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# Thematic Cartography and Interpretation

Course Handout for the Third Year Undergraduate Students of Ecology and Environment

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**Program Title: Ecology and Environment**

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**Subject Title 2: Thematic Cartography and Interpretation**

**Credits: 04**

**Coefficients: 02**

**Teaching Objectives:** The knowledge acquired in this module will enable the student to become familiar with new remote sensing techniques and Geographic Information Systems (GIS).

**Recommended Prerequisites:** An understanding of the ecological factors governing species distribution is required (bioclimatic, phytogeographic, orotopographic factors, etc.)

**Course Content:**

**I. Concept and Definition of Cartography**
**II. Advantages of Cartographic Representation**
**III. Review of Unit Systems**
**IV. Geographic Coordinates**
1. Longitude
2. Latitude
3. Azimuth
4. Altitude

**V. Projection Systems and Representations**
1. Lambert Conformal Conic Projection
2. Polar Stereographic Projection
3. Transverse Mercator Projection

**VI. Measurements on the Map**
1. Scale Concepts
2. Measuring the Coordinates of a Point

**VII. Elements Represented on a Map**
**VIII. Methods of Graphic Representation**
**IX. Applications of Thematic Cartography**
1. Vegetation Mapping
2. Digital Cartography

**Evaluation Method:**
Continuous assessment and semester exam

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## FOREWORD

Thematic cartography is more than a tool for visual representation; it is a scientific language that allows us to interpret spatial complexity through the lens of data. This course, Thematic Cartography and Interpretation, is designed to equip students with a foundational understanding of cartographic principles, while guiding them toward advanced applications in ecological and environmental sciences.

In an era where spatial data is abundant and environmental challenges are urgent, the ability to critically design, read, and interpret thematic maps has become essential. Whether depicting vegetation patterns, land use changes, climatic gradients, or biodiversity distributions, thematic maps serve as analytical instruments that bridge field observation and decision-making. Through them, spatial relationships are not only illustrated but also analyzed, contextualized, and communicated to scientific and policy communities.

This course introduces core cartographic concepts such as coordinate systems, projection methods, and scale interpretation, before advancing to thematic mapping techniques, including digital cartography and vegetation mapping. Emphasis is placed on the clarity, accuracy, and relevance of graphical expression, ensuring that students learn not only how to construct maps, but how to interpret and critique them in a scientifically rigorous manner. One key objective is that by the end of the course, students will not only have technical competence in cartographic methods but also a critical eye for the narrative power and limitations of maps. In doing so, they will be better prepared to address environmental questions with spatial reasoning and to contribute meaningfully to ecological research, conservation planning, and sustainable land management.

## Introduction

Cartography is a discipline of science as well as a communicative practice, in which the principal aim is to represent space through visual techniques for many different users. Thematic cartography is a focused collection of maps that illustrate specific themes or variables rather than simply representing geographic items. Unlike reference maps, which show multiple items such as rivers, cities, and political boundaries as a certain location on the earth's surface, no particular focus is the main task of thematic maps to eventuate a visual display that shows the spatial distribution of one or more phenomena. For example, phenomena that map themes might include demographics, land use, health statistics, climate variability, etc. (Dent et al, 2009). Thematic cartography's significance is in the suggestion of patterns and relationships that data files do not show and reveal to the naked eye. Consider the availability of statistical tables to show the details of numbers, while such data files usually lack geographic structure or spatial distribution altogether. However, if mapped, the same data might reveal gradients, clusters, outliers, etc., that can quickly suggest processes or relationships (Slocum et al., 2009). Thematic maps provide a visual summary that researchers, policymakers, and other professionals working within other organizations (ecology, environmental management, and spatial land use planning) have found to be attractive and useful. Now thematic mapping is operating within a tone of graphics based on data files collected in the field by theoretical and practical methods. Thematic maps begin with the data collection and preparation phase. This visual summary makes thematic maps a key tool for researchers, policymakers, and professionals within different fields such as ecology, environmental management, and overall spatial planning.

The construction of a thematic map starts with data collection and preparation, where their type (e.g., nominal, ordinal, interval, ratio, etc.) determines which mapping technique is appropriate. Nominal categories (e.g., soil types) are typically represented by distinctive colors, while interval or ratio data (e.g., temperature, income) are often shown through graduated color schemes or proportional symbols (MacEachren, 2004).

Projection and scale decisions represent the second major step in the mapping process. Due to the Earth's form, all map projections introduce distortions of area, shape, distance, or direction. The choice of projections must therefore reflect the thematic purpose of the map. For instance, equal-area projections are preferable when comparing

population or land use, whereas conformal projections may be more suitable for mapping navigation or meteorological variables (Snyder, 1987). In addition, scale similarly shapes the map's message, where small-scale maps emphasize general patterns at continental or global levels, while large-scale maps highlight local details.

Cartographers often employ visual variables, including size, colors, saturation, and orientation to represent the data. For example, choropleth maps classify numerical data within ranges and associate colors with those ranges; proportional symbol maps scale the size of symbols to reflect the magnitude of data. In each case, a successful thematic map is dependent on correctly presenting data, easy perception, and design, which can help readers interpret spatial patterns (Brewer, 2016).

Thematic maps are not objective illustrations of the world. They are representations that are influenced by methodological choices like projection selections, symbolization schemes, and classification techniques (Monmonier, 1991). For instance, depending on whether equal interval, quantile, or natural breaks classification is applied, the same dataset may appear highly polarized or relatively uniform. The same pattern can be interpreted differently depending on whether divergent or sequential color schemes are used. Learning to critically evaluate thematic maps is just as crucial for researchers and students as learning how to create them. This entails challenging the presumptions underlying the representation in addition to identifying obvious patterns: Which data were chosen? In what way were they categorized? Which distortions does the projection introduce? Creating this reflective method guarantees the use of maps.

In the era of Geographic Information Systems (GIS), remote sensing, and web-based platforms, thematic cartography has expanded its role from static representation to interactive visualization and spatial analysis. Interactive dashboards and web maps now allow users to explore multiple variables dynamically, supporting decision-making in real time (Kraak & Ormeling, 2020). Despite these technological advances, the fundamental principles of thematic mapping remain the same: clarity, accuracy, and effective symbolization are the hallmarks of high-quality cartography.

# Chapter I

# Concept and Definition of Cartography

## Chapter 1: Concepts and Definition

### 1. History of cartography and map making

From the earliest civilizations onwards, people have been drawing the world around them on stones, clay tablets, papyrus, and more. The earliest positive evidence of the graphical representation of Earth parts was shown a century before the Christian era, when the Babylonians drew maps on clay tablets, of which the oldest specimens found so far have been dated about 2300 BCE. It may be assumed that map-making goes back much further, and it may begin among non-literate people. It's logical to assume that very early man have made efforts to communicate with each other regarding their environment by searching locations, routes & hazards on the ground and later on bark and skins.

Personal experience and familiarity with local features are the basis of the earliest maps. Doubtless, routes were shown by the earliest maps to neighboring tribes, where other necessities & water might be found, and the location of enemies and other dangers. Stimulation of such efforts done by Nomadic life by recording ways to cross mountains and deserts, the relative locations of summer and winter pastures, & dependable springs, wells, and other information. Cave wall markings that are associated with primitive man's paintings have been identified by some archaeologists as an attempt to show the game trials of the animals depicted, though there is no general agreement on this. Similarly, hunting trails could be represented by a network of lines scratched on certain bone tablets, but definitely, there is no conclusive evidence that the tablets are indeed maps (Pand et al., 2021)

### 1.1.Early maps

From about 2300 B.C. the oldest known maps are preserved on Babylonian clay tablets. In ancient Greece, cartography was considerably advanced. Greece philosophers were well known of the concept of a spherical earth by the time of Aristotle (ca.350 B.C.) and since, have been accepted by all geographers. Map 1.1 is the world map of Babylonia. Clay material is used in making it. Its height is 12.2 cm, and width is 8.2 cm. The writing form of this map is Cuneiform. It was created in 6th century BC (Pand et al., 2021).

Roman and Greek cartographers reached a culmination with Claudius Ptolemaeus (Ptolemy, about A.D. 85-165). His “world map” depicted old world from about 60°N to 30°S latitudes. Map 1.2 is the world map. This map was created by Herodotus. It is one of the earliest maps. Map 1.3 is also a world map created by Ptolemy. This is also an example of earliest maps. Both maps can be considered as scientific maps.



**Figure1.** Babylonian Map of the World. *(Wikipedia)*

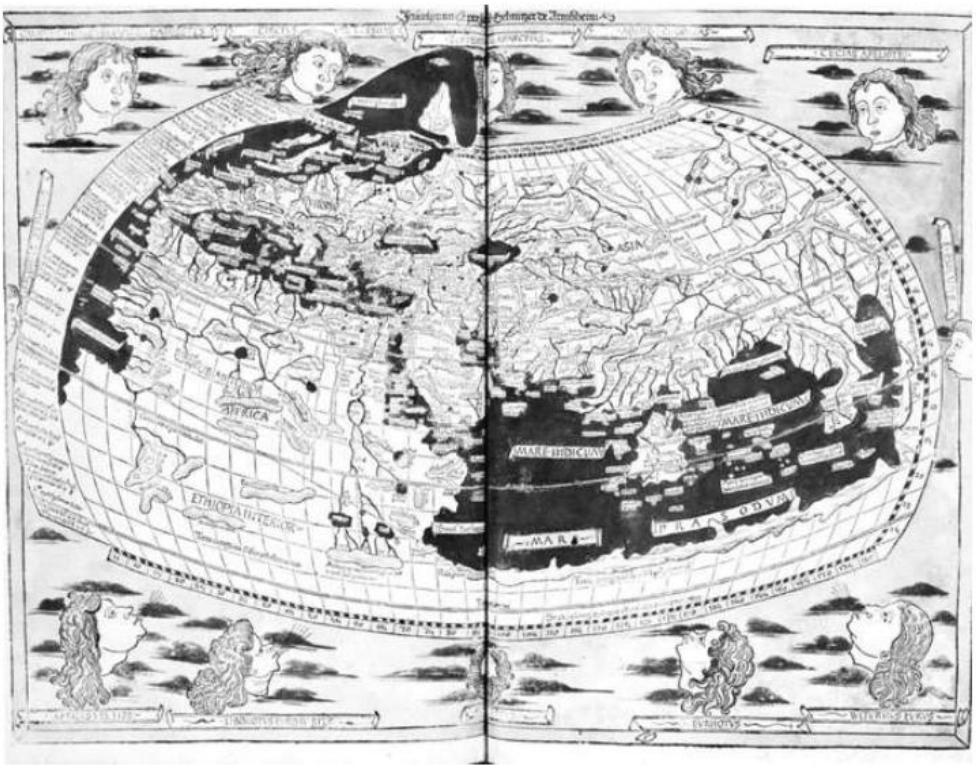



**Figure 2.** Herodotus' map of the world. (*Library of Congress, Washington, D.C*)

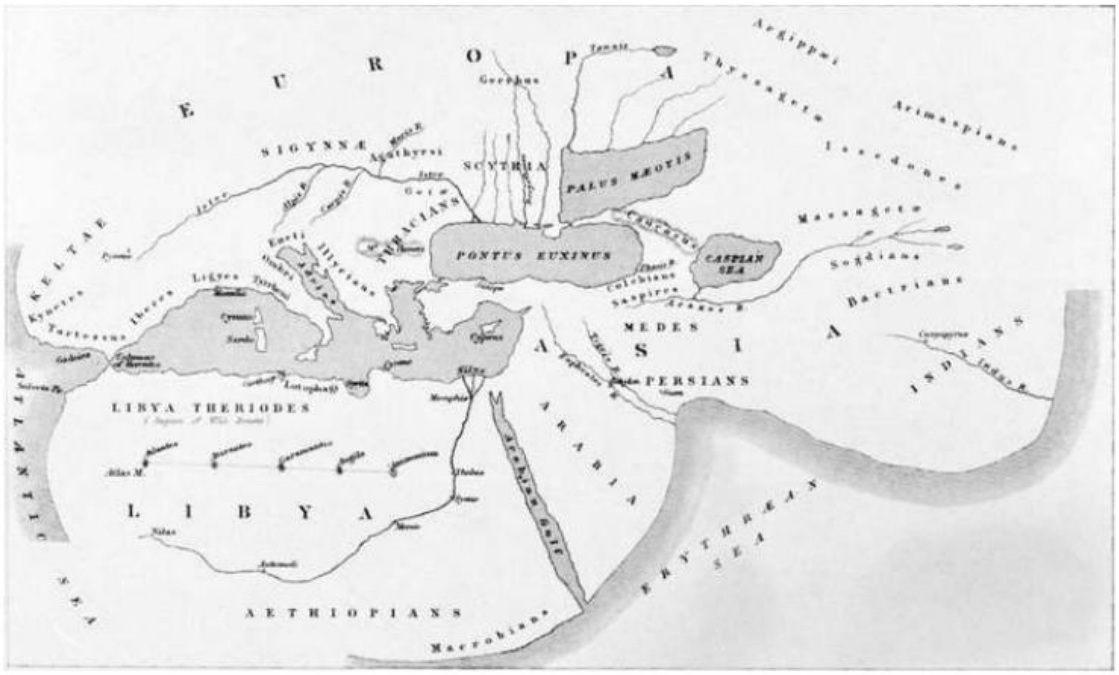



**Figure 3.** world map Ptolemy's map of the world, as printed at Ulm, 1482. (*Library of Congress, Washington, D.C*)

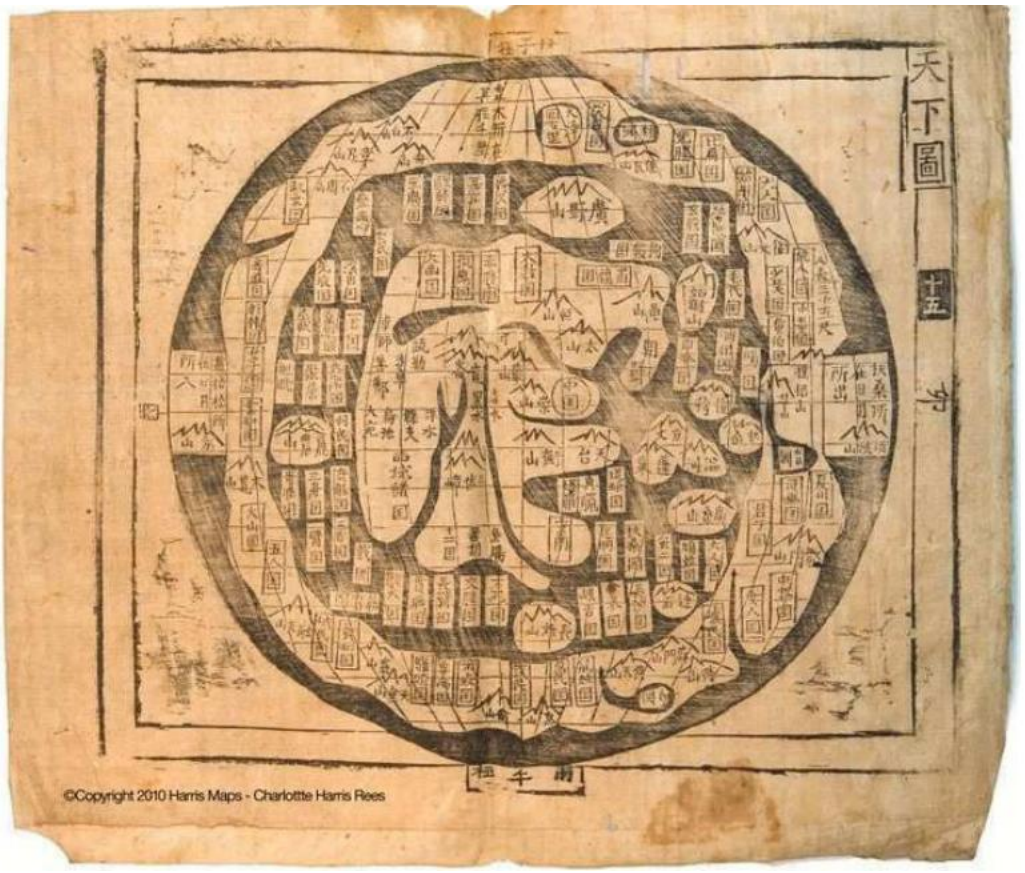



**Figure 4.** One of the ancient Chinese maps from the collection of Dr. Henson Harris Jr.'s collection, published in his book in 1973.

### 1.2.Medieval Maps

The Arab geographer Muhammad al-Idrisi produced his medieval atlas Tabula Rogeriana in 1154. He incorporated the knowledge of Africa, the Indian Ocean and the Far East, gathered by Arab merchants and explorers, with the information inherited from the classical geographers to create the most accurate map of the world up until his time. It remained the most accurate world map for the next three centuries.

The Europe Renaissance marked the period coming out of the Dark Ages as literature, music, art society flourished with new knowledge. In this period, advances in the art of map-making were made which have influenced modern geography and cartography as we know them today. Few different types of medieval European maps exist that have provided us with clues as how early cartographers saw and mapped with world around them. European maps were dominated by religious views during the medieval period. T-O maps were common at this time. In this map format, Jerusalem was depicted at the center and east was printed towards the map top (Pand et al., 2021).




**Figure 5**.T-O maps. (Wikipedia)

### 1.3.Modern Maps

Maps became accurate increasingly and factual during 17th, 18th, and 19thcenturies with the scientific methods applications. Nonetheless, much of the world was poorly known until the widespread use of aerial photography following World War 1. On combination of ground observations and Remote sensing Modern cartography is based. In 1970-80s period GIS emerged. Geographic information system represents a major shift in the cartography paradigm. In traditional cartography, the map was both a database & display of geographic information. Database, analysis, and display are physically and conceptually separate aspects of handling geographic data for GIS (Pand et al., 2021).

## 2. Definition of Cartography

Cartography is the study and practice of making maps. It combines science, aesthetics, and technical methodologies. It is based on the premise that spatial reality can be modeled to effectively communicate spatial information (Kraak and Ormeling, 2020).

The term cartography originates from the Greek words' charts (map or paper) and graphing (to write), reflecting its historical roots in descriptive geography. Traditionally focused on the accurate depiction of geographic features such as topography and hydrography, the field has evolved to embrace a broader range of applications. Contemporary cartography includes thematic mapping, which represents spatial variation of specific variables like vegetation, land use, population, or climate indicators (Slocum et al., 2009).

In 1967**,** the French Cartography Committee defined the cartography as the scientific, artistic, and technical operations carried out based on the results of direct observations or the use of documentation, aimed at the development and creation of maps, plans, and other modes of expression, as well as their utilization. Cartography aims to represent the Earth in a geometric and graphic form through the design, preparation, and production of maps. Cartography is both a science, an art, and a technique. The map, which is its ultimate purpose, tends to approximate the truth while embodying a certain beauty (Poidevin, 2007).

***Cartography is a science*** because its foundations are mathematical, particularly concerning the determination of the Earth's shape and dimensions, then the projection of the Earth's curved surface onto a plane (the map) using projection systems, and finally

the establishment of a planimetric and altimetric framework. The challenge lies in the accuracy and reliability of the map.

***Cartography is an art*** because, as a mode of graphic expression, the map must exhibit qualities of form (both aesthetic and didactic, through the clarity, expressiveness, and legibility of its lines) in order to make the best use of the reader's visual abilities. This requires that the designer and creator make choices in how the representation is constructed.

***Cartography is a technique*** because it requires, from start to finish, the use of instruments whose advances have revolutionized the entire cartographic process (aerial photography, satellites, computers, printing and distribution, etc.).

**The scientific fields that are directly involved are:**

- ***Astronomy*** which involves astronomical measurements of stars (such as the North Star) from fundamental points on Earth to determine positions and directions on Earth.
- ***Geodesy*****,** which is the science that aim at determining the shape and dimensions of the Earth. It is a set of techniques intended to determine the planimetric positions (X, Y) and altimetric positions (Z) of a number of geodetic points and leveling benchmarks.
- ***Photogrammetry,*** which represent techniques for exploiting aerial photographs or satellite images for cartographic use (production of orthophotos, Digital Terrain Models, maps, etc.).

## 2.1.Importance of Cartography in ecology and environmental sciences

The role of cartography in environmental sciences and ecology is critical. Maps serve as analytical instruments for understanding spatial patterns of biodiversity, habitat fragmentation, climate change impacts, and land degradation. They provide a means to synthesize field data, model spatial processes, and communicate findings to scientists, stakeholders, and policy makers (Goodchild, 2007). Cartography is not limited to the creation of static images. It is a dynamic process of spatial abstraction and communication that transforms data into knowledge. As Monmonier (1996) aptly noted, "*not only can*

*maps lie, but they can also clarify, persuade, and reveal truths, depending on how they are designed and interpreted*."

## 3. Definition of Map

A map is a symbolic depiction which denotes relationships between elements of some space such as objects, regions and themes. Most world maps are drawn to a scale to express a ratio between two or more units of measurements. The word 'map' originated from the Latin world 'mappa' which meant a napkin or paper. Why so? Because these were the usual materials the earliest maps of the world were drawn on

Many authors have tried to define the map and they revealed the following main characteristic:

Map is a graphic representation of the earth or part of it.

- It shows the physical and cultural features.
- It is a flat piece of paper.
- It is drawn on a definite scale.
- It has its extension on a graticule of lines known as latitudes and longitudes.
- The identification of objects is made either by symbols or lettering.
- It shows selected features.
- It is a two-dimensional representation of the earth.

### 3.1.Classification of maps

There are different types of maps. There is uniqueness in designing, construction, contenting & hence a self-type of each map. There are two types of maps classified broadly: Scale and purpose or content. Further on two other bases, these are also classified: topographic features and the nature of construction

#### 3.1.1. Classification Based on Scale

There are two broad categories of maps:

**a. Large Scale maps:**

These maps represent small areas of the Earth's surface on a large size of paper with greater details. Such types of maps are**:**

- **Cadastral maps:** From the French word *cadastre* the term cadastral is derived. It means a register of territorial property. To register the ownership of landed property

the cadastral maps are drawn. It shows the demarcation of the boundaries of fields, buildings. To realize land revenue and property taxes, these are especially prepared by the government. Village maps are large-scale maps showing the field boundaries, footpaths, water bodies, public places, residential houses and so on. These maps are drawn on a very large scale, varying from 20 cm to a km to 40 cm to a km, to fill up in all possible details. To this category Rural Land use maps also belong. Also in this category city maps may be included. Different details like water-line, individual houses, sewer line, public buildings, roads, playgrounds, parks etc. are showed by these maps. House layout plans are also included in it. This map is of very large scale. To this category town plan maps also belong. On a scale of 1:20000, Survey of India publishes city and town guide maps.

- **Topographical maps:** On a fairly large scale, these maps are prepared. On precise survey these are based that is conducted by the survey of India, Dehradun. General surface features are shown by them in detail comprising both natural & cultural landscape. 'A topographical map is on a sufficiently large scale to enable the individual features shown on the map to be identified on the ground by their shape and position' is according to the Survey of India. These maps do not have the boundaries of individual plots or buildings. Principal topographic forms like relief and drainage, swamps and forests, villages and towns, means of communication like roads and railways, spot and relative heights, contours are rather depicted from these. On the scales of 1:25:000, 1:50:000 and 1:250:000 in India, these maps are mainly prepared. It is to be noted that the nature of details increases with the increase in the largeness of the scale. For example, a map of 1:25:000 scale shows much more details than the map of a scale of 1:250:000. With the help of convection signs various details are shown on these maps. For the study of geography of an area these maps are very important. So, some scholars have defined them as tools of geographers. For the study of an area at micro level these maps are very important. According to their scale these maps are numbered; suppose if the number of a map is 53K, it means that the scale of map is 1:250,000, when the number of topographical map is 53K/15, it is understood that the map is on the scale of 1:50,000. The number of map with 53K/15/4 denotes the scale of 1:250,00. Such topographical maps are not still in much use.

**b. Small scale maps:**

Large areas on a small sheet of paper are represented by these maps. They have a few details. Wall maps and Atlas are the best examples of small-scale maps. The maps included in any book, magazines, or newspaper are also small-scale maps. They give only a general picture of the area represented

- **Wall maps**: Though wall maps have large scale than Atlas or book maps, but their scale is comparatively smaller one. These are drawn boldly so that they can be seen from a distance. They are used in cater and classrooms to the needs of the large audience. They are called wall maps because they are hanged on the flat surface walls. In real sense these are geographical maps. Large areas like world as a whole, continents, hemispheres, countries, states, districts & tehsils are shown by them. With certain purposes these maps are drawn like to show the types of soils, climatic conditions and distribution of minerals, types of vegetation and social, cultural, means of transport, population, economic and political patterns. These maps are of different size. On nature of objects it depends to be shown therein. Our Survey of India prepares these wall maps on a scale of 1:15,000,000 to 1:250,000.
- **Atlas Maps:** Book of maps is '**Atlas**'. On very small scale these are drawn and give a highly generalized picture of natural and cultural aspects, such as physical climate, drainage, soils, agricultural crops, industries and so on. These are mainly prepared on 1:20,000,000 scales or less than that. In our country, National Thematic Mapping Organization (NATMO) is a well known important organization. For various purposes it publish all kinds of maps, depicting different parts of the country and its product is known as National Atlas of India. Other important Atlas is Oxford Atlas, Reader's digest Atlas, School Atlas, District Atlas, State Atlas, Census Atlas, and so on. These maps are also called as chorographical maps.

### 3.1.2. Classification Based on Purpose

Mainly these are thematic maps prepared on small scales. Thematic maps are data maps of a unique topic or for a specific purpose. Specific features of the area concerned are highlighted by them. Into two main divisions they are broadly classified which are: Physical or natural maps and Cultural maps.

### a. Physical or natural Maps

They are the maps that represent various aspects of the natural environment. They highlight various physical aspects like relief, climate, natural vegetation, and soils. These may be categorized as follows:

- **Orographic or Relief Maps**: represent the physical features of the Earth's surface, particularly the elevation and shape of the terrain. These maps emphasize topographic variation using contour lines, shading, color gradients, or three-dimensional visualization to illustrate mountains, valleys, plains, and other landforms. The key purpose of orographic maps is to provide a clear representation of elevation and landform structure. Contour lines indicate equal elevation above sea level, and their spacing reflects the steepness of the slope: closely spaced lines indicate steep terrain, while widely spaced lines show gentle slopes. Some relief maps also include hypsometric tinting (i.e., coloring by elevation zones) or hillshading to enhance the three-dimensional effect. These maps are essential in geology, geography, environmental planning, civil engineering, hydrology, and natural hazard assessment (e.g., landslides or floods). They support applications like watershed modeling, infrastructure development, and landscape ecology (Evans, 2012).

- **Bathymetric Maps:** represen**t** the depth and shape of the ocean floor, lakes, and other submerged terrains using isobaths (contour lines of equal depth), color gradients, and shading. These maps are indispensable tools for marine geologists, coastal planners, naval operations, and conservation efforts in marine protected areas (Jakobsson et al., 2012).

- **Geological Maps**: represent the distribution, nature, and age of rock formations and structural features at the Earth's surface or beneath it. They may also show geological units (such as sedimentary, metamorphic, or igneous rocks), faults, folds, and mineral resources. These maps are essential tools in fields such as earth sciences, engineering geology, mineral exploration, and natural hazard assessment (e.g., landslides or earthquakes). Geological maps often use specific colors and symbols to distinguish between different strata and tectonic features (Press & Siever, 2001).

- **Climatic Maps:** Climatic maps illustrate long-term climate patterns in a region, including variables such as temperature, precipitation, humidity, and wind. These maps are based on climatic averages calculated over a long period (typically 30 years) and are useful for studying climate zones, biomes, and the impact of climate change. They are widely used in environmental research, agriculture, and urban planning (Peel et al., 2007).

- **Weather Maps**: also called synoptic charts, display real-time or forecasted meteorological conditions over a geographic area. They show atmospheric phenomena such as temperature, atmospheric pressure (isobars), wind direction, cloud cover, precipitation, and fronts. These maps are crucial for meteorology, aviation, disaster preparedness, and public weather forecasting. Symbols and color codes are standardized by the World Meteorological Organization (WMO, 2019).

- **Soil Maps:** classify and represent the spatial distribution of different soil types and their properties (texture, pH, organic matter, drainage, etc.). These maps are vital in agriculture, land management, forestry, and ecological restoration, helping determine soil suitability for different uses. They are based on field surveys and laboratory analyses and are often integrated into GIS systems for spatial analysis (FAO, 2006).

- **Natural Vegetation Maps:** illustrate the spatial distribution of major plant communities that have developed under natural environmental conditions, without significant human influence. These maps reflect ecological zones such as forests, grasslands, deserts, and wetlands, often linked to climatic and edaphic factors. They are important for biodiversity conservation, ecological research, and land-use planning (Whittaker, 1975).

- **Astronomical Maps:** Astronomical maps, or celestial charts, represent stars, constellations, planets, and other celestial bodies as seen from Earth. They are used in astronomy, navigation, and space science to map and study the structure of the universe. These maps can be either observational (e.g., star charts) or

computational (e.g., galaxy distribution models) and often use spherical coordinates such as right ascension and declination (Ridpath, 2017).

**b. Cultural Maps**

These types of maps illustrate the Human aspects such as population, socioeconomic factors, migration...etc. Into the following groups these are categorized.

- **Economic Maps**: illustrate the spatial distribution of economic activities and resources. These may include natural resource locations (e.g., oil fields, forests, mineral deposits), types of agriculture, industrial zones, trade routes, energy infrastructure, or economic indicators such as income levels or gross domestic product (GDP) by region.The purpose of economic maps is to visualize patterns of production, consumption, and trade, often helping policymakers and researchers understand spatial inequalities, resource dependencies, or development opportunities. They are also widely used in land-use planning, investment strategy, and regional development studies (Goodchild et al., 2000).

- **Political Maps**: represent territorial boundaries and human-defined divisions such as countries, states, provinces, and administrative regions. They often highlight capital cities, major urban centers, and international borders, but do not show physical landscape features in detail. These maps serve as tools for understanding geopolitical relationships, administrative structures, and territorial governance. They are crucial for teaching political geography, international relations, and for use in governance, policy development, and diplomacy (Flint, 2012).

- **Historical Maps**: depict past geographical conditions, events, or territorial boundaries at a specific moment in history. These may include the extent of ancient civilizations, colonial empires, migration routes, battles, or historical land use.Such maps are critical for understanding how spatial relationships have evolved over time due to war, colonization, environmental changes, or socio-political transformations. They are widely used in historical research, archaeology, heritage preservation, and education (Harley & Woodward, 1987).

- **Socio-cultural Maps:** represent the spatial distribution of cultural or social attributes. These may include languages spoken, ethnic groups, religious affiliations, traditional practices, or heritage site. These maps are useful in anthropology, cultural geography, and development studies, offering insights into cultural diversity, identity, and territoriality. They help visualize how cultural landscapes interact with physical and political environments, often revealing zones of cultural convergence, conflict, or resilience (Jordan-Bychkov & Domosh, 1999).

- **Population Maps:** show the distribution, density, and structure of human populations. They can be static (e.g., population per square kilometer) or dynamic (e.g., population growth, urbanization trends, age structure). Different mapping techniques include dot maps (each dot represents a set number of people), choropleth maps (color-shaded regions based on population density), and cartograms (distorted shapes to reflect population size). These maps are foundational in demography, urban planning, public health, and disaster risk management (Weeks, 2020).

There is also another type of map called **Military Map**, which are used or prepared by the defense services.

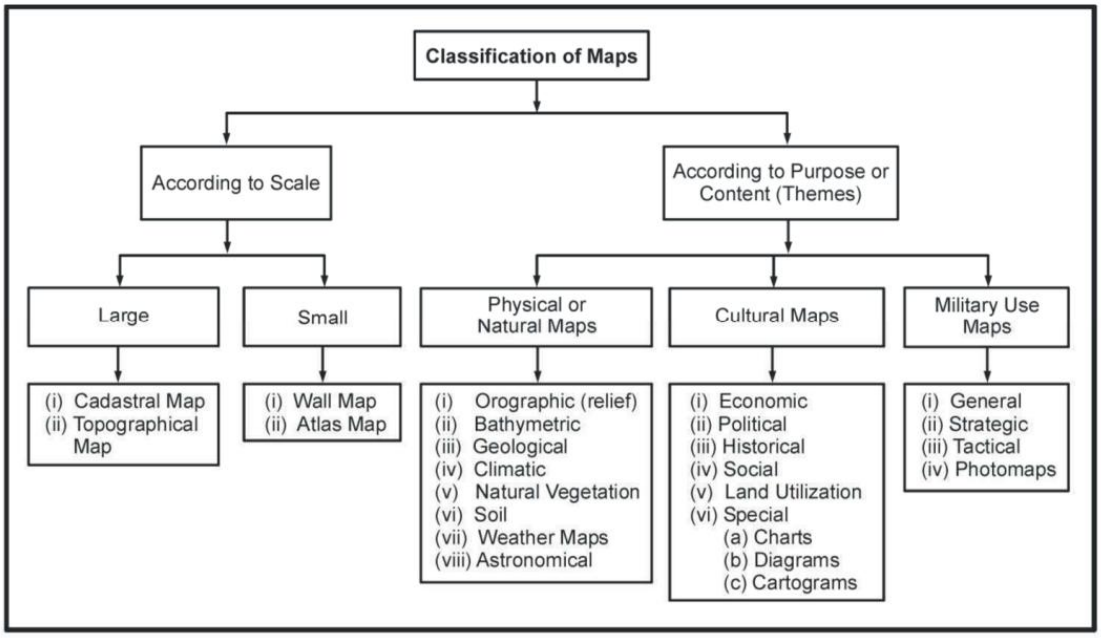



**Figure 6.** Main types of Maps

# Chapter II

# Advantages of Cartographic Representation

## Chapter II: Advantages of Cartographic Representation

Cartographic representation is the practice of translating spatial information into a visual format for analysis, interpretation, and communication. As a foundational tool in geography, ecology, environmental science, and spatial planning, the map serves not only as a visual aid but also as a scientific instrument. This chapter explores the various advantages of cartographic representation in scientific, technical, and educational contexts.

### 1. Visualizing Spatial Phenomena

One of the primary advantages of maps is their ability to make spatial patterns and relationships visible. Unlike tables or textual descriptions, maps allow users to quickly grasp the location, distribution, and interactions of geographical features. For instance, thematic maps can reveal how temperature, rainfall, or vegetation changes across a landscape, enabling spatial reasoning and hypothesis generation (Slocum et al., 2009). They allow users to detect clusters, gradients, and anomalies that would otherwise remain hidden in non-spatial data formats.

### 2. Revealing Spatial Distribution

Maps allow users to observe where things (i.e., phenomena) happen and how they vary across space. For example, a thematic map showing the distribution of rainfall or temperature across a continent can immediately reveal climatic gradients, regional disparities, and spatial trends—insights that would be difficult to extract from a table of numbers. This capacity to reveal spatial heterogeneity is essential in disciplines like ecology (e.g., species distribution), epidemiology (e.g., disease hotspots), and urban planning (e.g., land use density). According to Slocum et al. (2009), cartographic visualization fosters spatial pattern recognition, allowing analysts to detect clusters, gaps, or anomalies in data.

### 3. Understanding Spatial Relationships

In addition to locating phenomena, maps help in understanding spatial relationships such as proximity, connectivity, orientation, and spatial correlation. For instance, a vegetation map overlaid with elevation contours can help identify how plant communities shift with altitude. Similarly, a map showing industrial activity and air quality zones might reveal cause-and-effect relationships based on spatial proximity.

Visualizing these relationships is critical in environmental science, where interactions among variables (e.g., soil type, slope, land cover, and hydrology) are inherently spatial. Geographic Information Systems (GIS) enhance this analytical potential by enabling multi-layer spatial analysis, such as buffer zones, intersection, and spatial statistics (**Longley et al., 2015**).

**4. Detecting change over time (spatiotemporal visualization)**

Maps can also be used to visualize spatiotemporal dynamics, especially when comparing changes over time, such as deforestation, urban expansion, or temperature anomalies. Animation and time series maps allow users to track spatial phenomena across years, decades, or even centuries. For example, a series of maps showing glacier retreat or wildfire occurrence over decades provides compelling visual evidence of environmental change. This is especially useful for communicating scientific results to policy-makers and the public, who may struggle to interpret raw data or statistical summaries.

**5. Enhancing perception through design**

The power of visualization also depends on cartographic design. The use of colors, symbols, shading, and generalization techniques can dramatically influence the user's ability to interpret spatial patterns. Poorly designed maps can mislead or obscure data, while well-designed maps clarify and emphasize key information (MacEachren, 2004).

**6. Synthesizing complex information**

Another key advantage of cartographic representation lies in its ability to synthesize and integrate large volumes of complex, multidimensional data into a single, coherent visual format. Unlike textual or numerical datasets, which often require extensive interpretation, maps enable users to quickly understand complex spatial phenomena and relationships at a glance.

**7. Integrating multiple layers of data**

In contemporary cartography, especially through Geographic Information Systems (GIS), maps can combine multiple data layers, each representing a different thematic variable. These layers may include topography, land use, vegetation cover, soil type, climate variables, population density, and infrastructure. By overlaying these layers, analysts can explore interactions among diverse environmental and social factors.

### 8. Reducing cognitive load

Raw spatial data, such as satellite imagery, census tables, or climate time series, can be overwhelming due to their volume and complexity. A well-designed map acts as a filter, selecting relevant variables, summarizing them graphically, and reducing the cognitive effort required for analysis. For example, rather than presenting fire frequency values for hundreds of grid cells, a map using graduated colors or symbols can immediately highlight regions with higher recurrence. This helps researchers, planners, and decision-makers grasp the essentials without wading through raw numbers (MacEachren, 2004).

### 9. Facilitating pattern recognition

Maps enhance the human ability to recognize spatial patterns, especially in multi-variable settings. Through cartographic generalization and symbolization, thematic maps transform raw data into interpretable spatial forms, allowing users to spot correlations, gradients, thresholds, or outliers. For example, a bivariate map showing both temperature increase and vegetation decline may suggest climate stress zones. In public health, overlaying vector-borne disease incidence with land cover and water bodies may reveal favorable environments for disease transmission (Slocum et al., 2009).

### 10. Supporting interdisciplinary analysis

The ability to synthesize diverse spatial information also supports interdisciplinary collaboration, which is essential in fields like sustainable development, environmental planning, and conservation. Cartographic products can serve as a common visual language among ecologists, urban planners, hydrologists, sociologists, and policymakers. For instance, land-use planning that balances ecological integrity and urban expansion may require synthesis of biophysical, demographic, and economic data. Maps allow different stakeholders to analyze the same geographic space from their disciplinary perspectives, fostering integrated strategies (Longley et al., 2015).

### 11. Communicating scientific information

Cartographic representation is not only a tool for spatial analysis, but also a powerful medium of scientific communication. Maps can effectively convey complex scientific findings to diverse audiences, ranging from experts to policymakers to the general public. This capacity makes cartography a central element in environmental

science, ecology, epidemiology, climate research, and numerous other disciplines (MacEachren, 2004; Monmonier, 1996).

### 12. Enhancing scientific dissemination

Scientific studies increasingly rely on maps to present spatially explicit results. Whether it involves biodiversity hotspots, climate anomalies, or pollution dispersion, the spatial dimension is crucial to understanding environmental phenomena.

**Example:** Biodiversity assessments may map species richness gradients or endemic zones, facilitating the identification of conservation priorities.

### 13. Facilitating evidence-based decision making

Maps translate scientific information into policy-relevant insights, helping bridge the gap between research and action. Well-crafted thematic maps can support evidence-based decision-making in land-use planning, disaster management, conservation, and public health.

**Example:** Zonation maps for land suitability help prioritize areas for agriculture or reforestation.

### 14. Bridging the expert–layperson gap

Scientific language can be inaccessible to non-experts. Maps provide a visual narrative that transcends linguistic and educational barriers. A well-designed map can make data and scientific insights understandable to the public, journalists, and decision-makers without requiring technical background (Brewer, 2005).

### 15. Support transparency and reproducibility

Maps support transparency and reproducibility in scientific research. They reveal where data are strong or sparse, where uncertainty is high, and how conclusions are spatially bound. Metadata, scale indicators, legends, and symbology contribute to the credibility of cartographic outputs.

# Chapter III
# Review of unit systems

## Chapter III: Review of unit systems

Depending on the map's scale, publication date, and country of origin, the units used may vary. This applies to angular units, distance units, and various orders of magnitude, all of which are essential for properly using and interpreting a topographic map. Units of measurement are the foundational elements of quantitative communication in cartography and geographic analysis. In spatial sciences, the use of consistent, appropriate unit systems is essential to ensure accuracy in distance, area, volume, and spatial relationships. Errors in unit usage can lead to critical misinterpretations, especially in ecological and environmental studies that rely on precise data integration across disciplines and sources (Longley et al., 2015). There are various unit systems commonly used in cartography, including metric units (such as meters and kilometers) and angular units (such as degrees of latitude and longitude). The choice of unit system is closely tied to the type of coordinate system and map projection employed. For instance, geographic coordinate systems typically use angular units, while projected coordinate systems rely on linear (metric or imperial) units to enable accurate measurements of distance and area.

### 1. The radian

The **mathematical unit for measuring angles** is the *radian*, denoted as *rad*.

A **radian** is defined as the angle subtended at the center of a circle by an arc whose length is equal to the circle's radius (***R***).

Since the circumference of a circle is equal to **2πR**, a full circle corresponds to 2π radians, where $\pi \approx 3.14$

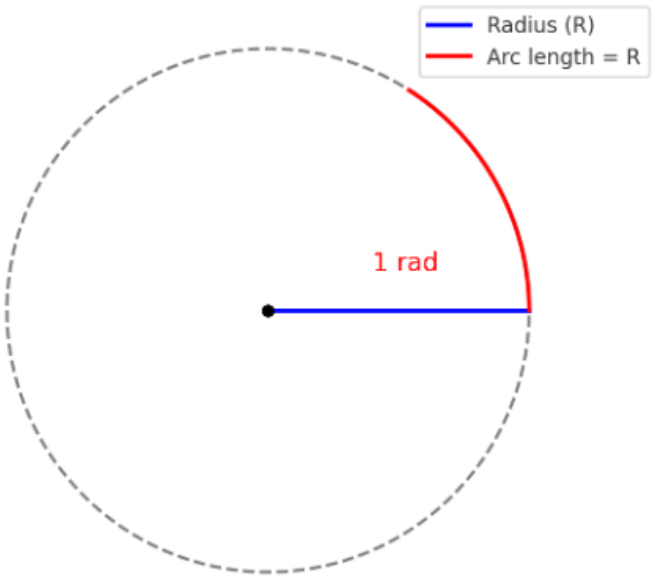



**Figure 7.** Illustration of 1 Radian

### 2. The Degree

The degree is the angular unit that divides a full circumference into 360 equal parts. The notation for a degree is "°". Calculations in degrees are sometimes considered "tedious" because, like time, the degree system is based on a sexagesimal system (base 60).

The subdivisions of the degree are:

- The arcminute, noted "'", where 60' = 1°.
- The arcsecond, noted "''", where 60" = 1'.

➔ Therefore: 1° = 60' = 3,600".

So, 1 degree is equal to 60 minutes of arc or 3,600 seconds of arc.

**Example:**

21°06'34",1035 (the second are decimals). We can convert it to decimal degree: 21º,1094732.

### 3. The Grad

The grad (also called gon) is an angular unit that divides a circle into 400 grads. The grad is denoted as "gr".

It is a decimal-based unit, whose submultiples are:

- The tenth of a grad, or decigrad (dgr): 1 dgr = 0.1 gr
- The hundredth of a grad, or centigrad (cgr): 1 cgr = 0.01 gr
- The thousandth of a grad, or milligrad (mgr): 1 mgr = 0.001 gr
- The ten-thousandth of a grad, or decimilligrad (dmgr), also called the hundredth of a centigrad (cc): 1 dmgr = 1 cc = 0.0001 gr

### 4. The Mil (or milliradian)

The mil is an angular unit such that a circle is divided into 6,400 mils. The mil is very close to 1/1,000 of a radian and can be considered as the angle under which one sees 1 meter at a distance of 1,000 meters.

The notation for the mil is: "mil" (sometimes also written as "‰" or "mils" depending on the convention).

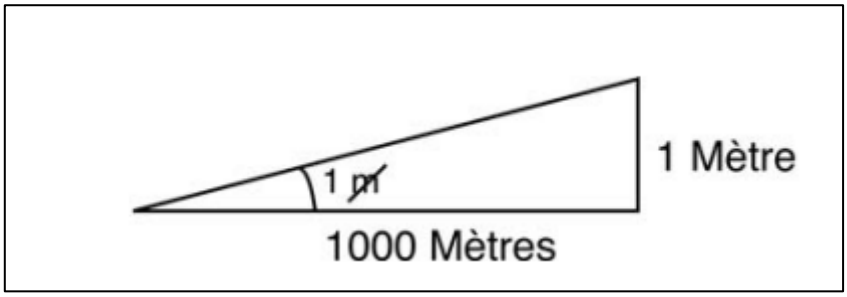
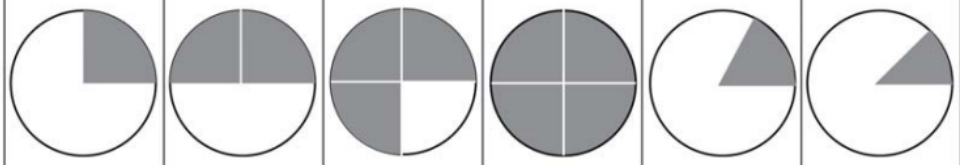



**Figure 8.** Illustration of one milliradian.

**Table 1.** Equivalence table of different unit systems.

| UNITÉ |  | | | | | |
|---|---|---|---|---|---|---|
| Radian | $\pi/2 \cong 1.57$ rd | $\pi \cong 3.14$ rd | $3\pi/2 \cong 4.71$ rd | $2\pi \cong 6.28$ rd | $\pi/3 \cong 1.05$ rd | $\pi/4 \cong 0.79$ rd |
| Degré | 90° | 180° | 270° | 360° | 60° | 45° |
| Grade | 100 gr | 200 gr | 300 gr | 400 gr | 66,666 gr | 50 gr |
| Millième | 1600 | 3200 | 4800 | 6400 | 1066,66 | 800 |

## 5. Time measurement

The Earth's diurnal rotation around its axis long seemed sufficiently uniform to define the measurement of time. Currently, the concept of time is based on an atomic definition of the “second,” which is particularly stable and reproduced using atomic clocks. It is from this “atomic second” that universal (UT) or legal time scales, which govern our daily life, are defined.

## 6. Metric Measurement

Throughout history, there have been various units of length: the foot, the toise, the inch. Some of these units are still in use (in England and the United States), but the internationally recognized legal unit of length is the meter.

Nowadays, a meter corresponds to the distance traveled in a vacuum by light during 1/299,792,458 of a second. The original meter, or archival meter, dates back to the late 18th century: at that time, scientists calculated the dimensions of the Earth and defined the meter as one ten-millionth of a quarter of the Earth's meridian.

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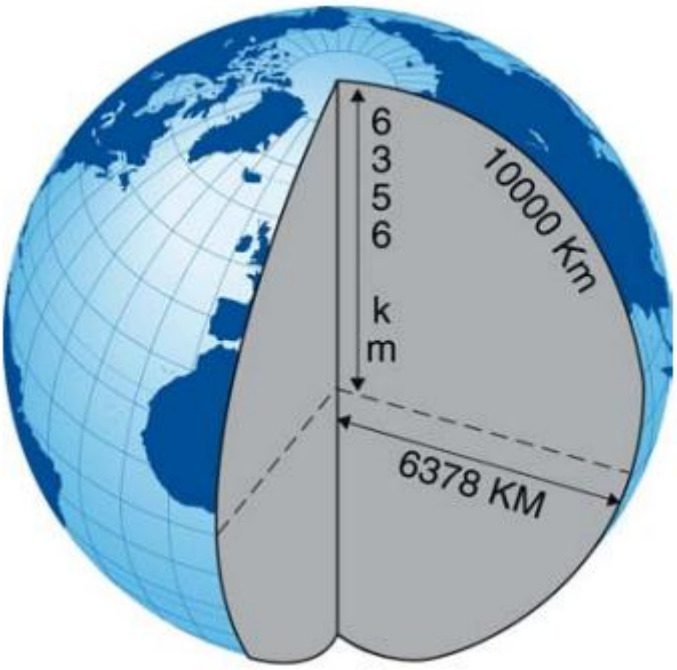
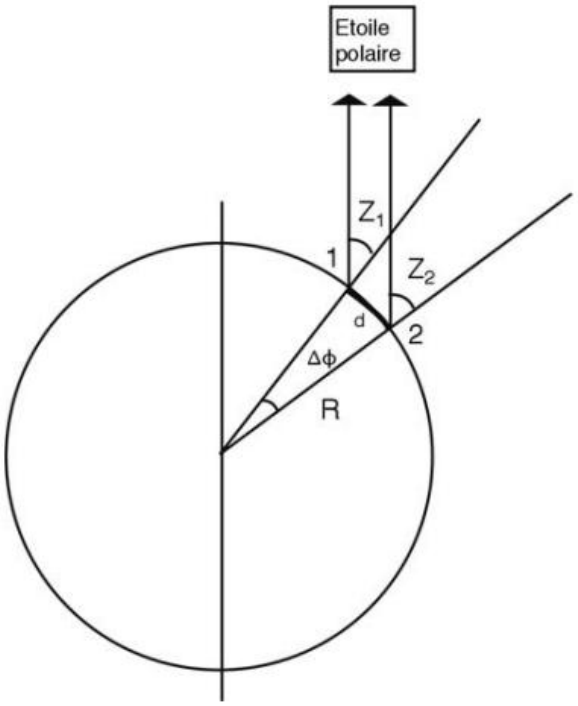



**Figure 9.** Earth's measures




**R: the radius of the Earth,**

**D: the observed distance between two points 1 and 2.**

Looking at Z1 and Z2, we can deduce:

$$\varphi 1 = 90^\circ - Z1$$
$$\varphi 2 = 90^\circ - Z2$$

and we determine:

$$\Delta\varphi = \varphi 2 - \varphi 1$$

The radius R of the Earth is approximately equal to:

$$R = \Delta\varphi d \text{ (rad)}$$

**Figure 10.** Geometric principle of latitude determination using the Polar Star

# Chapter VI
# Geographic Coordinates

## Chapter VI: Geographic Coordinates

Geographic coordinates constitute the fundamental system for locating any point on the Earth's surface with precision. Based on a network of imaginary lines—parallels of latitude and meridians of longitude—this system provides a universal language of position that transcends political and cultural boundaries (Snyder, 1987; Hofmann-Wellenhof & Moritz, 2006). Latitude measures the angular distance north or south of the equator, while longitude measures the angular distance east or west of the prime meridian. Together, these coordinates form a grid, often referred to as the geographic graticule, that underpins cartography, navigation, and geospatial sciences.

The development of geographic coordinates is rooted in centuries of astronomical observation and mathematical advances. From the ancient work of Eratosthenes and Ptolemy to the global standardization of the Greenwich meridian in 1884, the system has evolved to support increasingly sophisticated applications (Steers, 1970). Today, it forms the basis of modern technologies such as the Global Positioning System (GPS), Geographic Information Systems (GIS), and satellite-based Earth observation, ensuring accurate spatial referencing across scientific, engineering, and everyday contexts (Dana, 1995).

Understanding geographic coordinates is therefore essential for students of cartography, geography, and geosciences. This chapter introduces the principles of latitude and longitude, explains how coordinates are measured and represented, and highlights their practical applications in mapping, navigation, and spatial analysis.

### 1. Longitude (λ)

The longitude (λ) of a point is the angle formed by the meridian plane containing this point with a reference meridian plane taken as the origin. Longitude is measured from 0 to 180 degrees (or 0 to 200 grads) east and west of the reference meridian.

On Algerian maps, longitudes are generally expressed in degrees, and the reference meridian is the Greenwich meridian (international meridian). This convention aligns with international cartographic standards. Thus, the Greenwich meridian is taken as the origin ($\lambda = 0°$), and Algeria is located east of Greenwich, with longitudes ranging approximately from –9° to +12° depending on the region.

### 2. Latitude (ϕ)

The latitude (ϕ) of a point is the angle formed between the normal to the reference ellipsoid passing through that point and the plane of the equator. Latitude is measured from 0 to 90 degrees (or 0 to 100 grads) north and south of the equator.

For Algeria, which is located entirely in the Northern Hemisphere, latitudes range approximately from 19°N (Tamanrasset region, Sahara) to 37°N (Mediterranean coast).

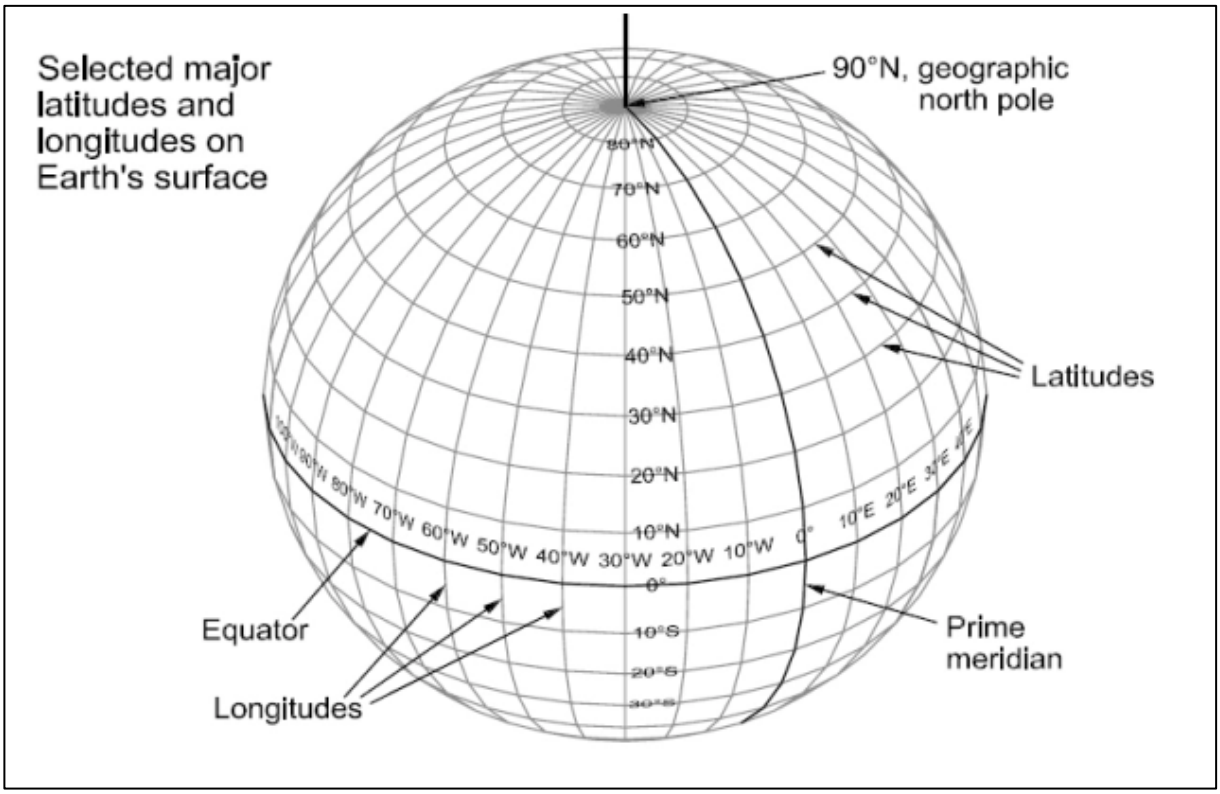



**Figure 11.** Representation of the geographic coordinate system on Earth's surface, showing selected major latitudes (parallels) and longitudes (meridians). (*web1*)

### 3. Azimuth (Az)

The azimuth (Az) of direction AB is the angle formed between this direction and the local meridian, i.e., the geographic north. The direction of true north (geographic north) is determined by the Earth's axis of rotation. In the Northern Hemisphere, it can be practically located by the North Star (Polaris), which lies almost exactly along the Earth's rotational axis.

Thus, in Algeria, azimuths are always measured clockwise from 0° (North), through 90° (East), 180° (South), and 270° (West), back to 360° (North).

### 4. Altitude (Z)

The Earth is an irregular surface with significant variations in relief. To define a common reference, the mean sea level surface has been chosen as the origin of altitudes. When extended under the continents, this surface forms a theoretical surface called the geoid. The altitude of a point is therefore the vertical distance separating that point from the geoid, considered as the zero-level surface.

In Algeria, the origin of leveling is defined from the tide gauge of Algiers (Port of Algiers), which serves as the reference point for the national leveling system. From this point, a network of leveling benchmarks could be established throughout the Algerian territory.




**Figure 12.** The Gauge of Algiers (Port of Algiers). (*web2*)

# Chapter V
# Projection Systems and Representations

## Chapter V: Projection Systems and Representations

One of the main problems in establishing a map is the representation of a portion of the ellipsoid on a plane. To achieve this, a mathematical representation of the Earth's surface is usually projected onto a developable surface (such as a cone or cylinder) or directly onto a plane. The goal is to represent a point, known by its latitude and longitude, as a point defined in a planar coordinate system (X, Y), which is more convenient for users. Therefore, mathematical functions are established such that:

$(X,Y)=F(\varphi,\lambda)$

Where:
$\varphi$ is latitude
$\lambda$ is longitude.

Naturally, the chosen system of representation should minimize distortions of length, angles, or surfaces.

### 1. Definition of map projection:

- A map projection is a means of representing the line of latitude and longitude of the globe on a flat sheet of paper (J.S.Stiers)
- A map projection is an orderly system of Parallels and meridians used as a basis for drawing a map on a surface (A.N.Strawles)
- Any regular system of parallel and meridians on which a map can be drawn can be called a map projection (Erwin Raiza(.

### 2. Map distortion

A sphere, unlike a polyhedron, cone, or cylinder, cannot be reformed into a plane, in order to portray the surface of a round body on a two-dimensional flat plane, you must first define a developable surface (i.e., one that can be cut and flattened onto a plane without stretching or creasing) and devise rules for systematically representing all or part of the spherical surface on the plane. Any such process inevitably leads to distortions of one kind or another. Five essential characteristic properties of map projection are subject to distortion: shape, distance direction, scale, and area. No projection can retain more than one of these properties over a large portion of the Earth. This is not because a sufficiently clever projection has yet to be devised; the task is physically impossible. The technical meanings of these terms are described below.

**2.1.Shape (also called co formality)**

Shape is preserved locally (within "small" areas) when the scale of a map at any point on the map is the same in any direction with this property are called conformal. In them, meridians (lines of longitude) and parallels (lines of latitude) intersect at right angles. An older term for conformal is orthomorphic (from the Greek authors, straight, and morpho, shape).

**2.2.Distance (also called equidistance)**

A map projection can preserve distances from the center of the projection to all other place on the map (but from the center only). Such a map projection is called equidistant. Maps are also described as equidistant when the separation between parallels is uniform (e.g., distance along meridians is maintained). No map projection maintains distance proportionality in all directions from any arbitrary point

**2.3.Direction**

A map projection preserves direction when azimuths (angles from the central point or from a point on a line to another point) are portrayed correctly in all direction. Many azimuthally projection have this property. In the third group of projection, correct bearings or azimuths are preserved. This quality is well achieved in zenithal projections in which the sphere is viewed from a point lying either at the centre of the globe, or at infinity. The line of sight in every case is normal to the map is required to show all directions correctly.

**2.4.Scale**

The second group of projection is known as conformal projection. It is relatively difficult to preserve the shape but for a very small area. Strictly speaking, only a few points of the sphere can be projected in their true form over a plane surface. In order to achieve the quality of orthomorphism, certain modifications need to be made. The scale is changed from point to point; it is true at one point in all directions. It is possible to make some of the meridians and parallels true, i.e., equal in length to the corresponding one on the globe

**2.5.Area (also called equivalence)**

A map can portray areas across it in proportional relationship to the areas on the Earth that they represent. Such a map projection is called equal-area or equivalent. Two older terms for equal area are homolographic or homalographic (from the Greek homalos or homos-same, and graphs-write), and authalic (from the Greek autos same, and ailos-area).

Note that no map can be both equal- area and conformal. Of these, area and shape are considered major properties and are mutually exclusive. That means, that if area is held to its true form on a map, shape must be distorted, and vice versa. Distance and direction, on the other hand, are minor properties, and can coexist with any of the other projection properties. However, distance and direction cannot be true everywhere on a map as discussed below. Anytime we create a flat map of a three-dimensional object, we must distort the three-dimensional object. Distortion is unavoidable when making flat maps of the earth. Distortion is not constant across the map, as distortion may take different forms in different parts of the map.

There are few points where distortions are going to be zero, however distortion is usually less near the points or lines are placed and will directly affect where the map will have the least and most amount of distortion. A map can show one or more, but never all, of the following map projection properties at the same time: true direction properties and they remain mutually exclusive.

## 3. Projections properties

### 3.1.Equivalent projections

The equal area map projection, also known as the equivalent map projection, aims to preserve the area relationships of all parts of the globe. You can easily identify most equal area map projections by noting that the meridians and parallels are not at right angles to each other. Additionally, distance distortion is often present on equal area map projection, and, shape is often skewed. Even with the distortion of distance and shape. Equal area map projection is useful for generating quantitative thematic maps when it is desirable to retain area properties. This is especially useful for choropleth maps, when the attribute is normalized by area. Holding real properties. To be true, allows for an apple to apple comparison of density between different enumerations units, such as counties. The cylindrical equal area map projection is an example of an equal area, or equivalent map projection, which aims to keep the areal relationships of all parts of the globe correct.

A second example of an equal area projection is the hammer aitoff map projection. Again, like the cylindrical equal area projection, this map projection aims to hold areas true. Also note, that on this map projection, the parallels and meridians do not intersect at 900 angles, which is a hint that lets us know that this may be an equal area projection.

### 3.2.Conformal projections

Conformal map projection, also known as orthomorphic map projection, preserves angles around points and the shape of small areas. Additionally, it allows for the same scale in all directions to or from a single point on the map. Conformal map projection can usually be identified by the meridians intersect parallels at right angles, areas are distorted significantly by its small scales, and shapes of large regions may be severely distorted even with the potential for large shape distortion. Conformal map projections are useful for large-scale mapping and phenomenon with circular radial patterns such as radio broadcasts, for average wind directions.

The Mercator projection, perhaps the most famous of all map projections, is a conformal map projection that preserves shape. However, notice the massive amount of distortion in the lower latitudes towards the South Pole, and the northern latitudes, near the North Pole. Also note that the parallels and meridians intersect at 900 angles.

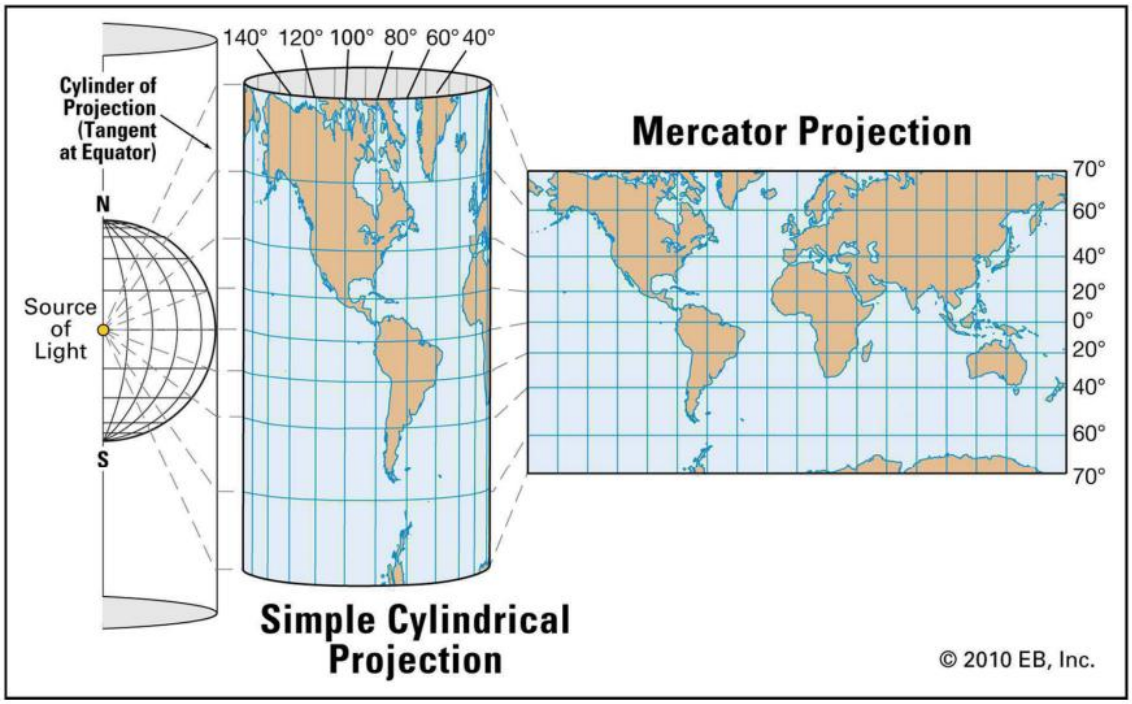



**Figure 13.** Mercator projection (Shape). *Source. Element of geography practical (web3)*

### 3.3.Equidistant projections

The third map projection family is the equidistant map projection, which aims to preserve great circle distances. That means a distance can be held true from one point to all other points, or from a few select points, to others, but not from all points. It is also

important to note the scale is uniform along these lines a true distance from the select points on the map. Identifying marks of the equidistant map projection are that they are neither conformal nor equal area and look less distorted.

Example of an equidistant map projection is the equidistant cylindrical map projection. Notice that compared to the conformal map projection, there is less distortion at the North and South Pole, and the shapes also do not look overly distorted.

The simple Cylindrical Projection is also known as the Equidistant Cylindrical Projection because in this projection both the parallels and meridians are equidistant. They are drawn as straight lines, cutting one another at right angles. As the distance between the parallels and meridians is the same, the whole network represents a series of equal squares. All the parallels are equal to the equator ($2\pi$R), and all the meridians are half of the equator in length. The scale along the equator is true. The meridian scale, i.e., the north-south scale, is also correct everywhere on the map because the parallels are drawn at their true distances. But the latitudinal scale increases away from the equator; this leads to great distortion in shape and exaggeration of area in high latitudes. Therefore, the projection is neither orthomorphic nor equal area.

## 4. Examples of projections

### 4.1.Lambert conformal conic projection

The Lambert Conformal Conic projection is a conic projection that preserves shapes (conformal). Lambert Conformal Conic- A conic, conformal projection typically intersecting parallels of latitude, standard parallels, in the northern hemisphere. This projection is one of the best for middle latitudes because distortion is lowest in the band between the standard parallels (Pand et al., 2020).

**Properties:**

- Conformal (preserves local angles and shapes).
- Distances are accurate along standard parallels.
- Distortion increases away from standard parallels.

**Applications:**

- Widely used in aeronautical charts.
- Suitable for mid-latitude regions with larger east–west extent (e.g., France, Spain, USA).

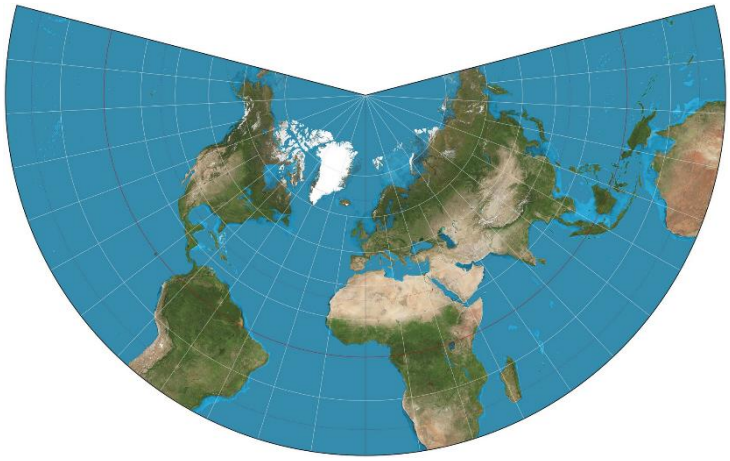


**Figure 14.** Lambert conformal conic projection with standard parallels at 20°N and 50°N. Projection extends toward infinity southward and so has been cut off at 30°S. (*wikipedia*).

**Representation**

Let O be the chosen projection center (the center of the area to be represented).

The projection is carried out on a cone circumscribed around the sphere. This cone is tangent to the sphere along the parallel passing through O (the standard parallel), and the apex S of this cone is located on the polar axis PP'.

Let A be a point on the sphere. The position of this point relative to point O is defined by the quantities x' and y' as follows:

x' = the arc length along the parallel between the prime meridian and the meridian of A, the distance being measured on the standard parallel $\varphi_0$.

y' = the meridian arc between the standard parallel $\varphi_0$ and the parallel of A.

The cone is then developed (unfolded) along its generator SO.

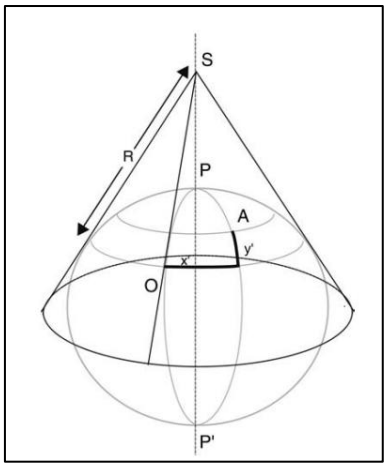



**Figure 15**. Schematic representation of the geometry of a perspective projection on a sphere.

The point "A", defined on the sphere by x' and y', is represented on the projection plane by the point "a", whose coordinates are Xa and Ya. The meridian passing through O is parallel to the Y-axis of the projection. The parallel passing through O (the standard parallel, or line of tangency) becomes a circle centered at S with radius R = SO.

The X-axis of the projection is parallel to the tangent at O to this circle. The meridians are transformed into a bundle of straight lines converging at S, with constant angular spacing. The parallels are transformed into concentric circles centered at S.

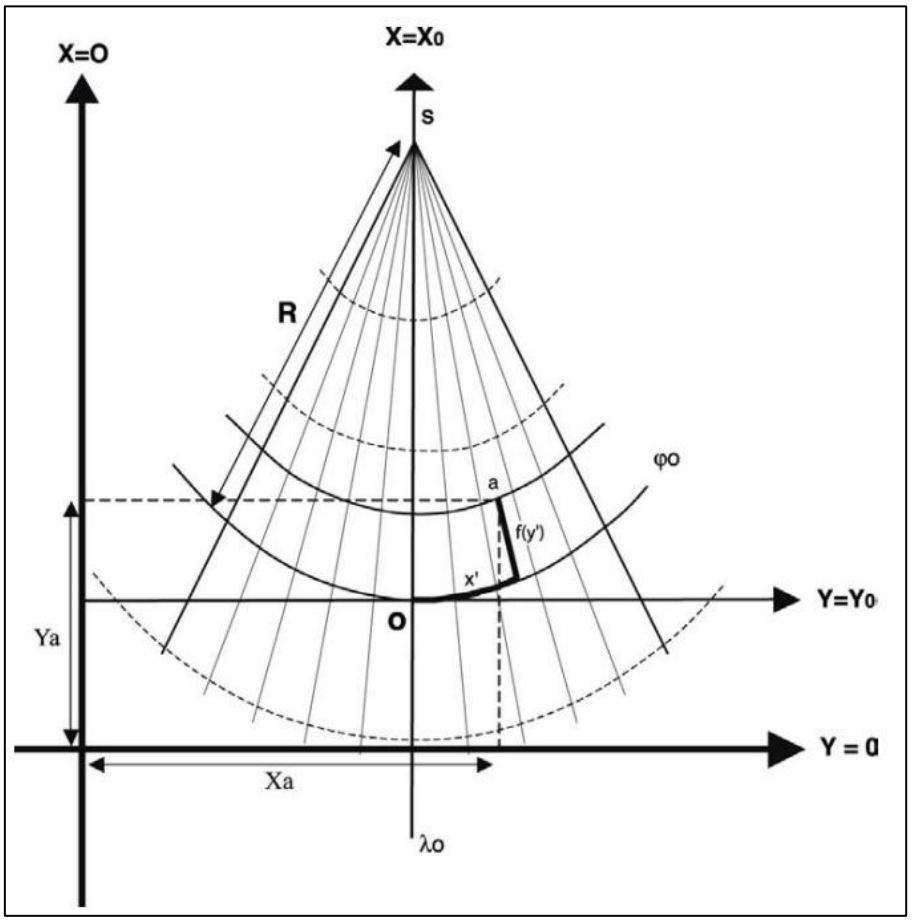



**Figure 16.** Geometric construction of a conic map projection (Bouron, 2005).

### 4.2.Polar Stereographic Projection

A polar stereographic projection is an azimuthal perspective map projection that maps one of the Earth's poles to a single point on a flat plane, making it ideal for depicting polar regions. It uses a light source at the opposite pole to project the Earth's surface onto a plane at the first pole, resulting in lines of longitude as straight lines radiating from the pole and lines of latitude as concentric circles. This projection preserves angles and local shapes (conformal) and shows great circles as straight lines, but it experiences increasing scale distortion as distance from the pole increases

**Properties:**

- Conformal (preserves local angles).
- True scale at the point of tangency (pole) or along a standard parallel.
- Distortion increases away from the pole.

**Applications:**

- Commonly used for mapping polar regions.
- Essential in polar navigation and satellite imagery.

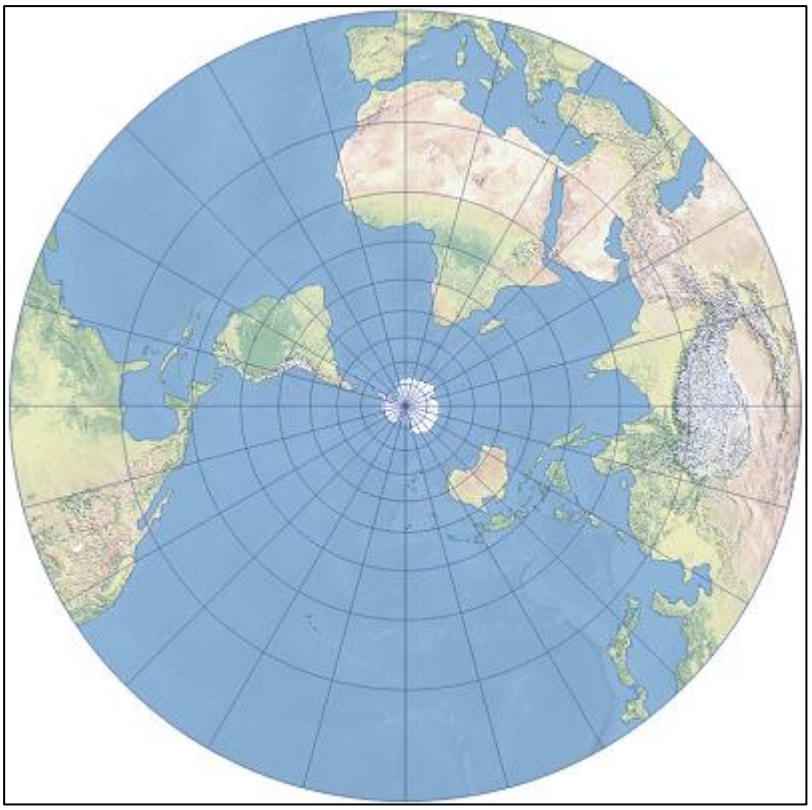


**Figure 17.** The stereographic map projection is centered on the South Pole (*Wikipedia*).

**Representation**

This planar representation is obtained very simply by projecting the surface to be represented onto a plane tangent at the pole (the center of the representation), with the point of perspective being the point diametrically opposite to the point of tangency (the opposite pole).

The meridians are represented by straight lines converging at the pole, forming between them angles equal to the differences in longitude.

The parallels are represented by concentric circles centered on the pole.

Distortion of lengths is very small in the vicinity of the pole but increases rapidly as one move away from it. This length distortion is constant along a given parallel.

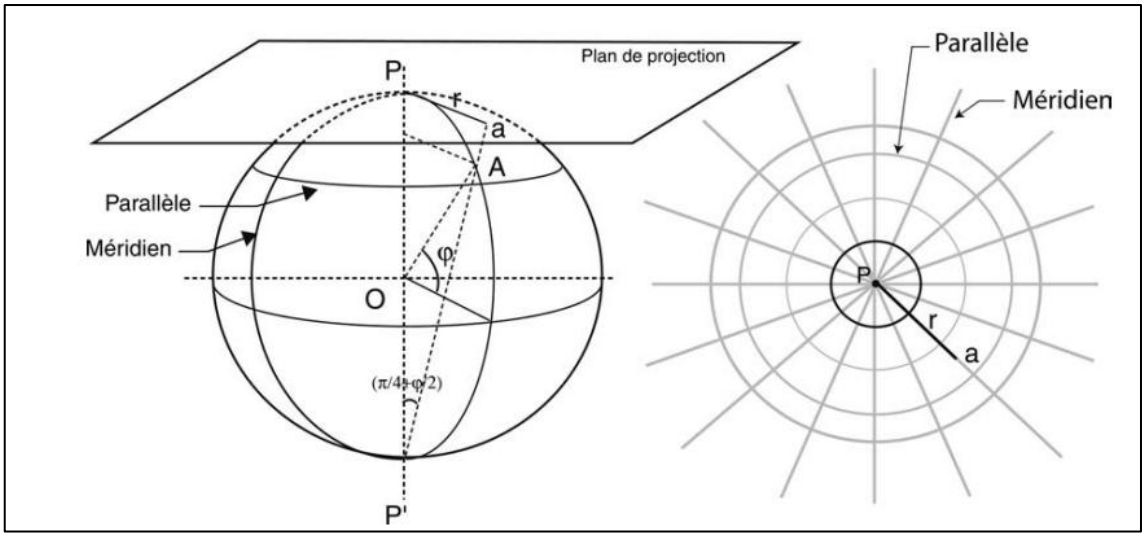



**Figure 18.** Illustration of the polar stereographic projection (Bouron, 2005).

### 4.3.Transverse Mercator Projection

The transverse Mercator projection is a map projection where a cylinder is oriented along a meridian (instead of the equator) to create a conformal projection that minimizes distortion for narrow, north-south-oriented regions. It's the basis for coordinate systems like Universal Transverse Mercator (UTM) and is ideal for detailed topographic maps of areas with a predominant north-south extent, like the United States' State Plane Coordinate System. (Esri 2025, Dozier, 1980)

**Properties:**

- Conformal (preserves local angles).
- Distortion is minimal near the central meridian.
- Distortion increases with distance from the central meridian.

**Applications:**

- Widely used in large-scale mapping (topographic maps).
- Basis of the Universal Transverse Mercator (UTM) system, which divides the Earth into 60 zones.

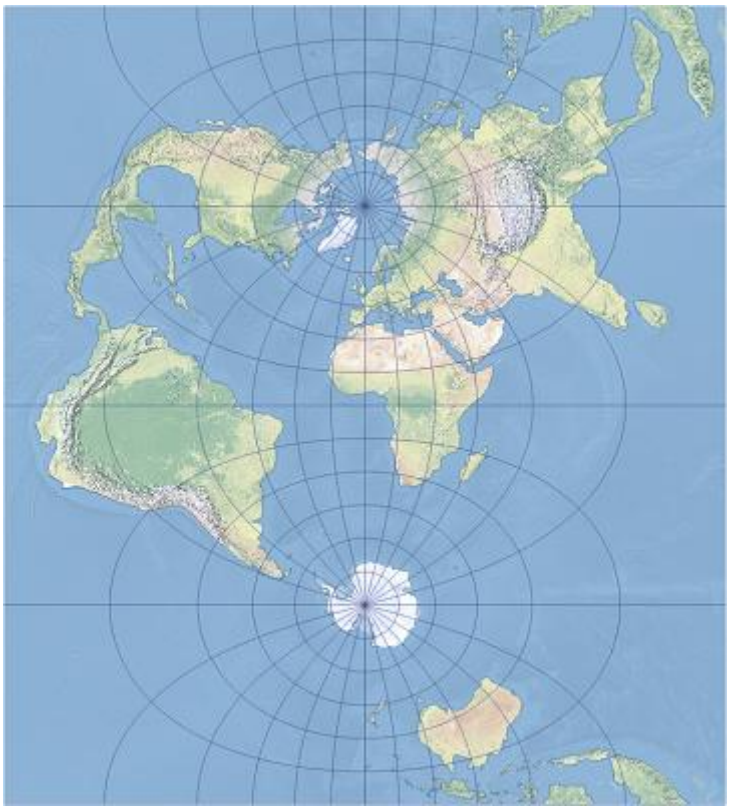


**Figure 19.** The transverse Mercator projection is shown centered on Greenwich (*Wikipedia*).

**Representation**

This projection is obtained by projecting the sphere or ellipsoid onto a cylinder tangent to it along the central meridian, which is then developed (unfolded).

The central meridian of tangency becomes, on the map, an axis parallel to the Y-axis of the projection.

The equator, which projects as a straight line, becomes the X-axis.

Let point A on the sphere be defined by the coordinates x' and y', where:

x' = AA', the distance from A to the meridian, measured orthogonally to that meridian.

y' = MA', the distance measured along the central meridian.

Point A will be represented on the projection plane by a point a with coordinates x and y such that:

$x = f(x')$

$y = y' + \varepsilon$

where y is calculated analytically to ensure that the projection is conformal

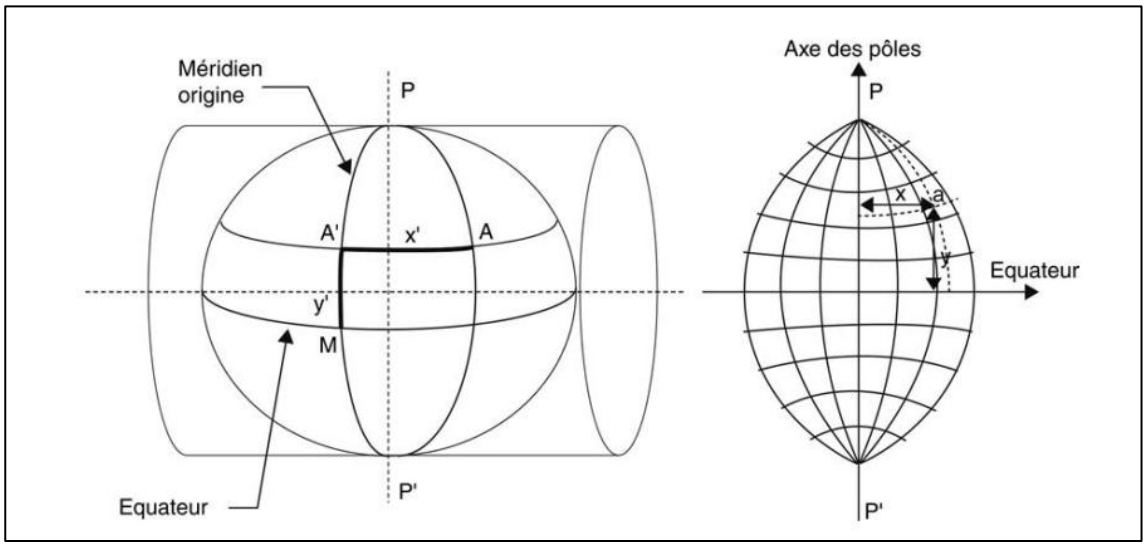



**Figure 20.** Illustration of the Transverse Mercator projection (Bouron, 2005)

**The UTM Zones**

This system is divided into 60 zones, each 6° of longitude wide, numbered starting from the meridian opposite the international prime meridian. The Greenwich meridian therefore lies between zones 30 and 31.

The zones relevant to France are zones 30, 31, and 32, with central meridians at 3° West, 3° East, and 9° East of the prime meridian, respectively. The representation system calculated for one zone is valid for all others; hence, the system is truly universal.

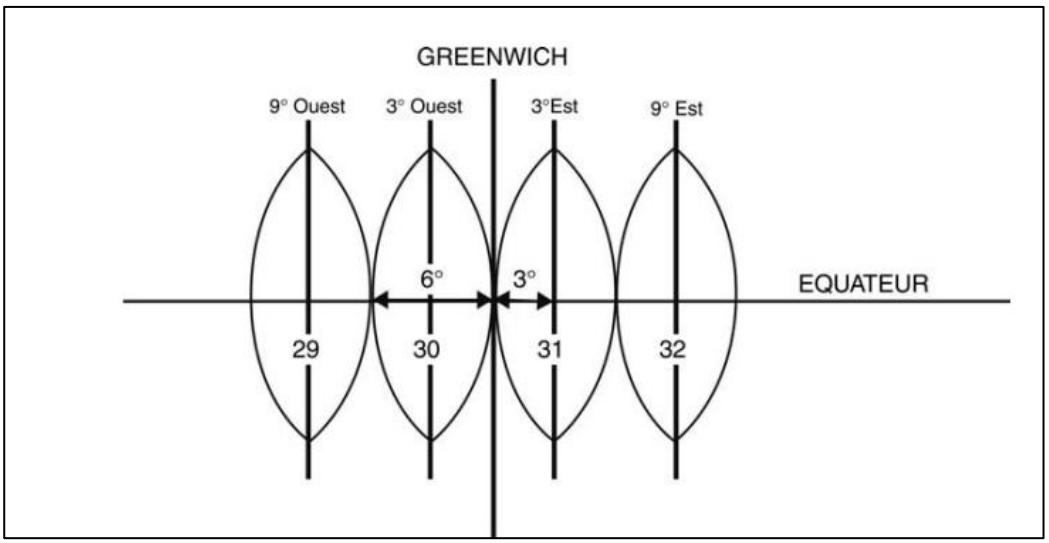



**Figure 21.** Division of the globe into Universal Transverse Mercator (UTM) zones (Bouron, 2005).

**UTM Coordinates**

In the UTM system, each central meridian is assigned to the Y-axis of the grid with a false easting of 500 km.

In the Northern Hemisphere, the Y-coordinates are measured starting from the Equator.

In Algeria, the zones used are zones 29, 30, 31, and 32. The coordinates are therefore:

X (or E, Easting) values between 0 and 1000 km, within each zone

Y (or N, Northing) values on the order of 3000 km and 4000 (the approximate distance from Algeria to the Equator).

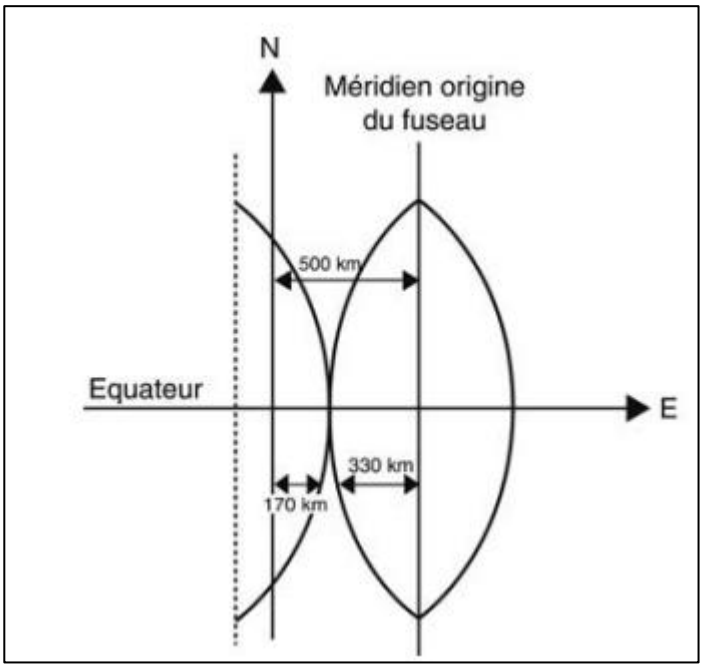



**Figure 22.** Schematic representation of the UTM (Universal Transverse Mercator) false origin system (Bouron, 2005).

**UTM Grids (hectokilometric and derived)**

The UTM zones of 6° in longitude are subdivided into equal bands of 8° in latitude. These zones are designated by letters. Each of these zones is then divided into squares of 100 km per side. These squares are identified by two letters.

**Example:**

Setif (Algeria) is located in zone 31U, while Tlemcen (Algeria) is located in zone 32T.

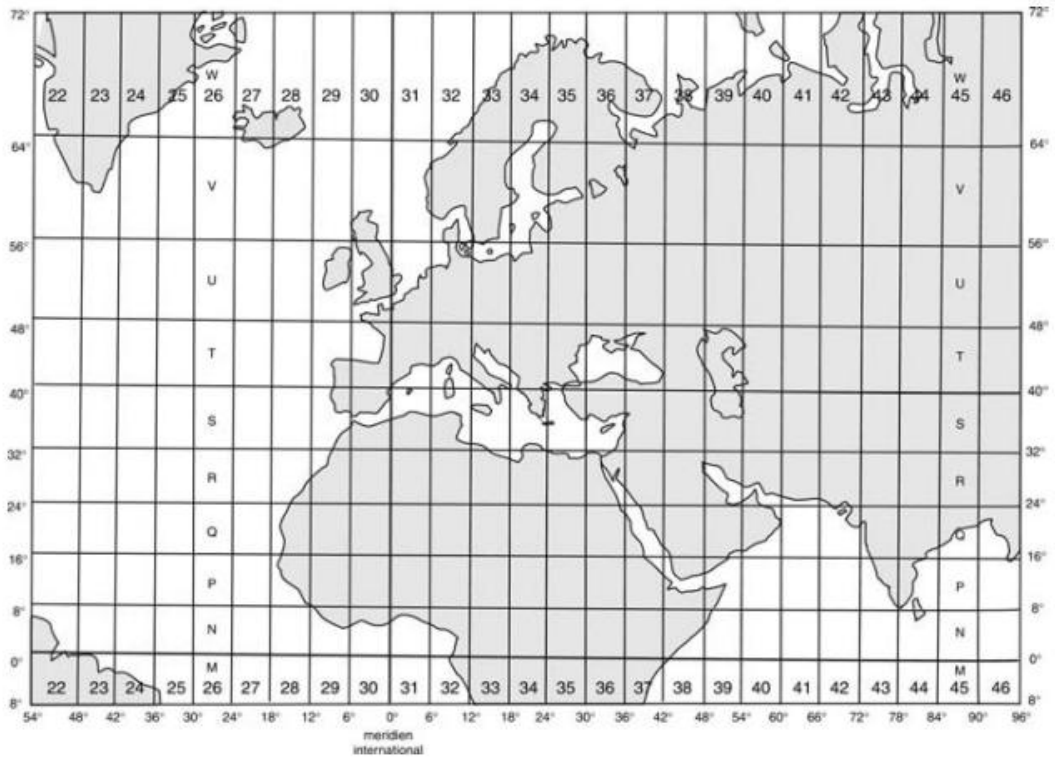



**Figure 23.** UTM grid zones covering Europe and North Africa. Algeria is located between zones 29, 30, 31, and 32, from west to east (Bouron, 2005).

# Chapter VI

# Measurements on the Map

## Chapter VI: Measurements on the Map

Maps are more than just visual representations of geographic space; they are also analytical tools that allow us to measure distances, directions, areas, and other spatial relationships. Since maps are projections of the curved Earth onto a flat surface, direct measurements require careful consideration of scale and projection properties. Understanding how to make accurate measurements on maps is essential in cartography, geography, environmental studies, and navigation.

This chapter introduces the fundamental concepts and techniques for measuring on maps. We will explore how scale influences measurement accuracy, how projections affect the representation of distance and direction, and how tools such as grid systems and coordinates assist in precise location and measurement. By the end of the chapter, students will be able to:

- Interpret map scale and apply it to distance measurement.
- Measure directions using azimuths and bearings.
- Estimate and calculate areas on different map projections.
- Recognize the influence of map projection on measurement accuracy.
- Developing these skills will strengthen the practical application of cartography, enabling more effective analysis and communication of spatial information.

### 1. Scale Concepts

The scale of a map is the constant ratio between the distances shown on the map and the actual dimensions of the terrain represented.

#### 1.1.Numerical Scale

The scale is expressed as a fraction 1/N.

**Example:**

A scale of 1:10,000 means that one must multiply the length measured on the map by 10,000 to obtain the actual ground distance.

**Table 2.** Order of magnitude

| **Scale of the map/plan** | **1mm on the map represents … on the ground.** |
|---|---|
| 1/1 000 000 | 1 km |
| 1/25 000 | 25 m |
| 1/20 000 | 20 m |
| 1/10 000 | 10 m |
| 1/5 000 | 5 m |
| 1/ 500 | 0,5 m |

### 1.2.Graphical Scale

The map or plan is accompanied by a graphical representation of the scale, which avoids the need for calculations.

The graphical scale is a line divided into equal segments, each representing the chosen unit.

Using this scale is very simple: one measures the desired distance on the map using a pair of compasses, a strip of paper, or a ruler. This distance is then placed against the graphical scale to obtain the actual ground distance.




**Figure 24.** Example of a linear (graphic) scale.

## 2. Measurement of distance

### 2.1.Straight-line Distance

Straight-line distances are measured on the map with a regular ruler. By multiplying the measurement taken between two points by the scale factor of the map, one obtains the horizontal ground distance between these points.

**Example:**

On a map at a scale of 1:25,000, two points separated by 7.00 cm on the map are apart on the ground by:

7.00 cm × 25,000 = 175,000 cm, i.e., 1,750 m.

If no ruler is available, one can mark the two endpoints of the distance on a strip of paper, a pencil, a piece of string, etc., and then use the graphical scale shown in the map legend to obtain the real distance.

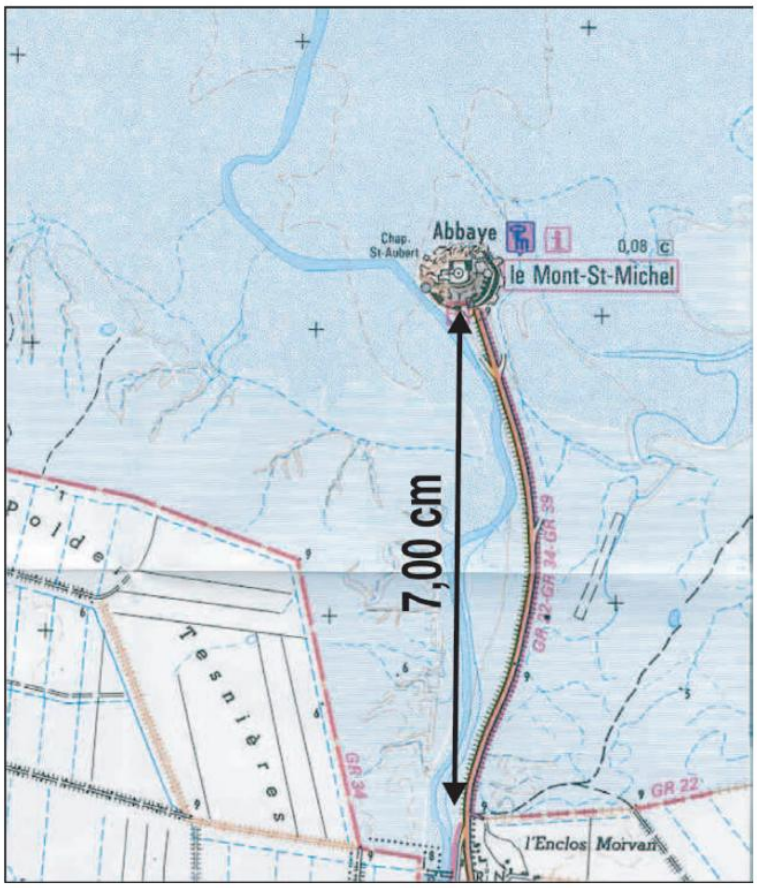



**Figure 25.** Example of straight-line distance measurement on a topographic map. The linear distance between two points is measured as 7.00 cm on the map (Bouron, 2005)..

**2.2.Curved Distance**

For non-straight distances, such as along a road or winding path, one can use a curvimeter. Without this instrument, a string, a strip of paper, or even a blade of grass can be adapted (by folding it along the line) to match the broken line whose length one wishes to measure.




**Figure 26.** Example of curved distance measurement on a topographic map. The curved distance between two points is measured as 7.02 cm on the map (Bouron, 2005).

## 3. Measuring the Coordinates of a Point

### 3.1.Identification of the Coordinate System

The most precise method for designating a feature on a map is to define it by its rectangular coordinates or its geographic coordinates.

Before determining the coordinates of a point, it is essential to first identify the systems represented in the map margins. These systems are generally specified in the map legend.

On maps, two coordinate systems are generally represented simultaneously.

In addition, each system can be expressed in two ways:

- In geographic coordinates on the ellipsoid (longitude and latitude)
- In planar coordinates according to the projection used (kilometers)

This results in several types of coordinate graduations shown in the margins of topographic maps.

### 3.2.Geographic Coordinates (Longitude, Latitude)

Longitude is represented by λ, latitude by φ.

**Reminder**

The interpolation of geographic coordinates (λA, φA) is somewhat delicate. Indeed, as previously seen, the geographic grid is not orthonormal.

Using the reference marks shown in the map margins, it is possible to reconstruct the geographic grid (in degrees/Greenwich or grads/Paris). The geographic coordinates of a point are therefore locally interpolated between parallels and meridians, by applying what is commonly called the rule of three. It is also possible, with the help of a set square, to directly determine these coordinates. If the point whose coordinates we wish to determine is located near the map border, it can be projected to the map margin using a set square, perpendicular to the edges.

### 3.3.Rectangular Coordinates

To interpolate rectangular coordinates, the map must include a kilometric grid, or at least reference marks that allow this grid to be drawn.

**Example**

If the scale is 1 : 25,000, then 1 mm on the map represents 25 m on the ground.

The coordinates of point A are:

E = 873,000 + (25,000 × 0.010) = 873,250 m

N = 2,265,000 + (25,000 × 0.018) = 2,265,450 m

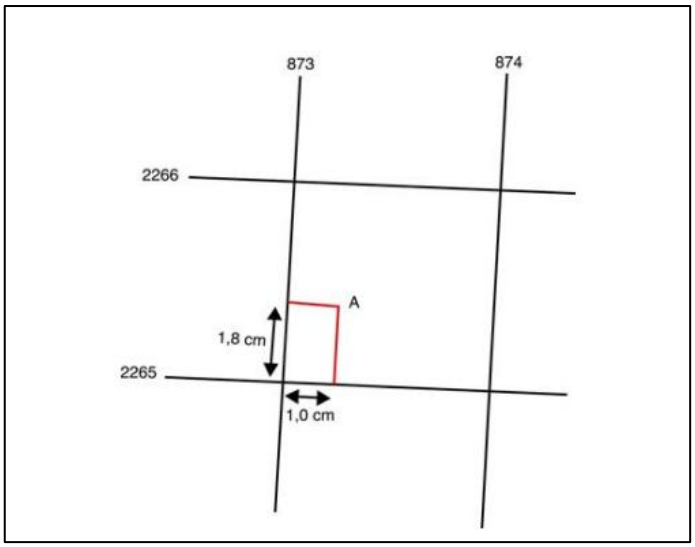



**Figure 27.** Example of determining a point's location using map grid coordinates.

# Chapter VII:
# Elements Represented on a Map

## Chapter VII: Elements Represented on a Map

Maps are simplified yet structured representations of reality. They translate the complexity of the physical and human environment into a visual language composed of symbols, colors, and graphic conventions (Bertin, 1983; MacEachren, 1995). The elements represented on a map such as relief, hydrography, vegetation, infrastructures, and administrative boundaries form the foundation of cartographic communication. Their careful selection and representation determine not only the accuracy of the map but also its clarity and usefulness for interpretation.

The choice of which elements to represent depends on the map's scale, purpose, and audience. For example, large-scale maps emphasize fine details such as buildings, roads, and property boundaries, whereas small-scale maps generalize features, focusing instead on broader patterns such as land use or regional hydrography (Robinson et al., 1995; Slocum et al., 2009). Each category of elements natural, anthropogenic, or cultural requires standardized symbols and conventions to ensure readability and universality across cartographic products (Kraak & Ormeling, 2020).

Understanding the principles behind the representation of these elements is essential for developing map literacy. By analyzing how topographic, thematic, and cultural features are encoded, students and practitioners can better interpret spatial information and design maps that are both scientifically accurate and visually effective (Dent et al., 2009). This chapter introduces the major categories of elements commonly represented on maps and discusses the conventions used in their graphic depiction.

The elements found on the Earth's surface are diverse and numerous. Depending on the map scale, some objects are drawn at their reduced size, while others are enlarged or replaced by conventional symbols.

The elements represented on the map can be classified into four categories:

- ***Planimetry***, which corresponds to the representation of details generally built by humans: communication routes, buildings, boundaries, types of crops and vegetation, administrative limits, and various details.
- ***Hydrography,*** which relates to water features.
- ***Orography,*** which refers to the depiction of terrain, is represented by contour lines.

- ***Toponymy,*** which concerns place names.

Planimetry is the process of creating a two-dimensional representation of features on the Earth's surface that are independent of elevation, such as roads, buildings, and bodies of water. It is used in applications like urban mapping, and land surveying. Planimetry can also refer to the measurement of areas on a flat plane, such as in mathematics or in the analysis of biological tissue. Planimetry itself and the related names are shown in black; vegetation is represented in green. Hydrography and its corresponding toponymy (hydronymy) appear in blue. Contour lines are shown in bistre or orange; the same orange color and yellow are used at the 1:25,000 scale for overlaying the road network.

Most planimetric details can be represented by the horizontal projection, reduced to scale, of their outlines. However, to depict certain linear or point features, conventional symbols are used.

For a path, the two figurative lines are drawn with a conventional spacing based on its width, which considerably exaggerates the actual width, especially at smaller scales (1:100,000, 1:250,000). To represent features with small surface areas, conventional symbols as evocative as possible are used: a circle for a tower, a cross for a calvary, a circle surmounted by a cross for a church or chapel, etc.

To differentiate types of vegetation, crops, or aquatic surfaces, one may use patterns of varying density (green for vegetation, blue for water areas) or regular structures of circles or lines called stereotypes.

Each map is accompanied in its margin by a key of conventional symbols, which it is essential to consult as often as possible: this is the map legend.

**Note:**

Without going into detail about the conventional symbols used in topographic maps at different scales, it seemed useful to provide in the following chapter, devoted to planimetry (in the broad sense of the term), some general principles that will facilitate map reading. The information provided is particularly applicable to the scales 1:25 000, 1:50 000, and 1:100 000.

# Chapter VIII:
# Methods of Graphic Representation

## Chapter VIII: Methods of Graphic Representation

Maps are more than simple tools for locating places; they are powerful instruments for analyzing and communicating geographic information. Through methods of graphic representation, cartographers transform the complex realities of the Earth's surface into clear, structured, and interpretable symbols (MacEachren, 1995; Slocum et al., 2009). These methods allow the depiction of diverse elements natural features, human constructions, and spatial phenomena while ensuring that information remains accessible across different map scales.

The choice of representation method depends largely on the type of data (qualitative or quantitative), the map's purpose, and its intended audience. Continuous phenomena, such as elevation or temperature, are better represented using isolines or color gradients, whereas discrete features like roads, cities, or administrative boundaries require the use of point, line, and polygon symbols (Bertin, 1983; Dent et al., 2009). Thematic cartography further relies on specialized techniques such as proportional symbols, choropleth maps, and dot density maps to highlight spatial distributions and patterns (Robinson et al., 1995; Kraak & Ormeling, 2020).

Understanding these graphic methods is therefore essential not only for students of cartography but also for professionals who rely on maps for planning, decision-making, and communication. Mastering these principles ensures the production of maps that are accurate, informative, and visually effective (Slocum et al., 2009). This chapter introduces the main approaches to graphic representation, outlining their theoretical principles, practical applications, and limitations

### 1. Roads and Paths

*On the 1:25 000 editions:*

Main roads classified as high-traffic routes are highlighted with a dense continuous orange overlay. Secondary roads receive a yellow overlay. Other roads or paths, whether in good or poor condition, are shown without any color overlay.

*On the 1:100 000 maps:*

Roads wider than 7 m are represented by two lines spaced 0.8 mm apart. Roads less than 7 m wide are represented by two lines spaced 0.4 mm apart. Main high-traffic roads are highlighted with a red or orange overlay. Secondary roads serving as connecting

routes are highlighted with a yellow overlay. Along this main and secondary network, distances are indicated in red figures of two sizes. Other roads or paths, in good or poor condition, do not have any color overlay.




**Figure 28.** Road's representation (Bouron, 2005).

***Embankments and Cuttings***

A path is called an embankment when the road surface rises abruptly above the lower natural ground. It is represented by a series of black ticks (barbules) leaning against the road line.

A path is called a cutting when the road surface is sharply lower than the natural ground above it. It is represented by a black slope symbol: a line bordering the path, usually offset from the actual top of the slope, with curved or variable thickness if the slope height varies, and ticks (barbules) attached to this line, leaving a slight gap between their base and the path line. The height of the ticks indicates the relative height of the slope.

**2. Forestry and Mountain Paths**

Logging roads and forest rides are shown (at both scales) by a solid black line. However, this does not guarantee continuous usability in practice; they may be partially or completely impassable. Clearing lines, rides, and important footpaths (notably in mountainous areas) are represented by a dashed line. This also does not guarantee that they are passable at the time of map use.

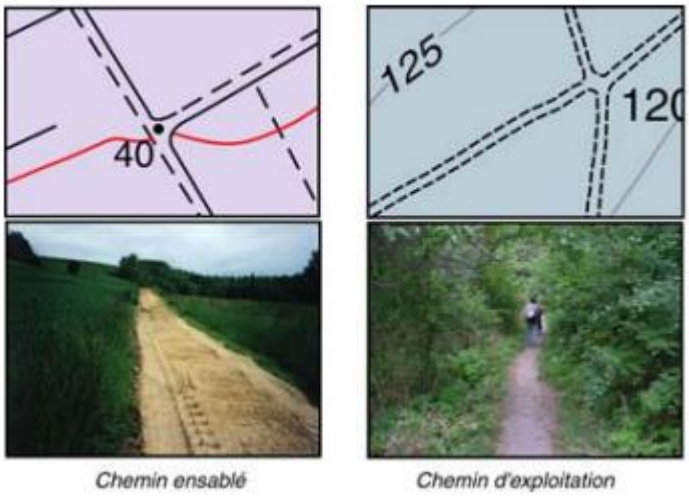



**Figure 29.** Examples of cartographic representation and field illustration of two types of paths. left: a sandy path, right: a logging/exploitation path (Bouron, 2005).

Long-distance hiking trails (GR routes) are represented differently depending on the scale: On tourist 1:100,000 maps (green series): by a red dashed line with the indication GR followed by its number. On 1:25,000 maps, they are represented by a solid red line.

### 3. Railways

Standard-gauge railways are represented by thick black lines. On 1:100 000 maps, the number of tracks is shown with small transverse ticks. On recent 1:25 000 or 1:50,000 editions, electrified lines are distinguished from others by the addition of a lightning bolt symbol. The legend specifies other conventional symbols for narrow-gauge tracks, abandoned lines, level crossings (superior or inferior), tunnels, rack railways, etc. A superior crossing means the road passes over the railway, while an inferior crossing means the road passes under it.

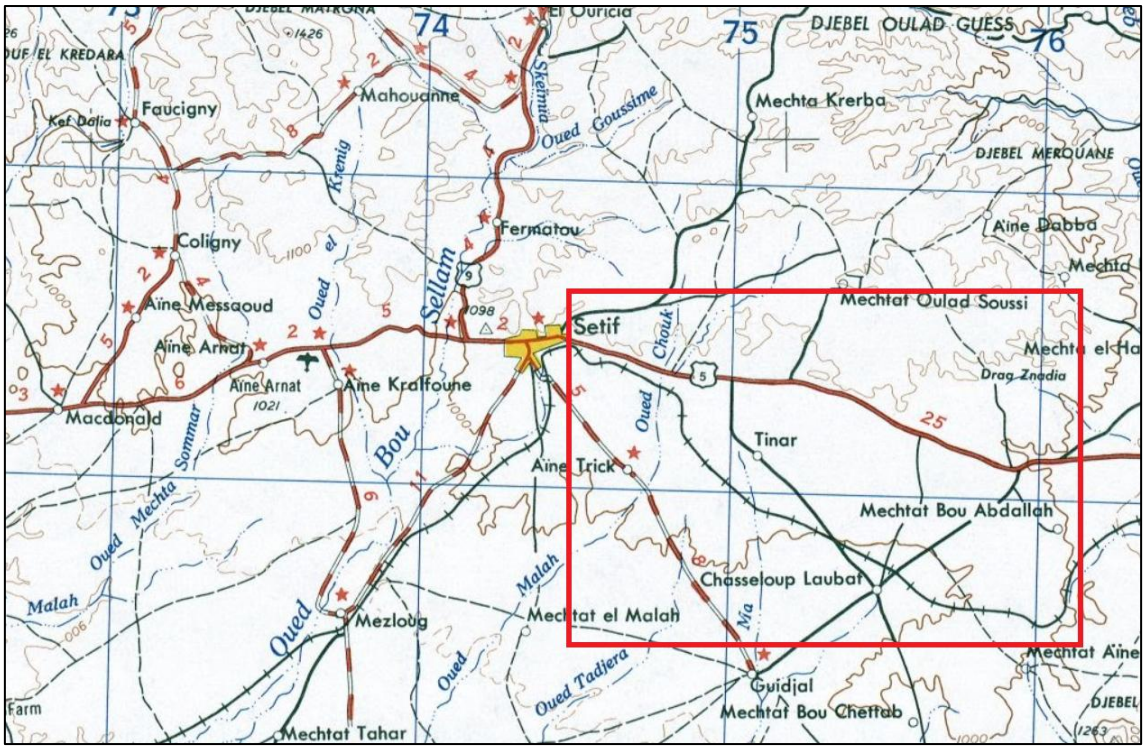



**Figure 30.** Example of railways representation.

### 4. Power Lines

Electric power transmission lines are represented by a thin black line with an arrow when their voltage is equal to or greater than 63 kV.

### 5. Boundaries

Walls → solid black line.

Fences → dashed black lines.

Dry ditches → dashed blue line.

Hedges and rows of trees → green line, or black line with black dots.

Earth embankments → bister line.

Vegetation boundaries → green line.

### 6. Vegetation and Crops

In general, vegetation is shown with green overprinted patterns. On large-scale maps, coniferous forests are distinguished from broadleaf forests. Scrubland is shown with a lighter green pattern than forests. Orchards and vineyards are represented by symbols or regular structures of circles or lines, called stereotypes.

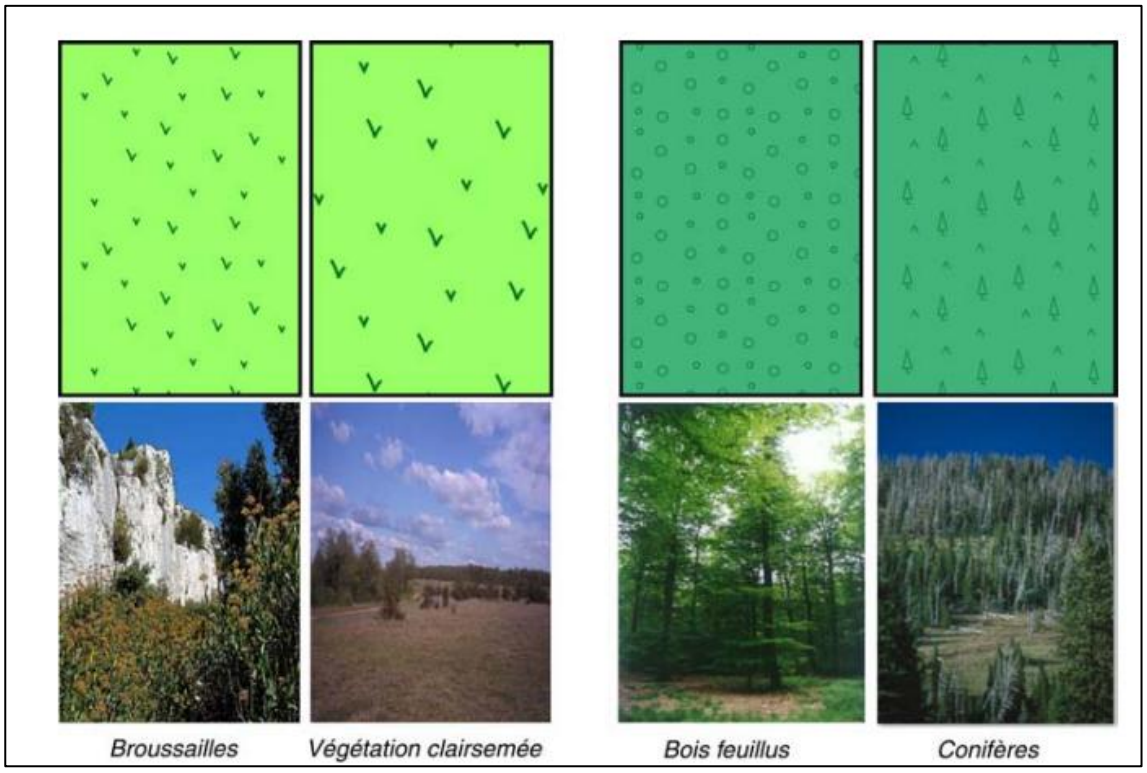



**Figure 31.** Examples of vegetation types with their cartographic representation (top) and field illustration (bottom). From left to right: shrubland, scattered vegetation, broadleaf forest, and coniferous forest (Bouron, 2005).

### 7. Miscellaneous constructions

Constructions are represented differently depending on their size and nature. Ordinary buildings are shown on the 1:25,000 base map with a solid black fill for small buildings, hatching for large buildings and noteworthy constructions, and cross-hatching for halls and warehouses. Buildings made of lightweight materials are represented only by their perimeter.

These rules also apply at the 1:50,000 and 1:100,000 scales, but one must take into account the generalization that occurs between 1:25,000 and 1:50,000 maps on the one hand, and between 1:50,000 and 1:100,000 maps on the other. As a result, at these smaller scales, a single rectangle may represent a group of two or three neighboring buildings, whereas they appear separately on the 1:25,000 scale map.

Remarkable Buildings: mosques, cemeteries, town halls, monuments, etc., are represented by a series of silhouettes or conventional symbols that are as evocative as possible.

### 8. Administrative Boundaries and Notations

All administrative boundaries, state, wilaya, districts, and municipalities (daïra) are represented by black dotted lines as defined in the legend.

Prefectures, sub-prefectures, cantons, and municipalities are indicated by a rectangular label placed generally next to the name of the settlement and containing the corresponding abbreviation. Finally, next to the name of each settlement appears its population, expressed in thousands of inhabitants.

### 9. Hydrography

Hydrography includes all elements related to water and watercourses. These elements are generally represented in blue.

#### 9.1.Sea, lake, pond

Two shades of blue are used: Permanent water areas are shown in dark blue. Temporary or marshy areas are represented with lighter blue and additional patterns (hachures, dots, etc.) to distinguish them from permanent waters.

Along the seashore, the lowest tide line (also known as the hydrographers' zero) is represented by a solid blue line marked (0). It separates permanent waters (dark blue) from the intertidal zone (light blue with patterns depending on whether it is sand, mud, gravel, etc.).

The intertidal zone is crossed by the 0 contour line of the French general leveling system, corresponding to the mean sea level of the Mediterranean at Marseille. Like other contour lines, it is represented in brown (bistre).

#### 9.2.River, stream, brook

Rivers and streams of sufficient width are represented by a double line filled with dark blue if permanent, or with stippling (sand, gravel patterns) if temporary. Narrow permanent watercourses and irrigation canals are represented by a solid line, while temporary streams are shown with a dashed line.

#### 9.3.Springs, wells, water towers

Water towers are represented by a filled blue circle. Reservoirs are shown according to their actual shape, filled in blue.

Only major springs are indicated, represented by a blue circle accompanied by a line marking the flow direction. At 1:50,000 scale, and even more so at 1:100,000, only isolated wells, cisterns, watering troughs, etc. that serve as important landmarks are shown. Their conventional symbol is a simple blue circle.

### 7. Toponymy

The collection of toponymies requires multiple precautions during the map completion process. The surveyor's task is to gather authentic cartographic toponymy, which often persists through usage, since many interesting place names (for example, in mountain areas) do not appear in the land registry (cadastre).

Uninhabited place names from the cadastre rarely appear on 1:25,000 and 1:50,000 maps, and even less so on 1:100,000 maps. In toponymy, it is difficult to satisfy both scholars who advocate spellings that remain as close as possible to the etymology and local inhabitants, who are accustomed to using spellings that have often evolved or been distorted over time.

The names of municipalities have an official spelling. Upright characters are used for inhabited places. Italicized, baseline characters are used for forests and certain uninhabited place names. Italicized characters are used for orography and hydrography. The font size of all labels depends on the importance of the feature being represented:

Localities with more than 5,000 inhabitants are written in capitals. Localities with fewer than 5,000 inhabitants are written in lowercase. On most 1:25,000 and 1:50,000 sheets, hydronymy (the set of names related to hydrography) appears in blue or black. When a municipality does not have a main settlement bearing its name, the name of the municipality is placed "in disposition," so as to cover as much of the municipal territory as possible.

On the 1:100,000 map series (topographic or tourist), features of tourist interest are labeled in bold characters. Some details are accompanied by abbreviations that are sufficiently explicit, written in italic black (or blue for hydrography). The table of conventional signs on the 1:25,000 map, reproduced in the appendix, includes the different types of writing used, as well as the list and meaning of abbreviations employed on topographic maps.

## 8. Orography

Orography refers to the representation of the Earth's relief. Several elements are used to describe landforms: contour lines, spot heights, and shading.

### 8.1.Contour Lines

A contour line is a line representing the intersection of a horizontal plane with the terrain surface. It connects points of equal altitude. To understand the representation of relief using contour lines, one can imagine a mountain cut into steps (terraces) and viewed from above.

Contours are spaced by a vertical distance known as the contour interval (equidistance). The value of this interval is indicated in the legend of the map. It can vary depending on the map's scale and the relief being represented. Contour lines are drawn as thin bistre-colored lines. Every fifth line is emphasized as an index contour, represented with a thicker line.

Index contours are usually labeled with altitude values, written with the base of the numbers-oriented downhill (the base of the digits points toward lower ground).

To distinguish depressions (sinks) from summits, depressions are marked with arrows pointing toward the bottom of the hollow.

### 8.2.Spot Heights (Points Cotés)

Spot heights play an important role in representing terrain. They must meet three objectives:

- Help in the interpretation of contour lines.
- Define areas not adequately represented by contour lines because of the contour interval (e.g., summits, depressions, slope breaks).
- Serve as reference points for altimetric operations in the field (for example, calibrating an altimeter).

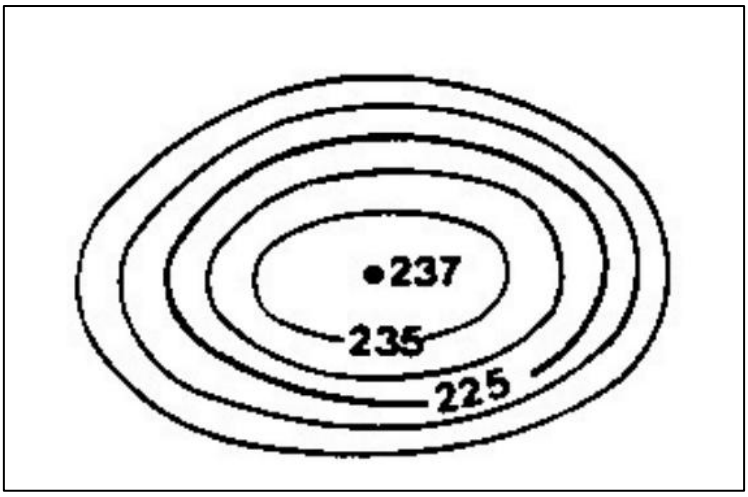



**Figure 32.** Topographic map fragment showing concentric contour lines representing a hill (Bouron, 2005).

# Chapter IX:

# Applications of Thematic Cartography

## Chapter IX: Applications of Thematic Cartography

Thematic cartography plays a central role in the analysis and communication of spatial phenomena, going beyond the representation of physical landscapes to depict specific themes or topics of interest (Slocum et al., 2009). Among the many applications of thematic maps, two areas stand out due to their relevance in environmental sciences and modern geoinformatics: vegetation mapping and digital cartography.

### 1. Vegetation Mapping

Vegetation mapping is one of the earliest and most widely used applications of thematic cartography. It involves the representation of plant cover types, distribution, and structure across geographic spaces. Such maps are critical tools for ecology, land management, climate studies, and biodiversity conservation.

Vegetation maps can be produced at different scales, from global and regional assessments (e.g., FAO Global Forest Resources Assessment) to local land-use planning. Traditionally, vegetation mapping relied on field surveys and manual interpretation of aerial photographs. However, advances in remote sensing and GIS technologies have revolutionized this field, allowing for the production of accurate, large-scale vegetation maps with frequent temporal updates (Franklin, 2001; Guisan & Thuiller, 2005).

Applications of vegetation maps include:

- **Biodiversity monitoring:** Identifying and tracking habitats and species distributions.
- **Land-use and land-cover change studies:** Assessing deforestation, reforestation, or agricultural expansion.
- **Fire risk assessment:** Mapping fuel loads and vegetation types to support wildfire modeling and prevention strategies (Chuvieco & Congalton, 1989).
- **Climate change studies:** Monitoring the response of ecosystems to temperature and precipitation changes.

### 2. Digital Cartography

Digital cartography refers to the design, production, and analysis of maps using digital technologies. It is a natural evolution of thematic cartography, driven by advances in

Geographic Information Systems (GIS), remote sensing, and web mapping platforms (Longley et al., 2015).

The main advantage of digital cartography lies in its ability to handle large datasets, perform spatial analysis, and enable interactive visualizations. Thematic maps in digital form are no longer static images but dynamic tools that can integrate multiple layers of information. Examples include online atlases, environmental monitoring dashboards, and navigation systems.

*Applications of digital thematic cartography include:*

- **Environmental monitoring:** Real-time mapping of air quality, vegetation health, or wildfire spread.
- **Urban and regional planning:** Supporting decision-making by integrating socio-economic, demographic, and environmental data.
- **Disaster management:** Interactive hazard maps for floods, earthquakes, and wildfires to aid preparedness and response (Goodchild, 2007).
- **Citizen science and participatory mapping:** Involving communities in producing and sharing spatial data through platforms like OpenStreetMap.

Digital cartography is also central to the transition toward big data and geospatial intelligence, where thematic maps serve not only as communication tools but also as analytical interfaces to explore and interpret complex spatial phenomena.

## 3. Presentation of QGIS software

QGIS (formerly known as Quantum GIS) is an open-source Geographic Information System (GIS) application that enables users to visualize, analyze, and manage spatial data. Since its first release in 2002, QGIS has grown into one of the most widely used GIS platforms worldwide, thanks to its accessibility, rich functionality, and active community of developers and users (Sherman, 2008; Graser, 2016).

### 3.1.Key Characteristics of QGIS

**Open-source and free**

QGIS is distributed under the GNU General Public License (GPL). This means the software is free to use, modify, and share, making it highly accessible for students, researchers, public administrations, and private companies.

**Cross-platform compatibility**

QGIS runs on major operating systems including Windows, macOS, Linux, and even mobile platforms (QField for Android).

**Wide data format support**

QGIS supports both vector and raster data formats (e.g., shapefiles, GeoTIFF, KML, PostGIS), and is fully compliant with Open Geospatial Consortium (OGC) standards, allowing interoperability with other GIS software.

**Integration with external tools**

It can integrate with spatial databases (PostGIS, SpatiaLite), remote sensing tools (GRASS GIS, SAGA), and statistical software (R), providing a versatile environment for geospatial analysis.

**Extensibility through plugins**

QGIS has a powerful plugin architecture. Users can add custom functionalities such as geocoding, network analysis, hydrological modeling, and web mapping. Thousands of community-contributed plugins are freely available.

**User-friendly interface**

Despite being powerful, QGIS provides an intuitive graphical interface that makes it accessible to beginners, while still offering advanced options for expert users.

### 3.2.Applications of QGIS

- QGIS can be used for a wide range of applications, including:
- Cartography and mapping: Designing professional maps with customizable symbology and labels.
- Environmental management: Monitoring land use, vegetation, biodiversity, and natural hazards.
- Urban and regional planning: Supporting spatial planning, transport analysis, and infrastructure development.
- Disaster risk management: Creating hazard and vulnerability maps to support decision-making.
- Education and research: Training students in GIS concepts and conducting spatial analysis across disciplines.

**Advantages of QGIS**

- Cost-free access for all users.
- Continuous improvement through a global developer community.
- Regular updates with new features and bug fixes.
- Strong documentation and community support (forums, tutorials, user groups).

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