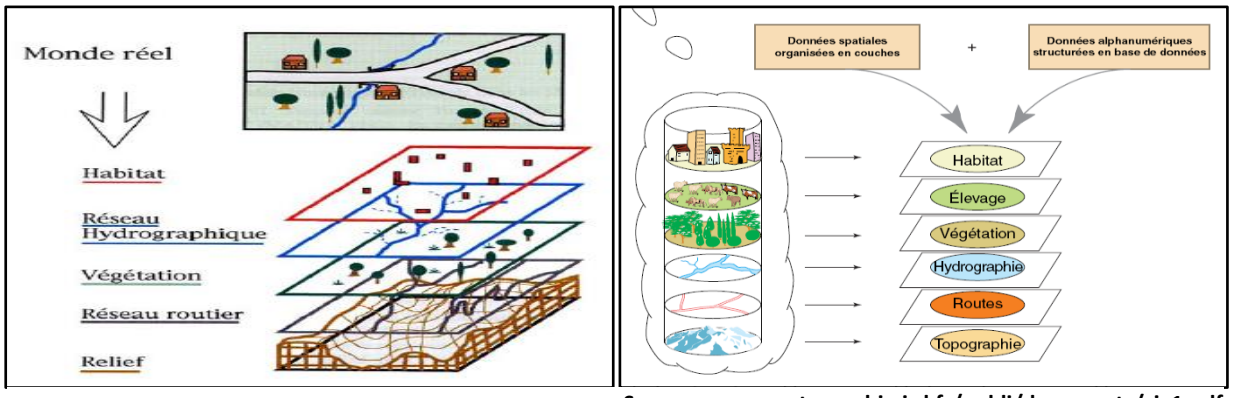


Source : Auteur, février, 2024.

I.2.5. The structuring of geographic information in a GIS

Geographic information is structured by overlaying multiple layers of spatial information organized as layers and alphanumeric data structured in databases.

Figure 11 : Examples of layer stacking in a GIS



Source : www.cartographie.ird.fr/publi/documents/sig1.pdf

Geographic Information Systems utilize two different types of geographic models:

- **Vector Model:**

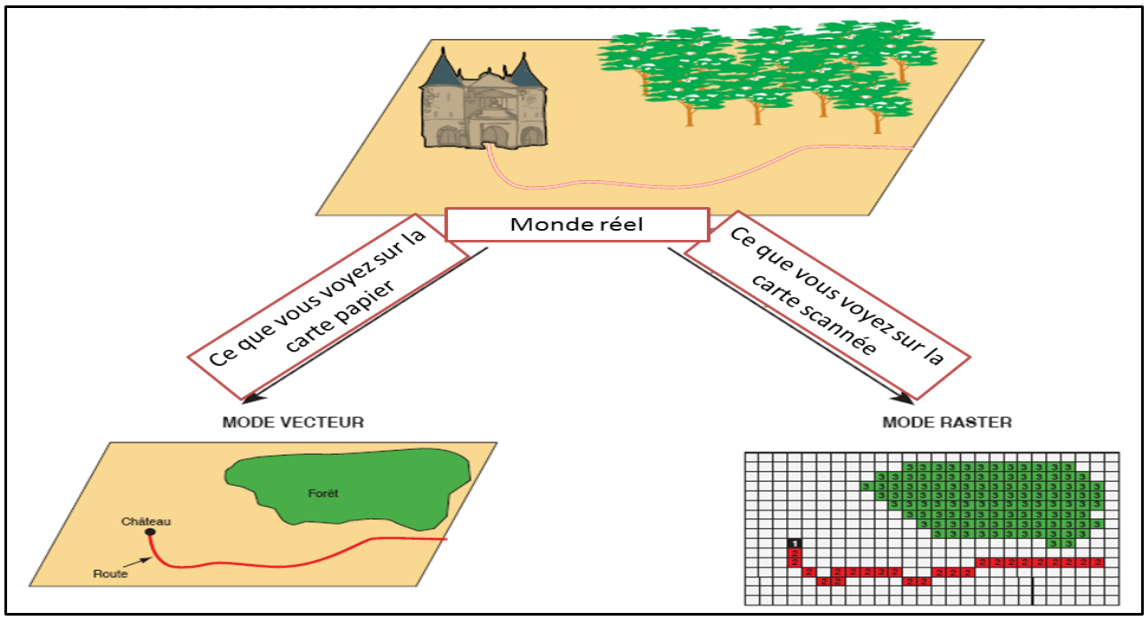
In the vector model, information is organized in the form of x, y coordinates. Point features are represented by single points. Linear features (such as roads, rivers) are represented by a sequence of coordinates (x, y). Polygonal features (such as geographic territories, parcels) are represented by a sequence of coordinates delineating a closed area. The vector model is particularly used for representing discrete data.

- **Raster Model:**

The raster model consists of a matrix of points, each of which can be different from the others. It is well-suited for representing continuous variable data such as soil types.

Each of these two data models has its advantages. A modern GIS should exploit both types of representation simultaneously.

Figure 12 : Modes of representation of geographic information in a GIS



Source : www.cartographie.ird.fr/publi/documents/sig1.pdf

I.2.7. GIS functionalities[4]

The literature that deals with the field quickly defines the expected functions of a GIS by "the 5A's," which are: Abstraction, Acquisition, Archiving, Analysis, and Display.

I.2.7.1. Abstraction:

It's the modeling of the real world through different perspectives.

Constructing the conceptual data schema allows modeling the database by defining the objects (object classes), their attributes, and their relationships. This step is necessary before any digitization, as it serves as the starting point for building geographic databases and as a platform for dialogue among various stakeholders (decision-makers, users, service providers, etc.). The goal of modeling is to make oneself understood by the widest audience possible.

I.2.7.2. Acquisition

We can obtain information from national or international organizations that produce or sell data:

[4] H. HAMMOUM, R. BOUZIDA, « Pratique des systèmes d'information géographiques (S.I.G)», Op.cit. P31-34.

- For reference data: INCT (National Institute of Cartography and Remote Sensing), ANC (National Cadastre Agency), INPS (National Institute of Planning and Statistics), CNTS (National Center for Space Techniques), Spot Image, Michelin, etc.
- For thematic data: ANRH (National Agency for Water Resources), DGF (General Directorate of Forests).
- From local professionals such as surveying experts, state study offices, and local authorities (municipalities).

If the data does not exist in digital form, it is possible to create it oneself or through a service provider.

- Acquisition Techniques

Acquisition from vector data: Sources can be either indirect, such as plans, photos, satellite images, or direct, through field surveys. This acquisition is done either from a digitizing tablet or by scanning data on a computer screen, digitizing objects drawn on the plan into vector data. The disadvantage of this method is the transcription of errors due to the original support (paper deformation, line thickness, etc.).

If the data is scanned and georeferenced, it becomes "raster" data.

- ***Acquisition from photos:*** From orthorectified (scanned) photo to vector data, this is one of the main sources for precise digitization over large areas (the creation of INCT's topographic data for the entire territory is done through photogrammetry). The precision of the data is related to the precision of the photo. This type of acquisition requires either field surveys or cross-referencing with other data to qualify the data; the photo is simply a collection of pixels.
- ***Acquisition from satellite imagery:*** Satellite imagery is the main source of information for land use thanks to remote sensing. Remote sensing is the set of knowledge and techniques used to determine physical and biological characteristics of objects through measurements made at a distance, without material contact with them.
- ***Acquisition from alphanumeric data:*** Literal data allows for the creation (geocoding) or enrichment of data.
- ***Acquisition from the field:*** Generally used for small-scale projects or as a complement to other techniques. GPS surveying (Global Positioning System) provides global-scale

positioning using a set of artificial satellites. Surveying with a theodolite involves measuring angles and distances.

I.2.7.3. Archiving

a. The management

Once acquired, data must be stored and easily retrievable. This is one of the least visible functions for the user. It depends on the software architecture, with the integrated presence or absence of a relational or object-oriented Database Management System (DBMS).

b. The work environment

We are no longer just talking about "storage space" but "workspace." This involves space for project management (organization) as well as the ergonomics of the software (interface).

I.2.7.4. Analyzing

The raison d'être of information systems is not solely the creation of plans or maps or the mere management of data, but rather to be a tool in service of geographic information.

Spatial analysis based on semantics involves the qualitative and/or quantitative description of a space using alphanumeric data stored within the geometric object or in an external database via a link. This analysis can be performed through queries or calculations, often supported by cartography.

Geometric spatial analysis, on the other hand, is based on the position of the object, its shape, and the existing relationships. Distance between objects is one of the simple functionalities of spatial analysis. Relationships between objects can be explored, such as selection based on distance, intersection, or positioning, without modifying the objects. Topology, if available, can be manipulated, and data can be manipulated by cutting, joining, or excluding it.

I.2.7.5. Display

Its purpose is to allow the user to understand spatial phenomena as long as the graphical representation adheres to cartographic rules. Display serves to communicate:

On a computer during the development of a study.

On the internet while adhering to constraints such as file size, color, format, etc.

On paper for working documents, reports, and promotional materials.

While display may not be the core of the system, it remains a crucial element due to the communicative power of maps.

I.2.8. General Functions[5]

In general, a GIS must fulfill the following functions:

- Importation, exportation, introduction, storage, manipulation, and management of multi-source data.
- Selection and querying of spatial and attribute data (geographic objects and attributes).
- Simple or complex queries (combinations of attribute values, arithmetic and logical operations (+, -, /, x, or, and...)).
- Calculations (distance, area, simple and complex formulas).
- Statistics (calculation of relative averages, ratios, and various combinations).
- Interactive analyses using scenario techniques and simulation games (manipulation of variables and visualization of dynamic results, assessment of the effects of an action on the entire system, evaluation of environmental impact, etc.).
- Cartographic reproduction.

I.2.9. Some areas of application of GIS[6]

A GIS typically intervenes appropriately in the following areas:

- Planning and management of spaces of all types and scales.
- Management of territories, cities, domains, and various spaces.
- Environmental management and natural resource management (water, vegetation, etc.).
- Management of networks of all types and scales.
- Management of all phenomena (social, political, economic, and environmental, etc.) in their spatial dimension.

[5] B. BENYOUCEF, Analyse urbaine : Eléments de méthodologie, OPU, Alger, P54.

[6] Idem, P53.

- Management of natural risks.
- Research and modeling of natural phenomena (climate, etc.) and socio-economic phenomena (mobility and transportation, etc.).
- Management of the location of businesses and other facilities, etc.
- Management and preservation of heritage.

I.2.10. The three dimensions of GIS projects[7]

Three dimensions of GIS projects can be identified. The first is the organizational dimension, which includes the organizational context of their implementation (individual projects, departmental, organizational, inter-organizational projects, level of involvement and strategies of stakeholders, characteristics of the organizations involved) and the organizational objectives assigned to the projects (improving individual effectiveness of people or services, improving coordination within the organization).

The second dimension is the territorial dimension: which territory is concerned, what role (integrator) does it play in the GIS project (or projects), what territorial phenomena do we wish to study with the GIS (not thematic domains, but complex situations generally involving multiple thematic domains), what are the objectives pursued on the territory concerned by the implementation of the GIS?

The third dimension is the thematic dimension: which areas of activity are concerned by the GIS, what questions are asked regarding these various domains (themes), are they single-themed or multi-themed GIS?

The concept that connects each of these three dimensions is that of actor: the person, the service, or the organization (depending on the level at which one is placed), which is situated in the organizational context and evolves it, which plays a role on the territory concerned through a certain number of areas of activity (thematic), and is involved notably in inter-organizational partnerships. We will subsequently use the term "actor" to refer to individuals rather than services or organizations.

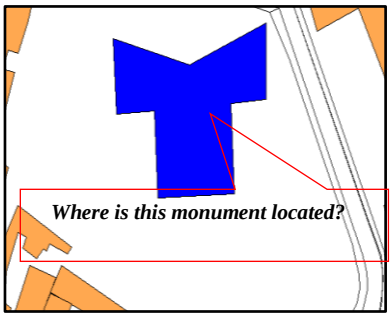
[7] Géo-événement 2006 – Henri PORNON – SIG : outil transversal ? - HP_Geoev2006.doc – 21/04/2006 – P2 et 3.

I.2.11. Advantages

- The key capabilities and benefits of a GIS include:
- Capacity and reliability of data storage.
- Speed of data retrieval.
- Integration and combination of data from different sources.
- Precision of cartographic processes and cost-effective repetition.
- Ease of updating: tools and tracking.
- Ability to analyze spatial relationships between objects or geographic phenomena.
- Production of maps: good quality-to-price ratio and time-saving.

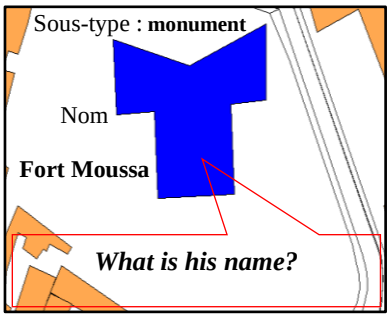
I.2.12. The fundamental questions that a GIS must be able to answer

- **Where? Where is this object? Where is this phenomenon located?**



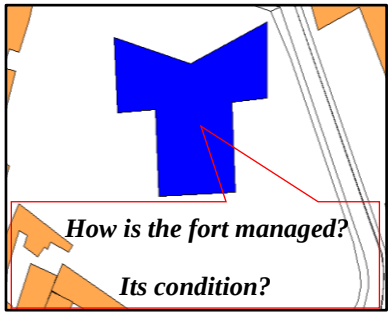
More generally, where are all objects of the same type located? This question helps to highlight the spatial distribution of an object.

- **What? What can be found at this location?**



The objective is to highlight all objects or phenomena present in a given territory.

➢ **Comment ? Quelles relations existent ou non entre les objets et les phénomènes ?**

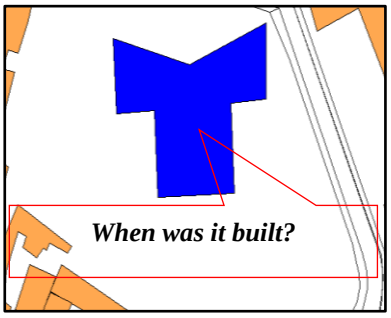


This is the problem of spatial analysis.

- **When? At what point did the changes occur?**

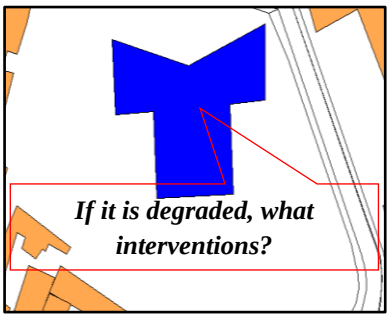
What is the age and evolution of such object or phenomenon?

This is the issue of temporal analysis.



- **What would happen if such an evolution scenario occurred?**

What consequences would affect the objects or phenomena concerned due to their location?



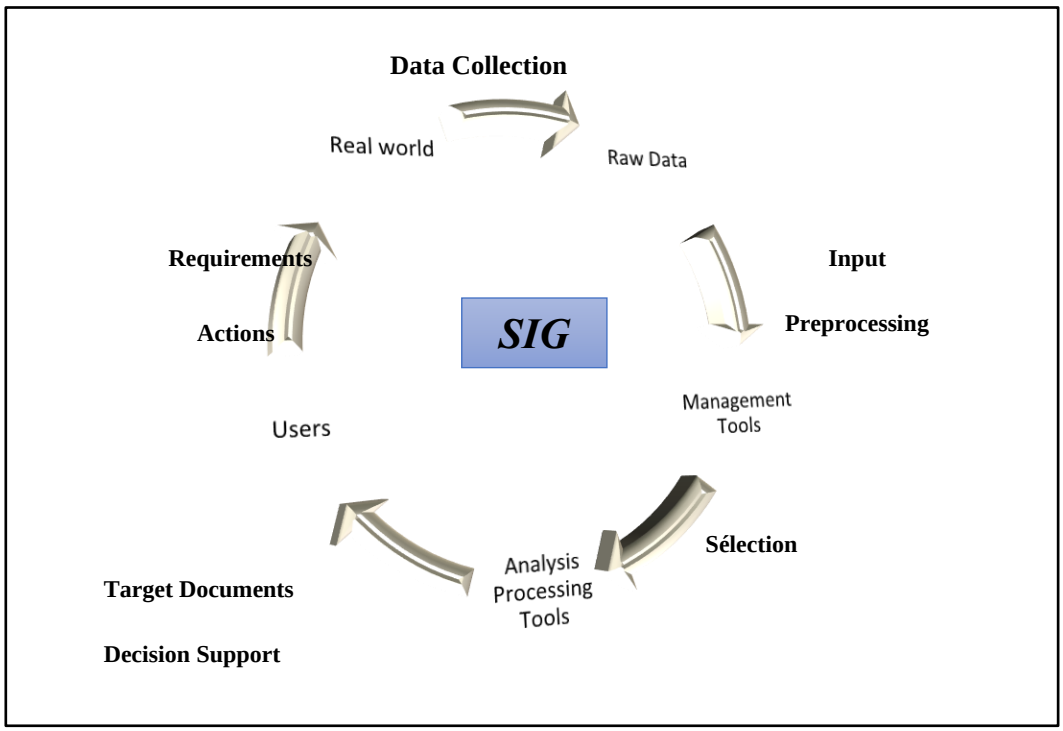
Conclusion

A geographic information system (GIS) requires several elements and factors, such as geographic information, whether spatial or attribute data.

These "raw" pieces of information need to be processed using a variety of analysis tools, namely GIS software, each offering different services.

In conclusion, we affirm the complexity of the GIS process, from data collection to the creation of various thematic maps. The ultimate goal of this process is, of course, the interpretation of the results obtained by GIS to anticipate actions in the real world.

Figure 13: Approach for the Implementation of a GIS



Source : Auteur, février, 2024.

Chapter II

Data representation in GIS

Introduction

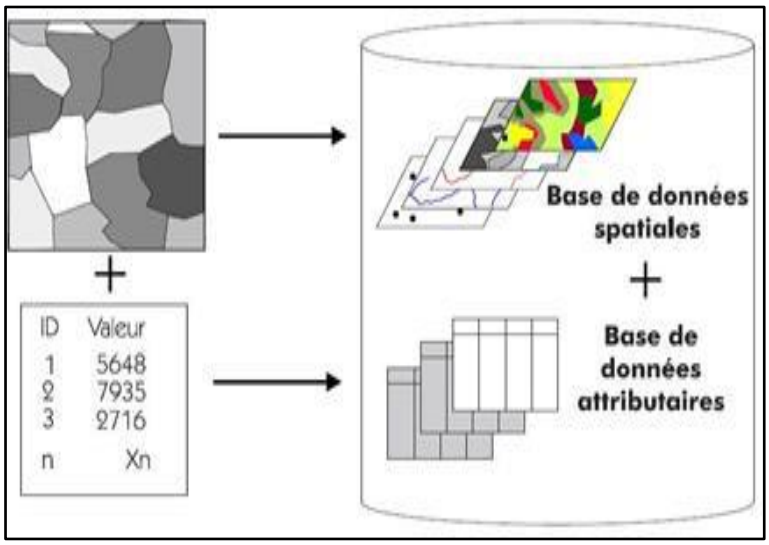
This chapter is devoted to the representation of data in Geographic Information Systems (GIS). It comprises several key points such as data types, data acquisition methods, and the relationship between mapping and GIS.

II.I. Types of Data in GIS

All spatial geometries can be described by four types of properties:

- Their position on the Earth's surface.
- Spatial relationships (topology).
- Their attributes.
- Their metadata.

Figure 1: The types of data in a GIS



Source: https:/www.esrifrance.fr

II.I.1. Spatial / Geographic Data

They determine the spatial characteristics of a geographical entity where all graphic objects are depicted and recognized:

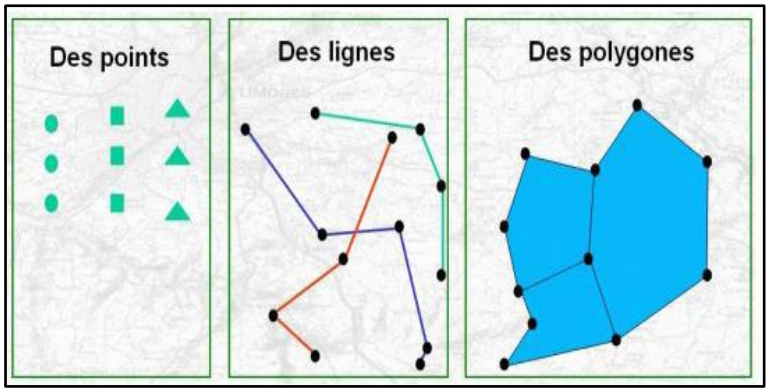
- Location: refers to the coordinates of the object relative to a reference (reference meridian).
- Shape: can be a point, a line, or a polygon.
- Size: length, perimeter, area

In GIS, there are two modes of projecting geographic data:

a. Vector mode: Vector data consists of a set of spatial objects, each represented by the following elements: point, line, and polygon. The vector format utilizes the concept of

geometric objects (points, lines, polygons) to represent geographic objects. These geometric objects are defined by their coordinates in a projection system.

Figure 2: Vector mode in GIS



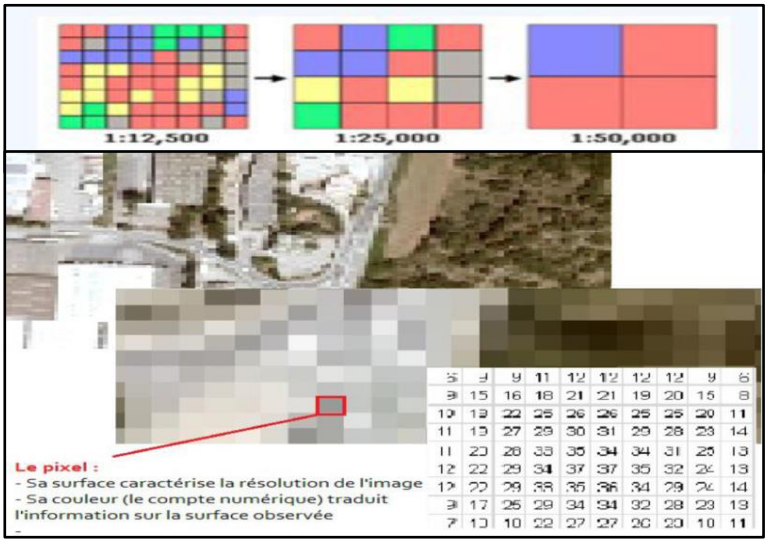
Examples of vector data include:

- ***Polygonal data:*** such as land parcels or any other thematic zoning, represented by polygons.
- ***Linear or linear data:*** such as utility networks, watercourses, or roads, represented by lines.
- ***Point data:*** such as wells, survey points, or mining sites, represented by points.

b. Raster (Image) Mode: Raster data (geographic information) represented in raster (image) form consists of a set of pixels (picture elements) organized in a grid format of rows and columns.

- ***Spatial Resolution:*** The pixel is the basic unit of the image, and its surface area corresponds to its spatial resolution.

Figure.3: Raster mode



• ***Images:*** These are primarily used for cartographic representation. An example is an aerial photograph where the information contained in the pixel matrix relates to the color representation of the information. This information is not directly accessible.

• ***Grids:*** These are used for computation and modeling. An example is a digital elevation model where the information contained in the pixel matrix relates to a quantitative value (e.g., elevation). This information can be viewed and modified in the attribute table.

II.I.2. Associated Data

Associated data of spatial objects complement the geometric representation of the spatial entity. In fact, each element of space (i.e., point, line, or polygon) receives an identification code (ID) that can be numeric or literal. The latter comprises a label determining the spatial entity. Among the associated data, the following distinctions are made:

a) Classification data:

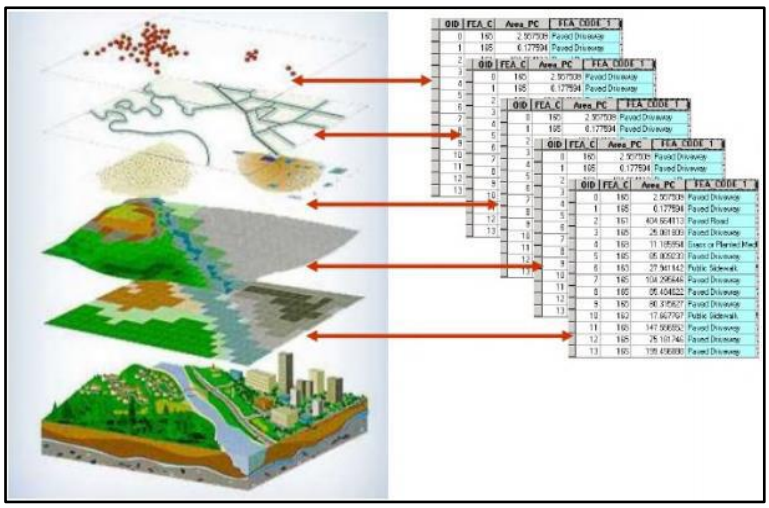
These allow for the classification of the point, line, or polygon into a specific class, such as the type of parcel (irrigated, non-irrigated), type of road (primary, secondary), etc.

b) Identification data:

These provide the ability to distinguish each object depicted on the map, for example, the name of the municipality, parcel number, valve number, etc.

These data enable the individualization of each object depicted on the map: the proper name of the object, for example, the name of the municipality, or a number allowing for its identification: parcel number, valve number, etc.

Figure 4: Concept of Data Layers



Source: http://www.seos-project.eu/modules/agriculture/agriculture-c03-s01.fr.html

c) Attribute Data (Alphanumeric or Semantic):

The descriptors of geographic objects, the attributes, are stored in an attribute table associated with geographic objects of the same theme.

Table

sub-basins

FID	Shape *	Id	Nom	Area Km²	Average al	Average an	Tem Averag	Con
0	Polygon	0	K'sob	3641	870	300	15,8	
1	Polygon	1	Soubella	183,87	790	250	15,7	
2	Polygon	2	Lougman	337	650	300	16,27	
3	Polygon	3	Leham	638,6	710	292	16,2	
4	Polygon	4	Mcif	5321	950	251	14,7	
5	Polygon	5	Elham	6187	819	250	15,44	
6	Polygon	6	Boussaada	2953,7	670	290	16,5	
7	Polygon	7	Barika	3823	920	345	15	

1 (0 out of 8 Selected)

sub-basins

For example, the attributes describing the sub-basins of Hodna (stored in the database) are stored in the attribute table defined by fields such as ID_CODE_NAME, etc., where the type can be "Character", "Numeric", "Date", etc.

Each sub-basin corresponds to a record in the attribute table and possesses a unique identifier. The attribute data can originate from other sources such as text files (e.g., dbf format) or databases (PostgreSQL, SQL Server, Oracle, etc.).

Definition of a Layer

The combination of geometric data and attribute data constitutes a layer. For each graphic object (sub-basins represented by polygons), there corresponds a record in the attribute table. The most commonly used storage format for a layer is the shapefile format.

Attribute data is stored in a ".dbf" file format.

The coordinates of the nodes (points) that make up the polygons are stored in a file with the extension ".shp".

Additionally, a file with the extension ".shx" serves as a link between the graphic data and the attribute data. A layer, a shapefile named "sub-basins," would be saved as follows:The combination of geometric data and attribute data constitutes a layer. For each graphic object

(sub-basins represented by polygons), there corresponds a record in the attribute table. The most commonly used storage format for a layer is the shapefile format.

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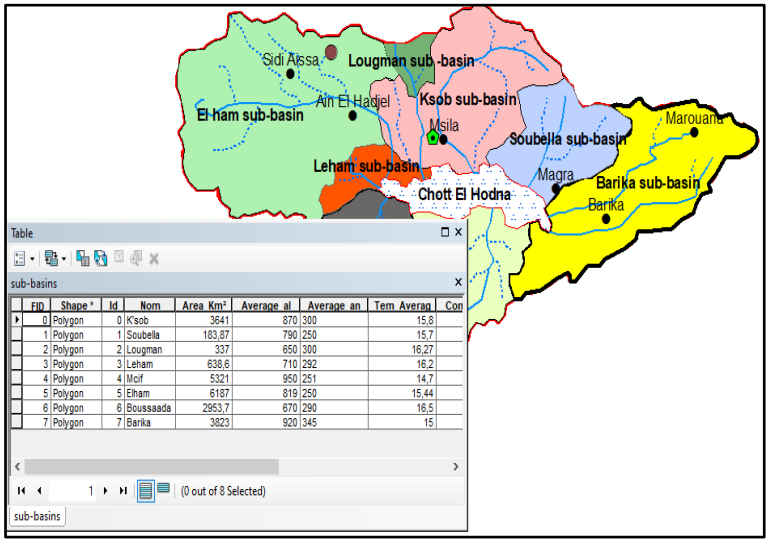
Additionally, a file with the extension ".shx" serves as a link between the graphic data and the attribute data. A layer, a shapefile named "sub-basins," would be saved as follows:

- Sous – basin_ K'sob.dbf
- Sous – basin_ K'sob.shp
- Sous – basin_ K'sob.shx

Figure 5: Example of a Thematic Layer



II.I.3. Metadata:

Metadata is literally data about data. More precisely, it is a structured set of information describing any resource. Metadata informs about the nature of certain other data, thereby enabling their relevant use. For example: the road network.

Metadata must be accurately filled out to be accessible to the widest audience. Three types of metadata are distinguished:

- ***Discovery metadata:*** A minimum of information allowing the identification of data that may correspond to one's needs.
- ***Cataloging metadata:*** More precise information serving as specifications, control during delivery.

- ***Operational metadata:*** Enables the user to understand the data and better understand its operational limitations.

II.2. Mode of Geographic Data Acquisition

Obtaining spatial data involves gathering various sources to capture data for integration into a GIS. Below, we outline the different methods of spatial data acquisition.

II.2.1. File Import

Generally, there are three ways to import spatial data:

Importing a database arranged in a format internal to a GIS. This method is valid between GIS systems of the same type but can be complicated between GIS systems of different types or versions.

Importing a text file (txt) containing all the information structured in a primitive manner. It's worth noting that this method requires arranging the imported data to match the internal structure of the GIS.

Using one of the exchange standards available on the market. This third method is the most cost-effective in the long run.

II.2.2. Topographic Surveys (using a Theodolite)

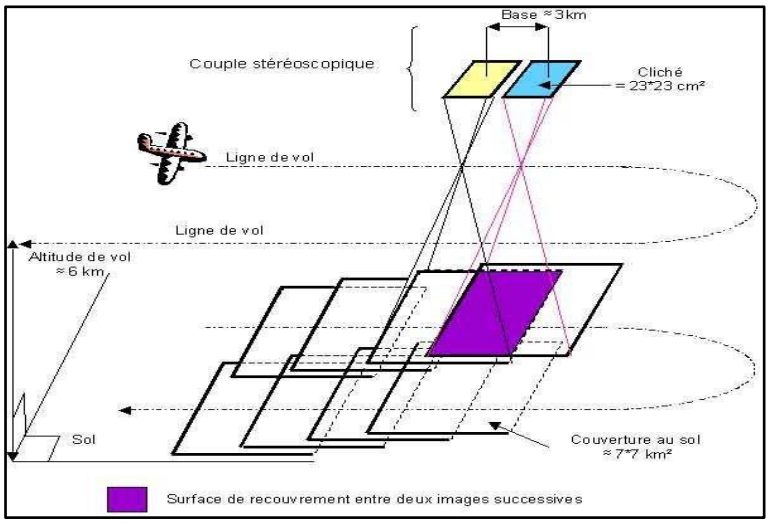
A theodolite is a geodesy instrument equipped with an optical device, capable of measuring angles in both the horizontal and vertical planes to determine a direction. It is used to conduct triangulation measurements. This instrument enables the plotting of points sequentially from an origin point to establish neighbouring points.

Figure 6: Example of a Theodolite

II.2.3. Aerial Photography

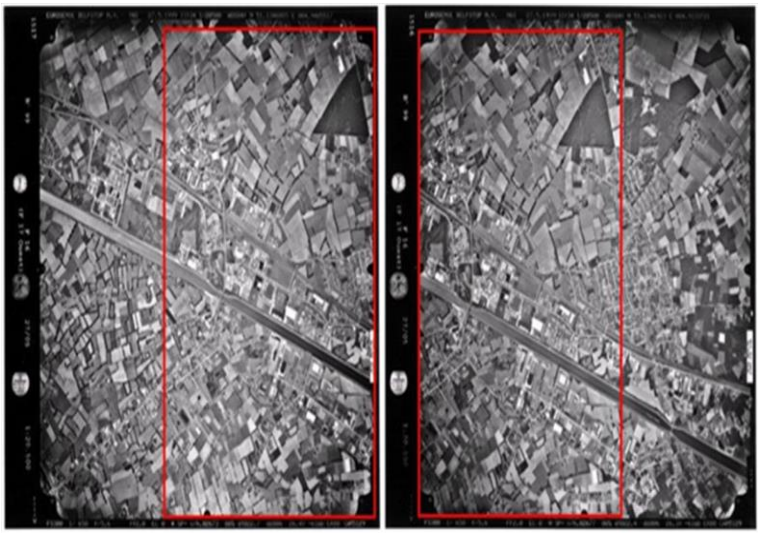
The set of merged photographs allows for obtaining a complete photo of an area. The photographic images obtained enable us to determine the coordinates and altimetry of points either using aerial cameras (airplanes, drones, etc.).

Figure 7: Flight Plan for an Aerial Photography Acquisition Aircraft



Source : https://perso-sdt.univ-brest.fr/

Figure 8: Stereo pair of Tongerlo, Belgium, 17-05-1999. Overlap is indicated by the red rectangles.

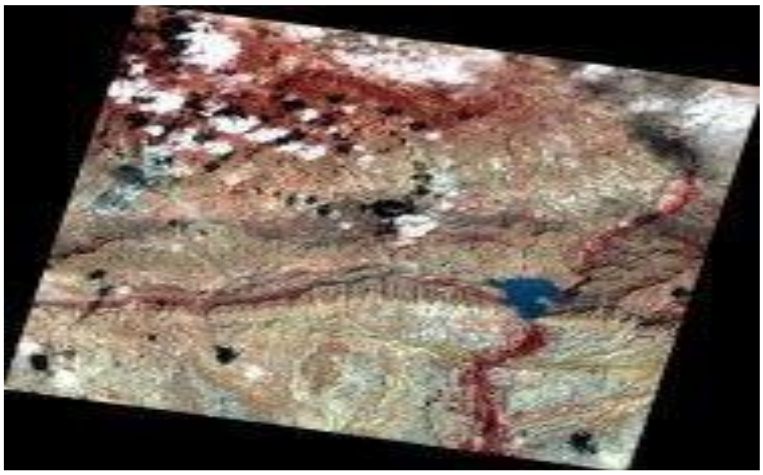


Source : http://www.seos-project.eu

II.2.4. Satellite Images

Earth observation satellites provide data transmitted in the form of digital images in raster mode. The data must undergo certain rectification processes before being integrated into a GIS.

Figure 9: Satellite image taken by the ALSAT-2A satellite

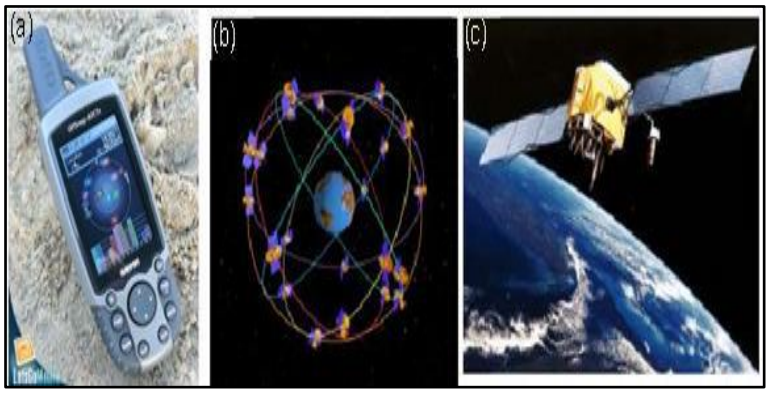


Source : http://www.asal.dz

II.2.5. Global Positioning System (GPS)

The GPS system allows for position calculation using signals emitted by satellites, providing coordinates with an accuracy of a few centimeters, or even millimeters.

Figure 10: (a) Global Positioning System (GPS) satellite positioning system and satellites (b and c).



II.2.6. Digitization / Scanning

Digitization is suited for vector representation. This technique ensures the preservation of information presented in the base document. Preprocessing on the base documents may be necessary if they are too cluttered.

Figure 11: Digitization Operation

II.2.7. Plan Scanning / Electronic Scanning (Scanning)

Suitable for raster representation. This input mode is fast and cost-effective. If the data is scanned and georeferenced, it becomes raster data. The only issue with this method is the possibility of introducing errors from the original document.

Electronic scanning (performed with a scanner) is another way to capture an existing map. It is faster than manual digitization.

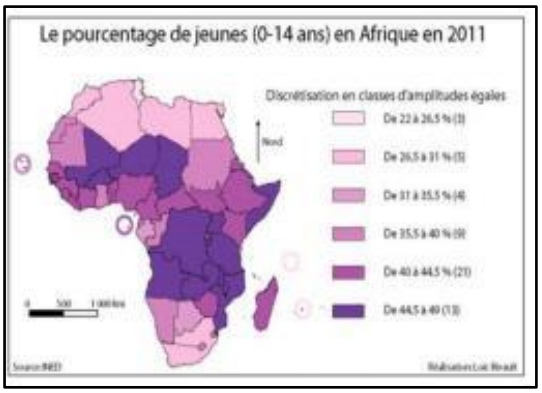
Figure 12: Automatic Scanner

Figure 13: Extract of a scanned map

II.2.7. Geometric Spatial Analysis

This analysis is based on the position of the object, its shape, and the potential existing relationships. Distance between objects is one of the simple functionalities of spatial analysis. We can work on the relationships between objects, for example, by selecting based on distance, intersection, positioning, without modifying the objects.

Figure 14: Geometric Spatial Analysis



II.3. Relationship between Cartography and GIS

The relationship between map making and related Geographic Information Systems (GIS) is inherently intertwined. Fundamentally, GIS has its roots in cartography; both disciplines involve the creation and manipulation of maps, as well as associated attributes. Additionally, they both utilize geographic data, which includes considerations such as scale, projections, and coordinate systems to accurately represent spatial information.

In essence, while cartography primarily focuses on the visual representation of geographic data, GIS expands upon this by integrating various spatial analysis and management capabilities, making it a powerful tool for understanding and making decisions based on geographic information.

Chapter III

Analysis in GIS and software

Introduction

In this chapter, we will delve into our working software, MapInfo, its environment, and explain how it operates, from capturing geographic or attribute data to producing thematic maps.

III.1. Presentation of MapInfo software

- A Geographic Information System (GIS).
- User-friendly software with a point-and-click graphical interface.
- Provides a set of tools for visualizing, exploring, querying, editing, and analyzing geographic information and presenting results on quality map documents.
- An application that integrates a set of ready-to-use data.
- The software allows for easy loading of both spatial and tabular (alphanumeric) data and displaying them as maps, tables, or charts.

MapInfo Professional is a simple and comprehensive tool for processing and visualizing georeferenced data. It is used in various fields including urban planning, geomarketing, banking, and public administrations.

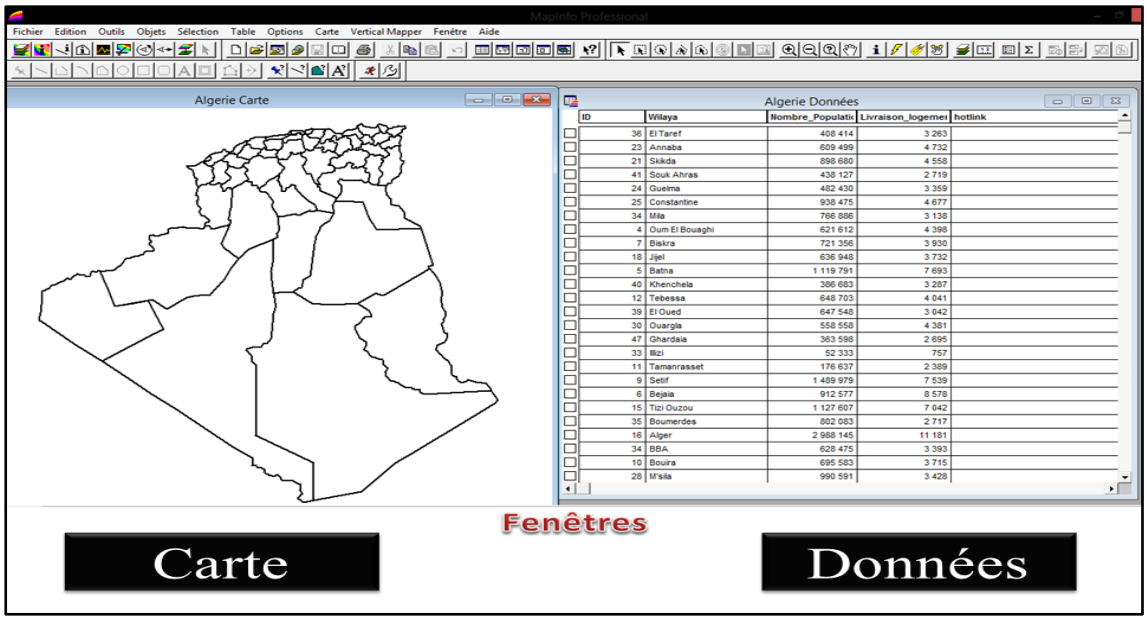
III.2. MapInfo and its environment

The information is stored in the form of Tables, which consist of a graphical part (the map window) and a semantic part, also known as attribute data, contained in a table (data window).

The map window displays the graphical data contained in the .map file. It allows you to visualize one or more layers of raster or vector information. From the Map/Options menu, you can choose the display units for area, distance, and coordinates.

The data window displays the attribute data stored in the .dat file in table format. Each row in the table corresponds to a geographic object in the table.

Figure 01: MapInfo's Map and Data windows (Algeria)

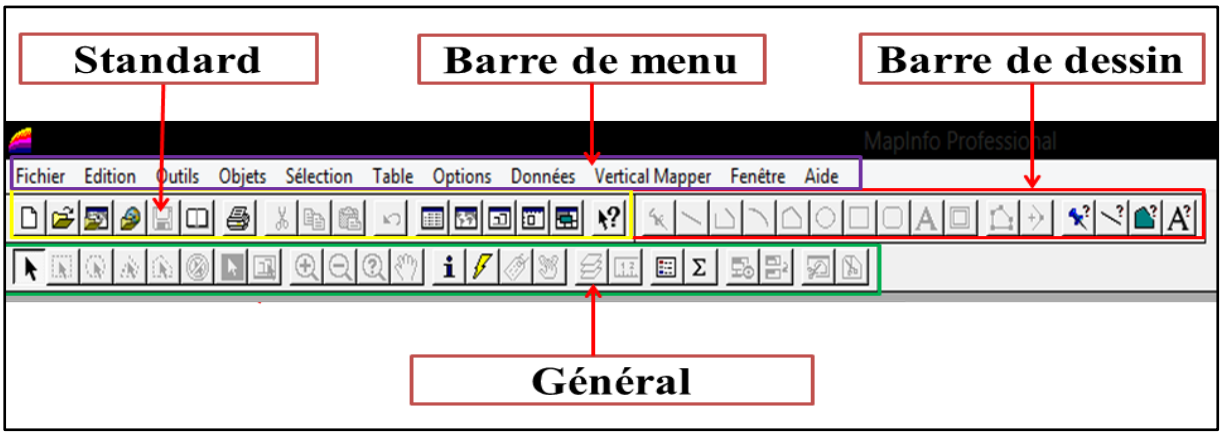


Source : Auteur, février, 2024.

A third window completes the MapInfo environment: the "Layout" window, accessible from the Window/Layout menu. It allows for the preparation and formatting of work in MapInfo. Multiple map and data windows can be integrated into such a document.

MapInfo has numerous menus and tool palettes. By default, only the menu bar and two floating menus named "General" and "Drawing" appear. Contextual help is accessible with the "F1" key.

Figure 02: Some tool palettes in MapInfo



Source : Auteur, février, 2024.

III.3. The data structure in MapInfo

As previously mentioned, MapInfo is software that structures information into tables. A table is a set of files that are manipulated together by the software.

Thus, the "Open Table" functionality is translated into a set of basic computer activities that will open each of the files constituting the table, check the coherence of the set, and display the graphical content of the table in a window. Therefore, the information managed by MapInfo will consist of at least four files.

III.4. Operation of the MapInfo software

III.4.1. Layer control

Understanding the management of layers in MapInfo and mastering the functionalities (organization of layers, layer properties, layer symbology, creation of hotlinks) accessible through the "Layer Control" dialog box.

III.4.1.1. The "Layer Control" dialog box

Several methods are available to access this dialog box:

- Through the Map/Layer Control menu
- By right-clicking on the map window and choosing "Layer Control" from the menu
- Using the icon representing a stack of layers in the "General" palette
- Finally, by using the keyboard shortcut Ctrl + L when the map window is active.

III.4.1.2. To organize the layer stack

MapInfo does not stack layers (tables) in the order they are opened, but it tries to manage their display based on their geometric type. At the bottom of the stack are raster layers, followed by polygon layers, polyline layers, and finally point and text layers.

However, within each type, MapInfo organizes layers by default in the order the tables were opened. Changing this initial order is possible using the "Move Up" and "Move Down" buttons in the "Reorder" section. This operation applies to the layer selected in blue. You can also click on a layer and drag it with the mouse to rearrange it in the layer stack.

It is also possible to add an open table and remove a table from the map window using the buttons in the "Layers" section.

Figure 03 : Layer control

Source : Auteur, février, 2024.

Note: Removing a layer through the "Layer Control" does not close the table. Additionally, an open table can appear multiple times in the layer manager.

In the case of a raster table (IGN 1/25000 scan, aerial photo, or satellite image), the editable box is inactive, as well as the Display and Labels buttons. These tables are images and serve as visual support. They do not have associated attribute data.

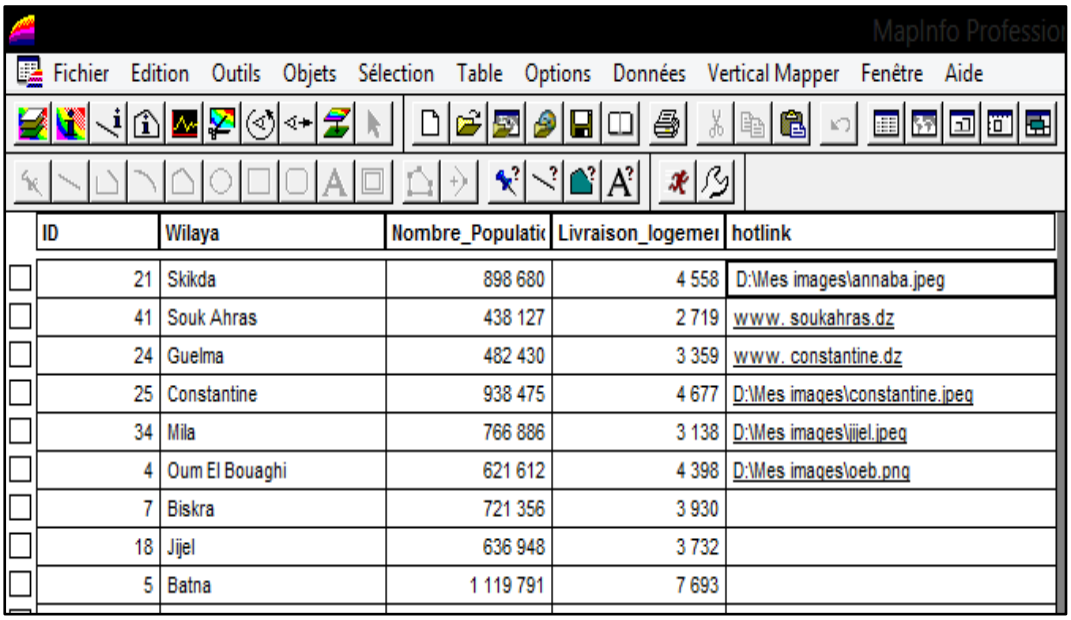
III.4.2. - Creating Hotlinks

Hotlinks are used to associate media with a graphic object. For example, a photo, a website, a Word document, PDF, etc., can be activated by clicking on a graphic object, its label, or both.

To create a Hotlink, you must first create a field in the attribute table that will contain the paths to the media. This path can be an Internet address (http://www....) or a path on your computer leading to a document, for example, C:\My Documents\sigird.pdf.

After this operation is done, click on the "hotlink" button in the "Layer Control" dialog box to set up the Hotlinks.

Figure 04: Hotlinks creation



ID	Wilaya	Nombre_Populati	Livraison_logemer	hotlink
21	Skikda	898 680	4 558	D:\Mes images\annaba.jpeg
41	Souk Ahras	438 127	2 719	www. soukahras.dz
24	Guelma	482 430	3 359	www. constantine.dz
25	Constantine	938 475	4 677	D:\Mes images\constantine.jpeg
34	Mila	766 886	3 138	D:\Mes images\jijel.jpeg
4	Oum El Bouaghi	621 612	4 398	D:\Mes images\oeb.png
7	Biskra	721 356	3 930	
18	Jijel	636 948	3 732	
5	Batna	1 119 791	7 693	

Source : Auteur,2024.

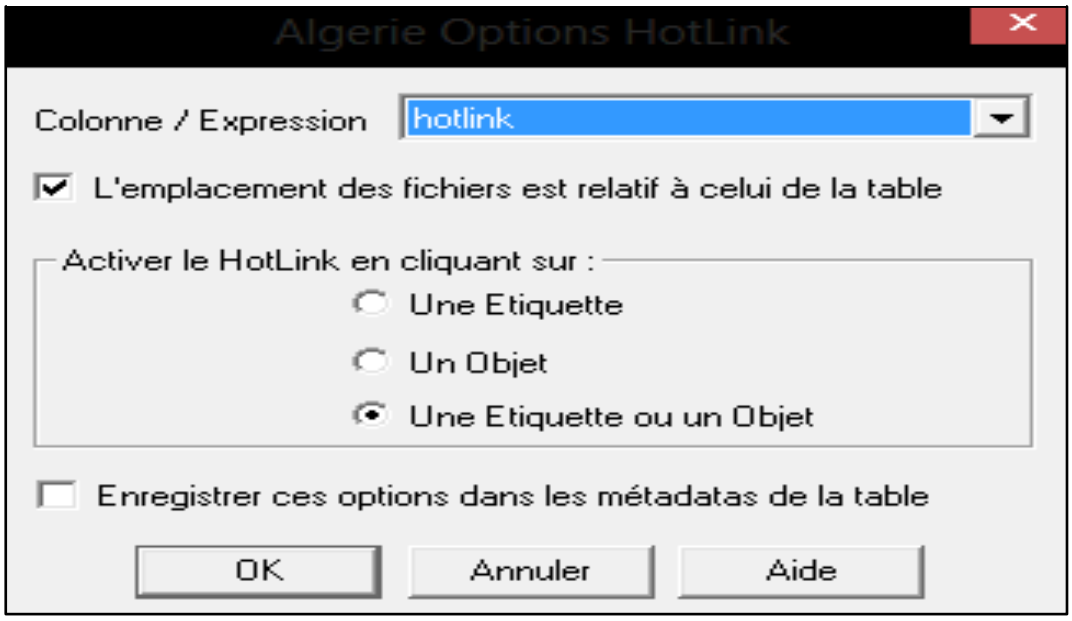
The dropdown list allows you to choose the field where the URLs and paths to the various media are contained. The fields displayed in the dropdown list are those of the table highlighted in blue in the "Layer Control".

If you check the box below, you will only have to fill in the filename instead of the full path in the designated field. However, it is imperative to store all media files in the same directory as the table containing the hotlinks.

The "Enable hotlink" section allows you to choose whether the activation applies to the object, the label, or both.

The last checkbox "Save options..." allows you to save the HotLink options of the table in the metadata of the .TAB file. This option will automatically restore the options when using the HotLinks of this table again.

Figure 05: Hotlinks Window



Source : Auteur, février, 2024.

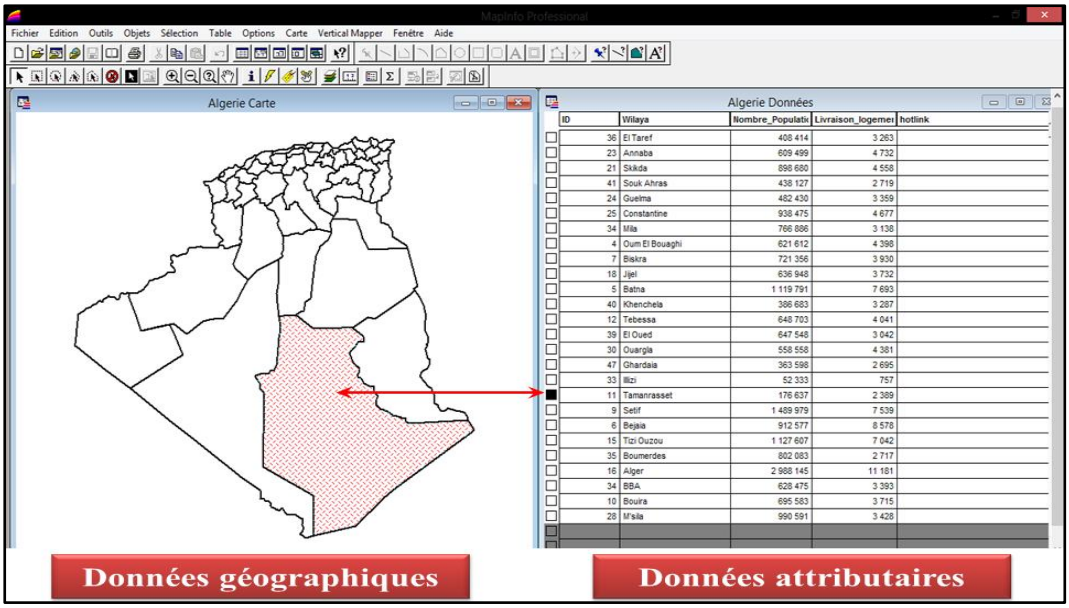
To activate a Hotlink, choose the tool  located in the "General" palette and click on a graphic object in the layer containing a Hotlink.

III.5. Data manipulation

III.5.1. Relationship between geographic data and attribute data

By selecting a graphic object on the map or a record in the attribute table using the "arrow" tool, we notice that these two manipulations are equivalent. When one is selected, the other is also selected! Therefore, we are manipulating complete "objects", not just their geometry or attributes.

Figure 06: Relationship between geographic data and attribute data

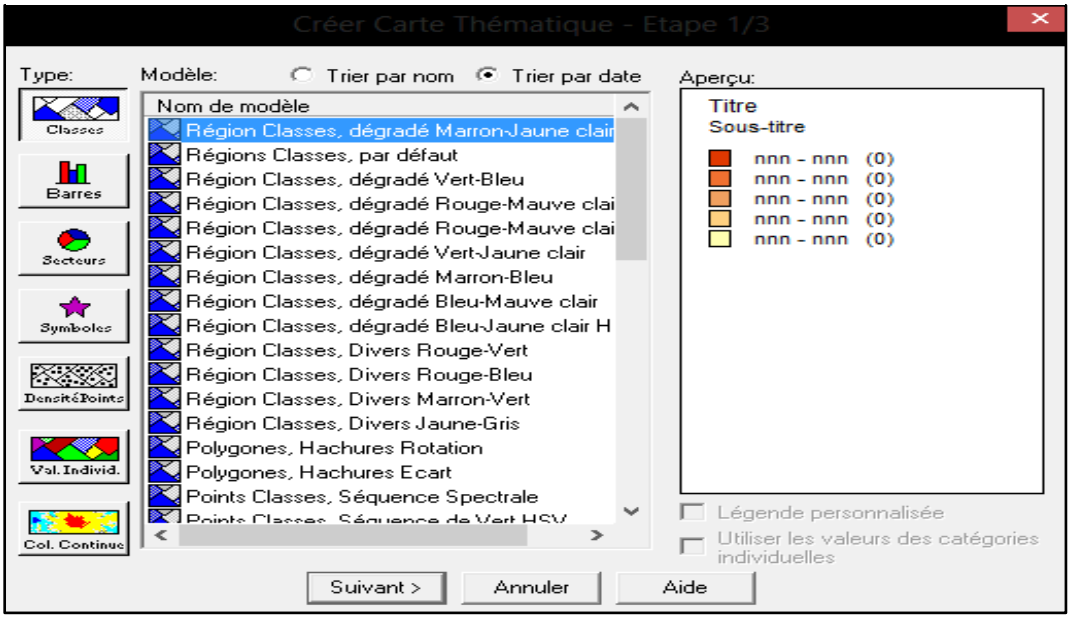


Source : Auteur, février, 2024.

III.6. Thematic analyses

Under MapInfo, for any change in map representation, it is often necessary to use thematic analysis. Thematic analysis allows for changing the color, size, or shape of objects based on data. It is a powerful functionality that occurs in three steps. To perform thematic analysis, you should use the command: "Map/Thematic Analysis".

Figure 07: Thematic Map Creation Window, Step 1/3



Source: Auteur, février, 2024.

On the left, the button panel allows you to select the type of analysis to perform. There are 7 types available in MapInfo, each used for particular cases.

Tableau 01: Criteria for choosing types of analysis based on variable types

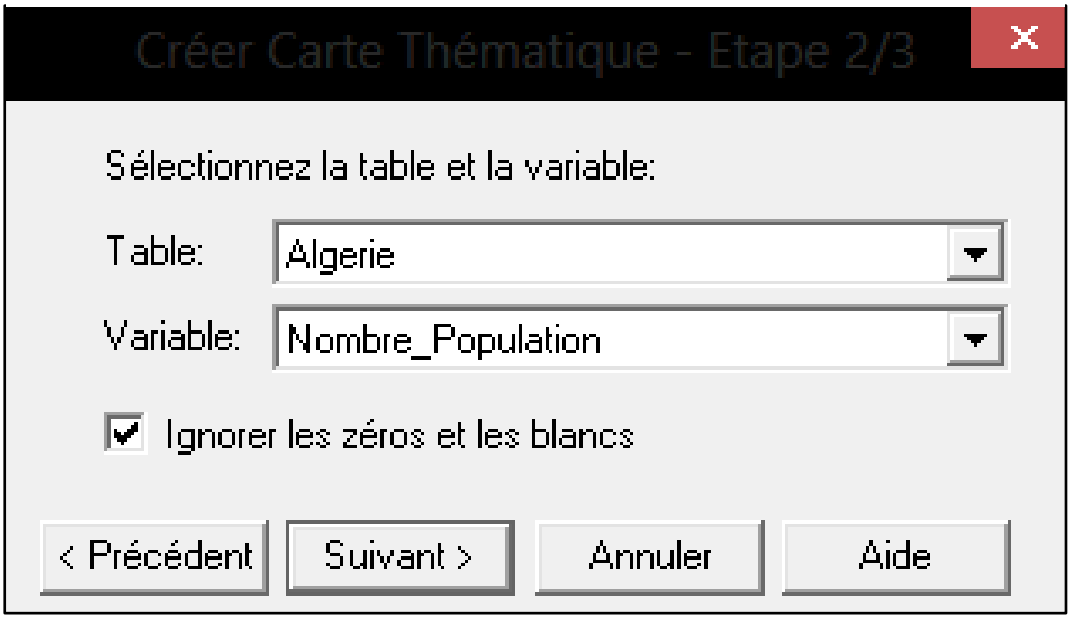
Analysis on a numerical variable	**Multivariable analyses**	**An analysis on a numerical or alphanumeric variable**
Classes, symbols, point density, continuous coloration	Bars, sectors	The individual value

Source: LAKHDAR. A, Extensions périurbaines de Constantine diagnostic et évaluation, cas de la zone Zouaghi Ain El Bey, Application d'un SIG (MapInfo), Op.cit. P61.

In the center, you have a selection of different models. For analyses by class or individual values, it is important to choose a model that corresponds to the object type of the table.

It is possible to choose a proposed analysis and then customize it to your own needs by clicking on the "Next>" button.

Figure 08: Thematic Map Creation Window, Step 2/3



Source : Auteur, février, 2024.

This is the most important step of the analysis. You choose what you want to color based on what. This order may seem a bit illogical, as the type of thematic analysis depends on the type of data to be analyzed; the reverse order might have seemed more logical.

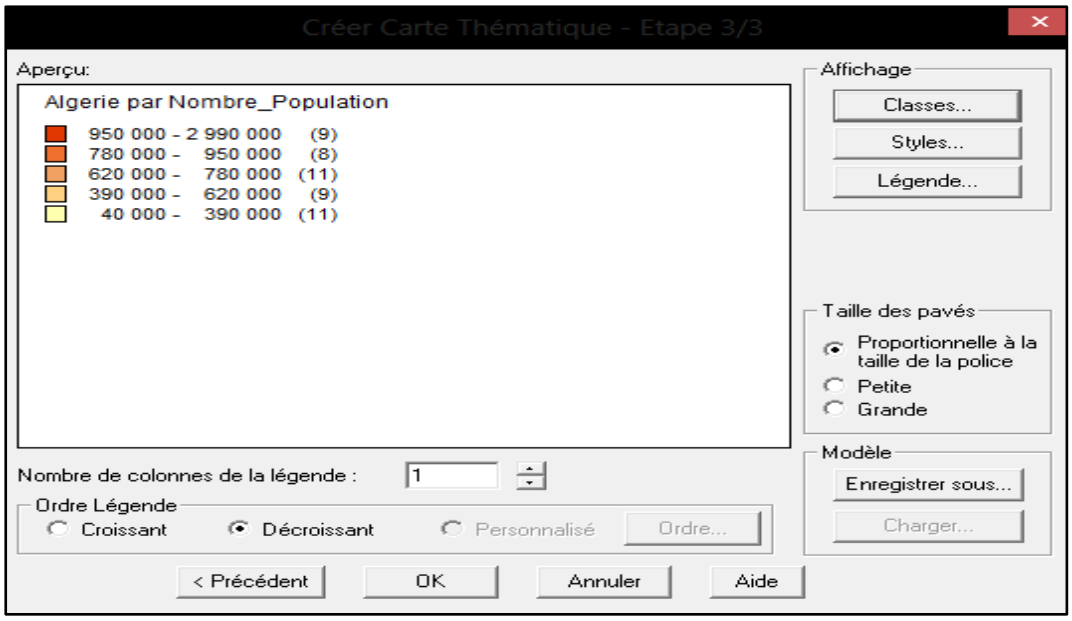
First, select the table that will serve as the basis for the analysis (the table to "color"). Then select the variable to analyze; you simply choose a column from the list that corresponds to a field in the attribute table.

You can also choose to select from the dropdown list "expression" to analyze the result of a calculation, for example.

Finally, in step 3/3: At this level, you perform the thematic analysis, defining:

- The classes.
- The representation styles;
- The legend.

Figure 09: Thematic Map Creation Window, Step 3/3



Source : Auteur, février, 2024.

III.7. Import and export of data in MapInfo[1]

The universal translator provided with MapInfo®, or the import/export functions it offers, allow for bidirectional conversions with the main software on the market: Autocad - DXF and DWG (s11, w12, r13, r14, 2000), Microstation (DGN, DXF), Arc-Info (ESRI E00), ArcView (Shape), ER Mapper (ECW), Vertical Mapper (Grid),...

Some editors have developed specific gateways for exchanging data in formats such as EDIGéO, CARINE2, APIC, Géocity, URIAH, etc. The Arc-Link toolbox (version 3.2.3) included in MapInfo facilitates exchanges with all Arc-Info files.

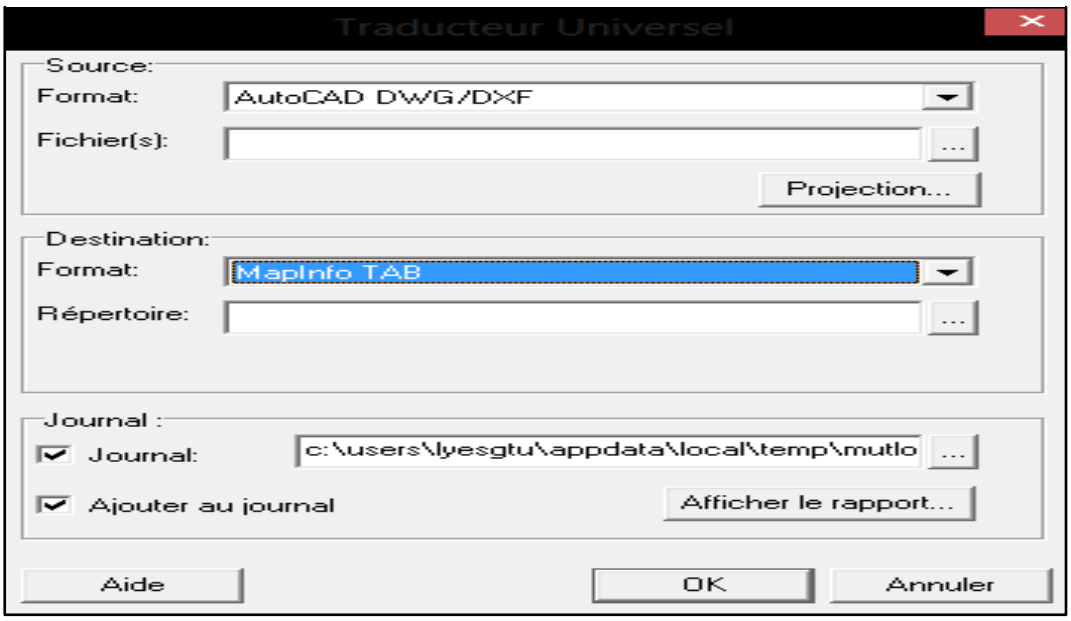
Reading and integrating raster images is possible in various formats: BMP, GIF, JPEG, PCX, SPOT, TGA, TIFF, MrSID, with excellent performance.

Semantic information is accessible:

- natively: Access, Dbase, Excel, Lotus 1-2-3, ASCII, Oracle 8i;
- through ODBC drivers: DB2, SQL Server, Sybase, Informix, etc.

[1] LAKHDAR. A, Extensions périurbaines de Constantine diagnostic et évaluation, cas de la zone Zouaghi Ain El Bey, Application d'un SIG (MapInfo), Op.cit. P65

Figure 10: MapInfo Universal Translator



Source : Auteur, février, 2024.

III.8. Save a map as an image file

MapInfo allows you to take a screenshot of the map window to export a map in Bitmap format. The command "File/Export Window" enables this operation.

Once the image format is chosen and the name is entered, the "Settings" dialog box (see screenshot above) appears after clicking the "Save" button. It allows you to choose the size of the image; by default, the dimensions will be those of the map window. However, you can choose the "Custom Size" option to enlarge or reduce the image. When you modify the width or height, MapInfo adjusts the other dimension to maintain the image proportions. You can also choose the image size by selecting the number of pixels of the image.

Finally, choose the resolution of your image in DPI (Dots Per Inch). For medium-quality printing, 150 dpi will suffice, while 300 dpi is more suitable for high-quality printing. These numbers are indicative as they depend on the characteristics of your printer.

The operation concludes by clicking the "Export" button.

III.9. Open data

III.9.1. Raster data

With the command "File/Open Table," you can open raster images of various formats such as *.bil, *.tif, *.bmp, *.gif, *.tga, *.jpg, etc., by selecting the "type" from the dropdown menu in the "Raster Image" or "Grid Image" dialog box.

Upon opening, MapInfo will inquire whether the image needs to be geometrically referenced, which is generally the case. Some images, such as logos, may not require geometric referencing. Nevertheless, images can be integrated for map layout purposes.

III.9.2. Vector data

MapInfo v7 can directly open data in ArcInfo and Shapefile formats. From the "Table/Open" menu, you can access these files. However, only attribute data is editable directly. To edit spatial data, you need to use the "Save As" function to create a *.tab file.

III.10. Export MapInfo data

MapInfo can export its data to other software programs. Typically, the export formats are ASCII-based, as they are the most portable, albeit with different structures. To do this, use the "Table/Export" command, select the table to export, and specify its export format from the drop-down menu in the "Save" dialog box.

Mid/Mif : This is the most commonly used format for exporting data to a GIS software from MapInfo. In fact, it is MapInfo's export format. It's worth noting that the .MID file (viewable with a text editor) contains the attribute information, while the ".MIF" file contains the table structure and geometry (as well as the associated symbology).

Conclusion

Indeed, among the software used in geographic information systems (GIS), we focused on MapInfo, which serves both as drawing and analysis software. Therefore, it enables its users to manipulate data easily to achieve very explicit results in any field.

Chapter IV

Remote sensing

Introduction

This chapter provides an overview of the main elements of remote sensing. Along with GIS, it represents a revolutionary and highly effective means of analyzing phenomena in their spatial dimensions.

II.2.1 Definition

The term remote sensing refers to all techniques that allow the study of objects or phenomena from a distance without direct contact with the Earth's surface, through the acquisition of images (Larousse, 2019).

Remote sensing encompasses the entire process of capturing and recording the energy of electromagnetic radiation emitted or reflected by any target, as well as processing and analyzing the information, and then applying this information (Soudani, 2005; Guillet, 2005).

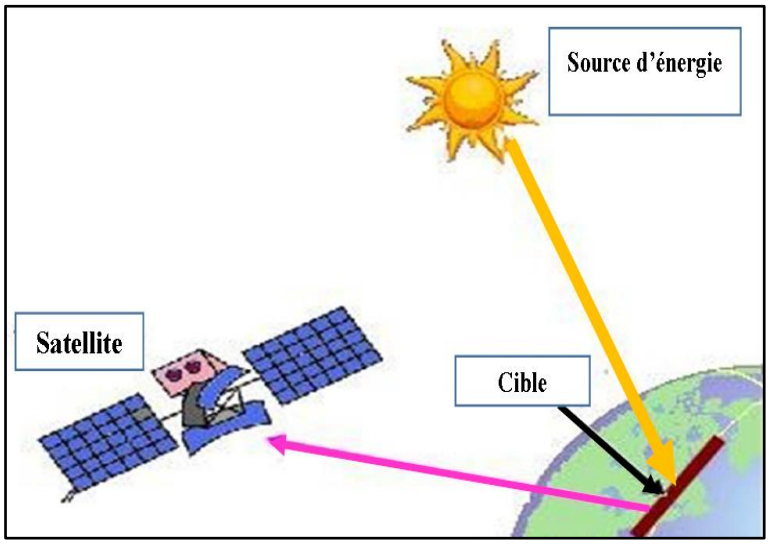
Remote sensing is a very convenient means of creating data to be introduced into GIS. It involves using, under specific and rigorous conditions, either aerial photographs or images recorded and transmitted by satellite (Sauvagnargues-Lesage et al., 2005; Lamine et al., 2014, 2017, 2019; Evans et al., 2018).

II.2.2 Principle of remote sensing

The basic principle of remote sensing is similar to that of human vision. Remote sensing is the result of the interaction between three fundamental elements: an energy source, a target, and a sensor.

- The target: is the Earth's surface captured by the satellite.
- The energy source: is the flux of photons or electromagnetic wave emitted by the element illuminating the target.
- The sensor: also called the remote sensing platform, measures the electromagnetic radiation of solar energy reflected by the target. The sensor can be a satellite or an aircraft. (Soudani, 2005)

Figure 1: Basic principle of remote sensing



Source: Centre Canadien de Télédétection

II.2.3 The characteristics of satellite images

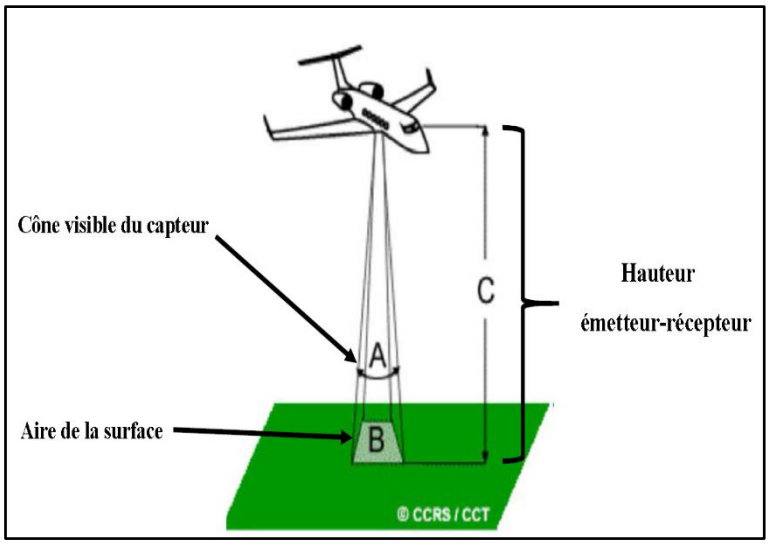
In the measurement of remote sensing data, where different types of images (Landsat, orthophotography), obtained from airborne or satellite platforms, are most often structured as spatially organized digital matrices, it is important to understand the specificities of each. In order to understand what each type can provide and to choose between different vector/sensor combinations, three characteristics must be considered: spectral resolution, spatial resolution, and temporal resolution (Servadio, 2011).

II.2.4 Types of Resolutions

II.2.4.1. Spatial resolution

The spatial resolution corresponds to the size of the smallest perceptible object in an image. This is referred to as a pixel, which is the smallest homogeneous unit constituting a digital image. Generally, spatial resolution is expressed in meters (Clark, 2004). Spatial resolution, being a function of the dimension of the smallest detectable element, depends on its instantaneous field of view (IFOV), which is the visible cone of the sensor (A), and its ground resolution cell, the area of the visible surface at a given altitude and time (B) (CCRC/CCT.2008).

Figure 2: Spectral signature on the Earth's surface

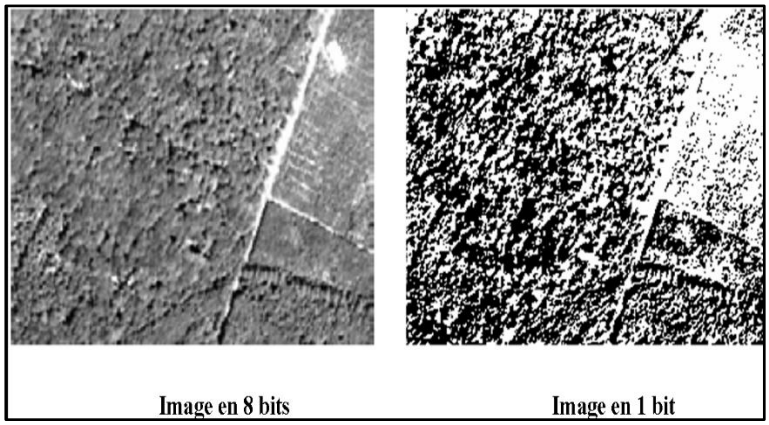


Source: CCRC/CCT.2008

II.2.4.2. Radiometric resolution

Radiometric resolution describes the ability to recognize small differences in electromagnetic energy and distinguish between two adjacent energy quantities through a dynamic range: a range of wavelengths within which a sensor is sensitive, for example, a sensor using 1 bit, 8 bits (Wiederkehr et al., 2008).

Figure 3: Difference in the absorbance of electromagnetic energy between 1 and 8 bits.



Source: CCRC/CCT.2008

The radiation reflected by ground targets and recorded by the sensor is encoded in binary digital format, and the resulting image is in grayscale.

II.2.4.3. Spectral resolution

The spectral resolution corresponds to the sensor's ability to distinguish electromagnetic radiations of different frequencies. Since objects do not all absorb the same part of solar radiation, the spectrum of reflected radiation will be different for each object.

Spectral resolution is defined by the number of bands, the width of the sensor bands, and the spectral sampling interval of the instrument. A sensor is considered to have high spectral resolution when the band width is narrow and hyperspectral resolution when the bands are both narrow. Improved spectral resolution often results in a better understanding of the spectral signature of the surface under consideration.

II.2.4.4. Temporal resolution or repetitiveness

The temporal resolution corresponds to the period between two acquisitions of the same scene. This resolution depends not on the sensor but on the orbit and maneuvering mode of the satellite. It is worth noting that the SPOT satellite offers the possibility to target a specific site upon request, thus ensuring excellent temporal resolution. Without maneuvering, the temporal resolution of SPOT is 26 days, 16 days for LANDSAT TM, and 14.5 days for NOAA-AVHRR.

The effective satellite passing cycle depends on the overlapping area between adjacent swaths, the satellite's capacity and sensors, and latitude. (Soudani, 2005 ; Petropoulos et al., 2016 ; Suman et al., 2018 ; Deng et al., 2019a, 2019b).

II.3. Water Quality Remote Monitoring

II.3.1. Remote Sensing Basics for Water Quality

Research supported by the EU BON project has demonstrated that satellite remote sensing (SRS) would be one of the most cost-effective approaches for identifying the quality of surface water and predicting changes related to physicochemical composition.

Traditional monitoring makes it difficult to assess water quality over short periods, which is essential for planning, assessing, and managing water bodies. Remote sensing techniques are used to measure and monitor water distribution, quantity, and quality remotely(Wang et al., 2001)..

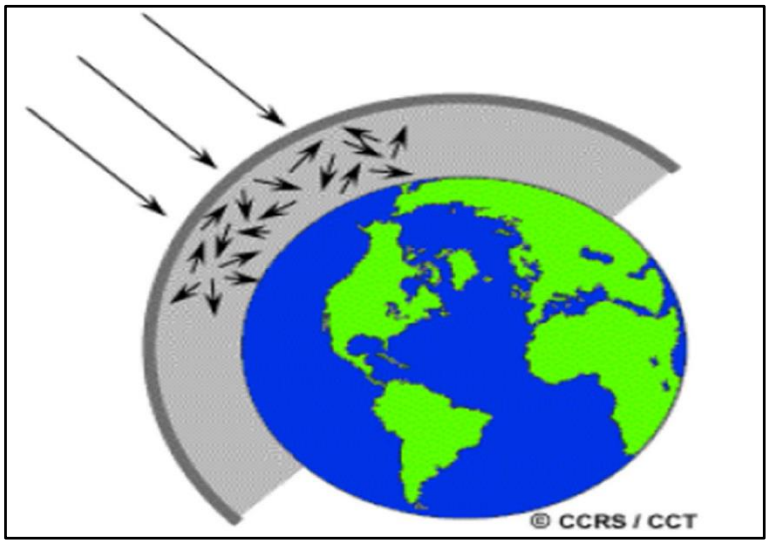
Incorporating remote sensing data into a GIS enables rapid calculation and evaluation of water levels, damages, and flood-prone areas, establishing a spatiotemporal monitoring process (Hellweger et al., 2004).

II.3.2. Atmospheric Interferences

Before the electromagnetic radiation used for remote sensing reaches the Earth's surface, it must pass through a certain thickness of the atmosphere. Particles and gases in the atmosphere can deflect or block the incident radiation. These effects are caused by scattering and absorption mechanisms. Scattering occurs when incident radiation interacts with particles or large gas molecules present in the atmosphere.

Particles deflect the radiation from its initial trajectory. The level of scattering depends on several factors such as wavelength, particle and molecule density, and the thickness of the atmosphere that the radiation must pass through. (Centre canadien de télédétection, 2008).

Figure 4: Interaction: radiation-atmosphere



Source: CCRC/CCT, 2008

Chapter V

Example of application of GIS and remote sensing in the field of water

Introduction

The GIS has become an essential tool for study and management in hydraulics. But not only that, software companies are increasingly developing features that allow for basic hydrology calculations.

V.1. Design and management of collectors and drinking water supply networks (DWSN)

By its ability to create and manage a large database, by its ability to interconnect different objects in the field, and by easy data updating... (cf. Supra), the transition to the design and management of AEP, as well as the entire hydraulic infrastructure with GIS tools, becomes necessary and even mandatory.

V.1.1. Objectives and benefits

In general, the objective of using GIS in the design of WSS (or sanitation networks in general) is to establish a database in which the different components of the network are identified and presented. Each of these elements is then associated with its characteristics (attribute data), and the various elements of the network are interconnected, all linked to the same spatial reference. Such a designed database has numerous benefits, including:

- A very good tool for management, planning, and decision-making.
- A tool that ensures organized and harmonious development of networks at different scales.
- A highly effective tool for crisis management, enabling quick and adequate response in case of malfunctions (pollution, breaks, fires, etc.).
- The establishment of such a database is a long-term investment that is economically beneficial, resulting in a reduction in the number of intervention agents (labor) and working time.**V.1.2. Stages of design**

The design process of these types of networks (AEP, sanitation network) can be divided into two main phases:

V.1.2.1. Data acquisition

• Acquisition of all plans that exist in paper format, as well as descriptions of the infrastructure (construction materials, section diameter, evacuation capacity, etc.);

• Acquisition of all existing or ongoing computer activities;

• Acquisition of additional data necessary for the design of AEPs, such as geological, geophysical (seismology), hydrographic, and topographic information.

• Acquisition of aerial photographs, satellite images, etc.;

• Statistical data: population census, average consumption per person (or per household), development forecasts;

• Identify major known network problems by acquiring intervention records for network anomalies, pressure observations, flow rates;
• Validate and/or supplement acquired data through fieldwork.

The data acquisition stage is a lengthy and challenging process for several reasons, including the fact that information is often scattered across different departments, data is not updated leading to a mismatch between the actual network and the designed database, and the problem of information redundancy due to multiple sources and the risk of partial updates.

Therefore, after data acquisition, a thorough process of organization, classification, and elimination of redundant data must be carried out. At this stage, it is necessary to create one's own work sheets in which all network entities are defined. These sheets will be used to build the conceptual data model (CDM), which in turn is used to produce the logical data model (i.e., the LDM is the adaptation of the CDM to the GIS software used).

V.1.2.2. Digital Data Production

Once the MLDs are designed, we move on to the data digitization phase. The choice of the working scale is determined by the desired precision and the importance of the network elements to be integrated. It involves digitizing the acquired data, starting with:

• Digitizing the segments and providing their characteristics including dimensions (diameter, length, theoretical capacity), materials used, design date, network resistance to pressure, stops, pipeline locking, actual capacity.
• In a second step, all other network elements such as valves, key outlets, air valves, fire hydrants, manhole covers, etc. are digitized and coded.
• An information layer encoding the anomalies and deficiencies identified in the network is to be added to the database.

To design a network with ArcGIS, you must master georeferencing and vector data creation, as learned previously.

V.2. Digital Terrain Model (DTM) Assembly

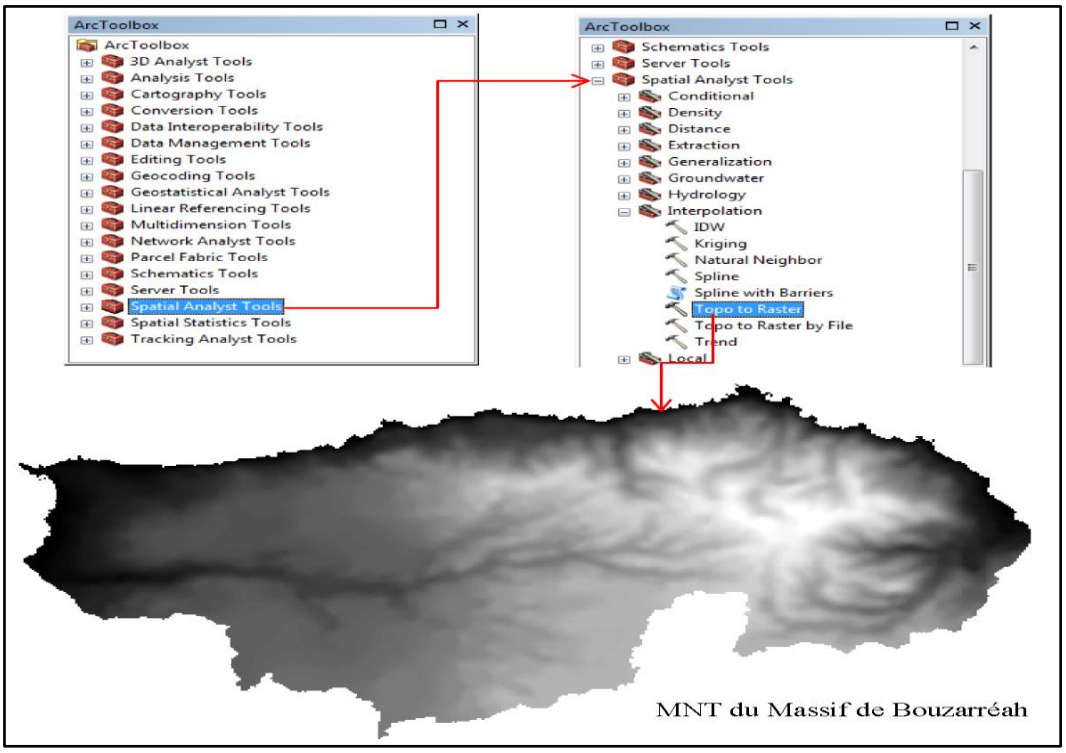
A Digital Elevation Model (DEM) is a numerical representation of the terrain or the altitude values of a given area. It should not be confused with the Digital Terrain Model (DTM), which takes into account the heights of objects (vegetation, buildings, etc.) placed on the terrain.

The digital terrain model is a valuable data source in hydrology, from which several derived information can be obtained, including contour lines, the hydrographic network, its topology and hierarchy, the slope map, hypsometric curve, the delineation of watersheds and their sub-basins, etc. Not to mention the countless calculations that can be performed, such as

the surface area of watersheds, their perimeters, the lengths of segments in the hydrographic network, the drainage density, etc.

V.2.1. Mounting a DEM from a topographic map.

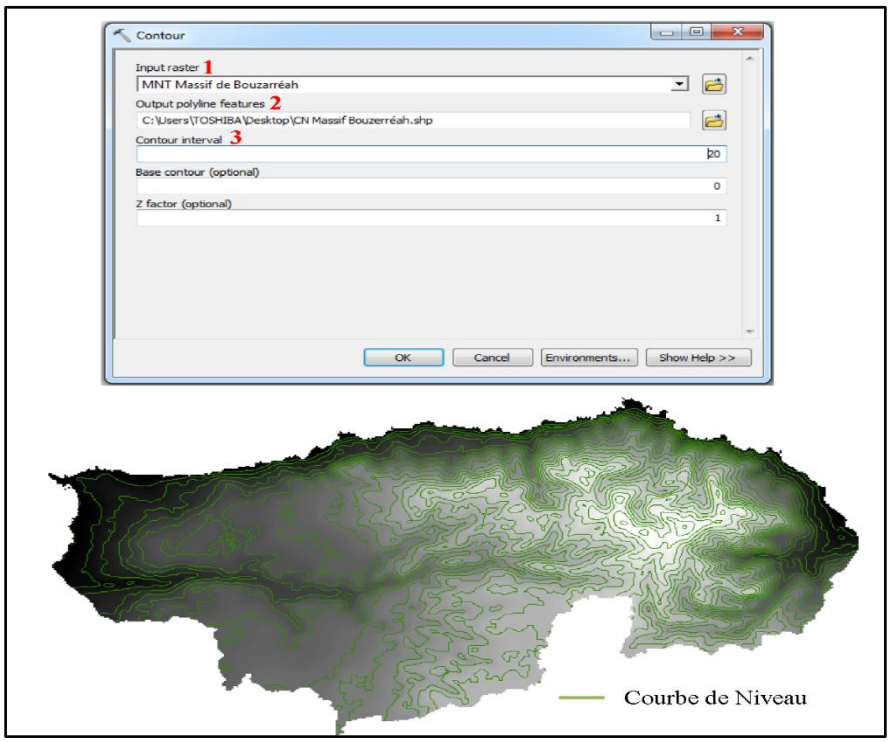
1. Digitalization of contour lines
2. Fill the attribute table with altitude values
3. Creation of a DEM (Digital Terrain Model): ArcToolbox/ Spatial Analyst Tools/ Topo to Raster.



V.2.2. Some derivatives of the DEM

V.2.2.1. Contour line

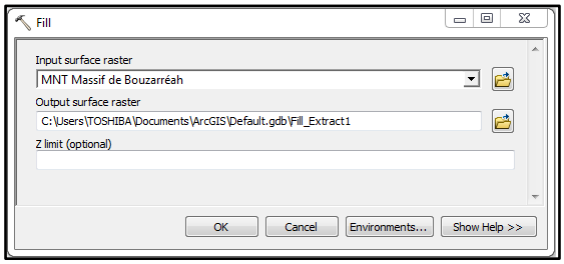
To extract contour lines from a Digital Elevation Model (DEM), follow the steps below: ArcToolbox/Spatial Analyst Tools/Surface/Contour. In the Contour window, three pieces of information need to be provided: (1) the DEM from which the contour lines will be extracted, (2) the location of the output file, and (3) the contour interval value (in this case, we have set it to 20, meaning a contour line will be extracted every 20 meters).



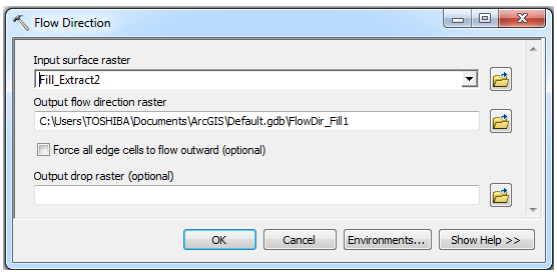
V.2.2.2. Hydrographic network extraction

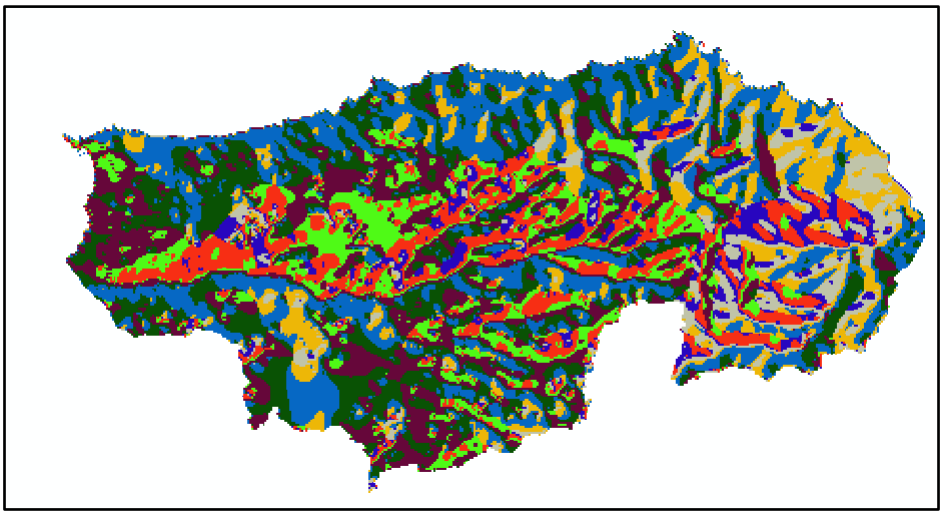
To extract the hydrographic network from a DTM, certain steps need to be followed:

• Calculate the Fill: This first step is used to correct small imperfections in the DTM. ArcToolbox/Spatial Analyst Tools/Hydrology/Fill/Ok. (1) the DTM to be corrected, (2) the location of the output file.

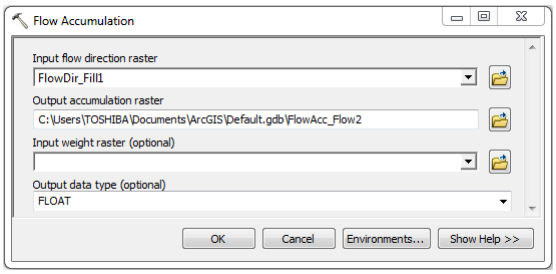


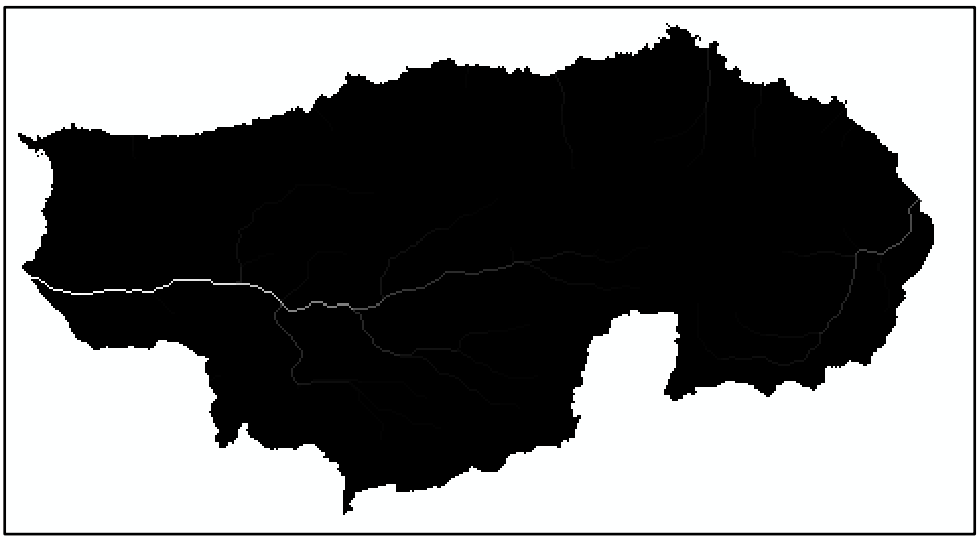
•Trace the flow direction in each cell. ArcToolbox/Spatial Analyst Tools/Hydrology/Flow Direction. (1) Enter the calculated Fill (the raster from which the flow directions will be traced), (2) specify the output location.



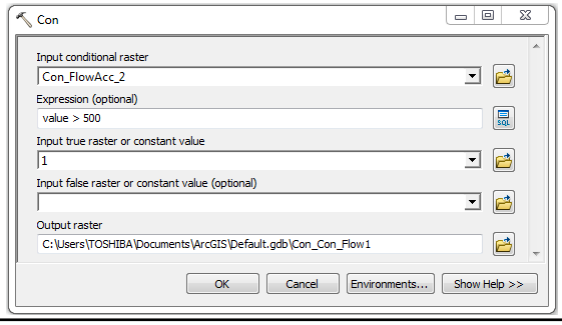


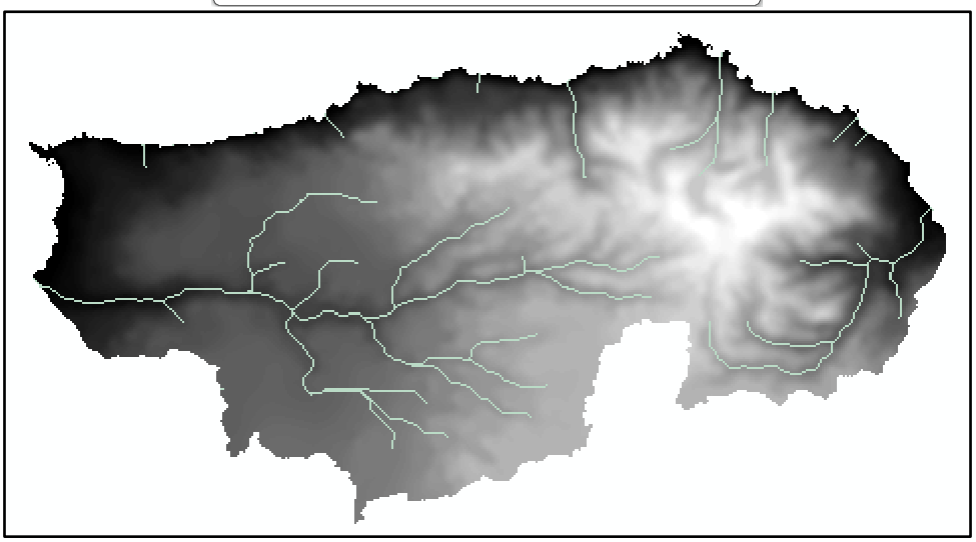
•The creation of a flow accumulation grid in each cell. ArcToolbox/Spatial Analyst Tools/Hydrology/Flow Accumulation. (1) the resulting raster from tracing flow directions, (2) the output file location.





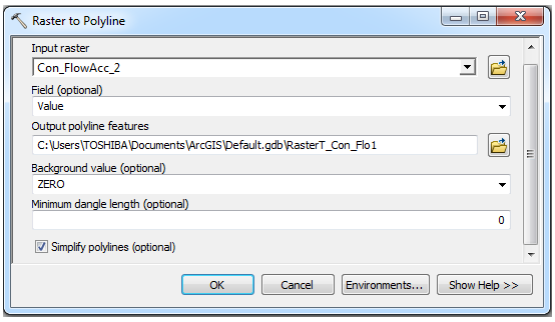
•The last step is to condition the reproduction of the network in each cell (setting an input value from which the cells will be classified as true or false). ArcToolbox/Spatial Analyst Tools/Conditional/Con. (1) the resulting raster from the calculation of flow accumulation, (2) condition the input value (here there is no fixed rule, the user, and according to their needs, is often required to make two or three attempts to obtain the desired network trace), enter an integer or floating point number, or a constant value that will be used as output values for cells that meet the condition (true), (4) the location of the output file..

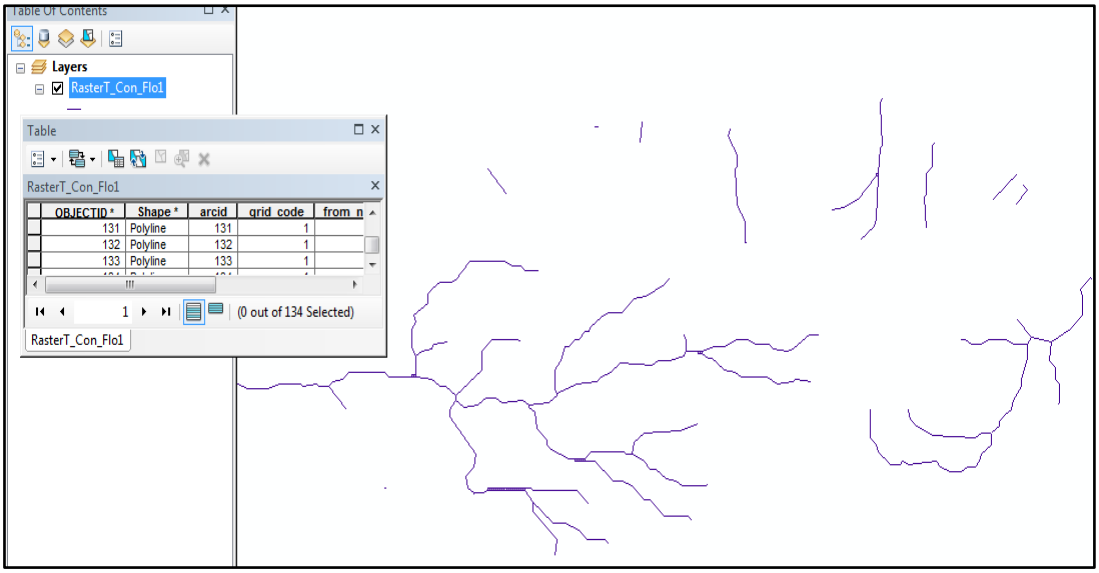




To perform calculations such as confluence ratios, average drain lengths, length ratios, drainage density (km/km²), etc., the hydrographic network needs to be in vector format.

The conversion of the hydrographic network from raster format to vector format is done as follows: ArcToolbox/Conversion Tools/From Raster/Raster to Polyline. (1) the hydrographic network raster (Con), (2) the output file location.





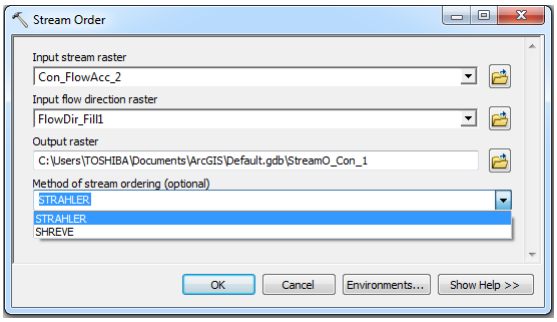
V.2.2.3. Hierarchization of the hydrographic network

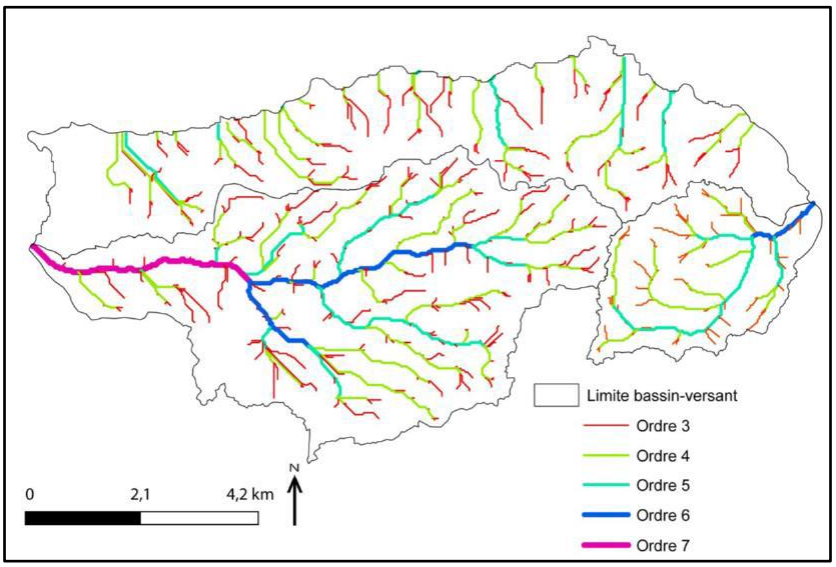
There are several methods of stream network ordering, the most commonly used being:

• The Strahler method (1957) proposes to order the hydrographic network by assigning the number 1 to streams without tributaries; two streams of order n merge to form a stream of order n + 1; when it is a stream downstream of two confluences of different orders, it takes the number of the larger one.

• The Shreve method (1966) treats the hydrographic network as a tree structure formed by segments with a "magnitude"; it assigns a magnitude of 1 to the first-order streams; a stream resulting from the confluence of two streams of magnitudes n and n' will have a magnitude of n + n'.

ArcToolbox/Spatial Analyst Tools/Hydrology/Stream Order. (1) the raster of the hydrographic network (Con), (2) the raster of flow directions, (3) the output file location, (4) the choice of the ordering method.

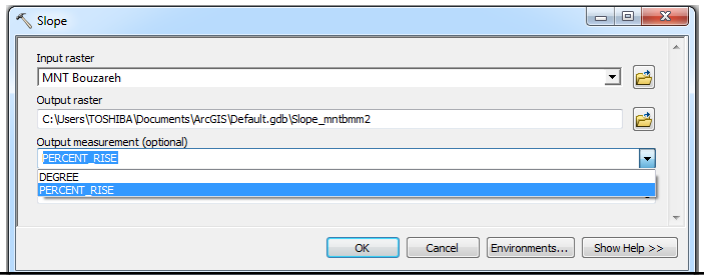


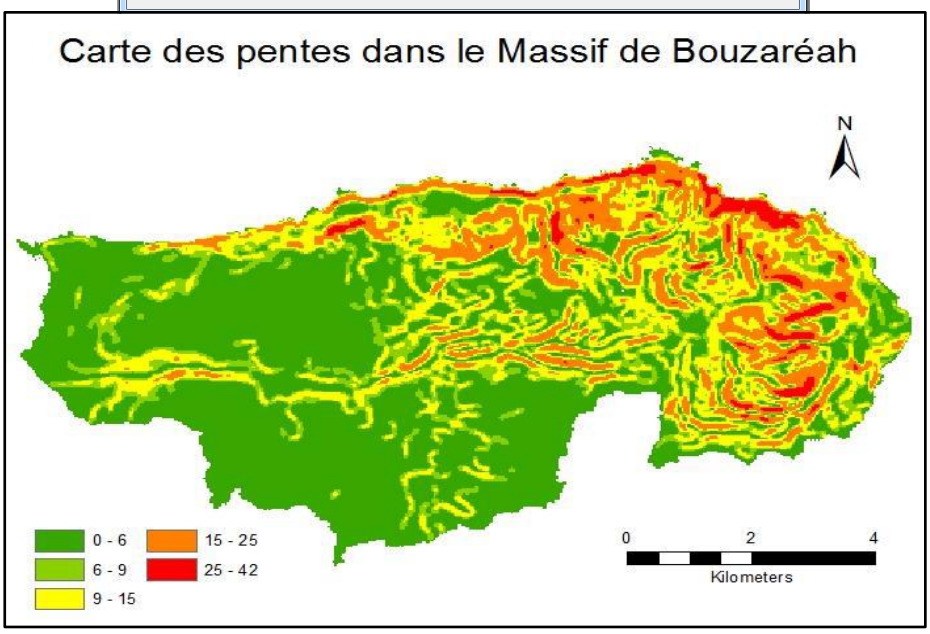


V.2.2.4. Slope map

The slope corresponds to the inclination of topographic surfaces. It is a very important hydrological parameter as it controls the kinematics of flow (velocity, power, response time) but can also be evaluated as a criterion for comparing watersheds.

To obtain the slope map from a Digital Elevation Model (DEM), follow the steps below: ArcToolbox/ Spatial Analyst Tools/ Surface/ Slope. (1) DEM, (2) output file location, (3) unit of slope calculation (degrees, percentages).





V.2.2.5. Watershed delineation

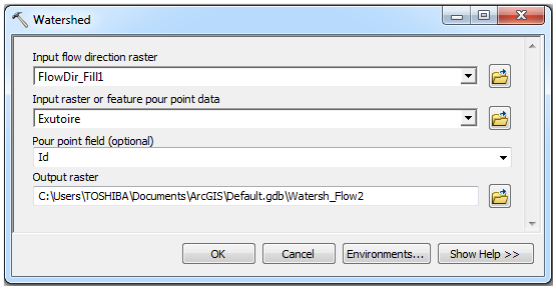
From the hydrographic network, it is possible to delineate the watershed(s) by following the steps below:

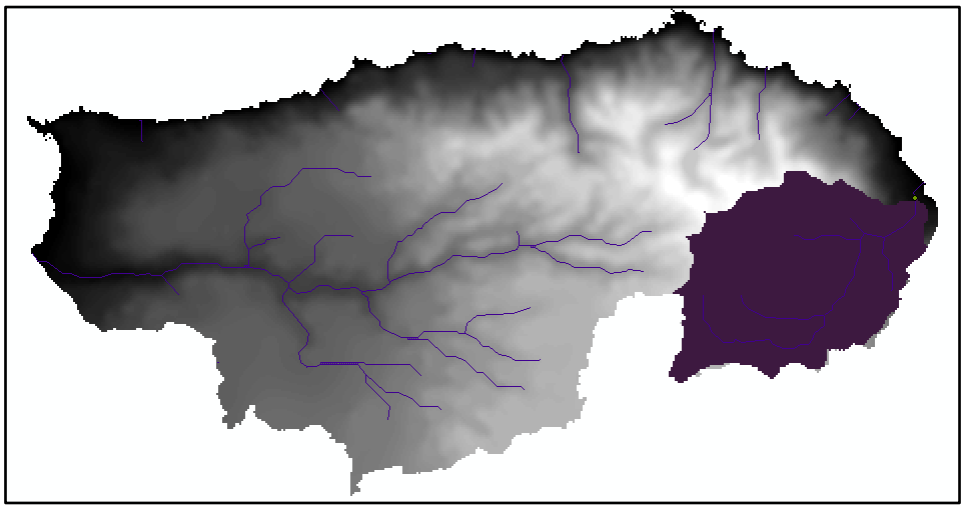
• Create a point shape layer.

• Add the layer to ArcMap and use the Editor tool to edit a point on it. The point should be placed at the outlet of the watershed (or sub-watershed) being delineated.

• ArcToolbox/ Spatial Analyst Tools/ Hydrology/ Watershed. (1) the flow direction raster, (2) the point shape layer with the outlet point, (3) the output file location.

To convert the watershed delineated in raster format using this method to vector format, the steps are almost the same as those followed to convert the hydrographic network. ArcToolbox/ Conversion Tools/ From Raster/ Raster to Polygon.





Conclusion

The use of geomatics, Geographic Information Systems (GIS), and remote sensing in water-related domains offers significant advantages in terms of management, monitoring, and preservation of water resources.

Through these technologies, it is possible to accurately map watersheds, monitor the evolution of water resources, identify areas at risk of drought or flooding, and make informed decisions regarding water resource planning and management. By integrating spatial data with other sources of information, professionals can better understand hydrological and ecological processes, contributing to a more sustainable and efficient use of water resources.

In summary, the use of geomatics, GIS, and remote sensing plays a crucial role in the integrated and sustainable management of water resources, promoting resilience in the face of water-related challenges.

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