MODULE 1: Introduction to GIS

OBJECTIVES	✓ Define geographical information systems (GIS) and related terminologies ✓ Analyse the potential uses of GIS ✓ Discuss how to project spatial data in GIS ✓ Create a map with given data (depending on if they will be discussed in the exercises) ✓ Basics of cartography ✓ Create data in GIS ✓ Run a spatial analysis in GIS
METHODS	Live session, reading material, video's, links to resources, application exercises, quizzes & discussions
DURATION	5 hours for participants

SESSION			**DURATION**	**PARTICIPANTS…**
Online	1.0	Introduction to the course	60 min.	✓ Get introduced to the course ✓ Get to know each other personally ✓ Receive a first presentation on the concepts of GIS
	1.1	Definition and Key concepts	25 min.	✓ Receive a description of GIS and its components and types of geographical projection systems. ✓ Have understood the areas where GIS can be applied to solve real-world problems
	1.2	Spatial data	35 min.	✓ Learn about several forms of GIS data and associated properties ✓ Learn about different sources of spatial data and instruments
	1.3	Mapping references	45 min.	✓ Are introduced about geographic coordinate systems and projections.
	1.4	Spatial data analysis	45 min.	✓ Get an understanding of Spatial Data analysis by learning about the main concepts and tools.
	1.5	Application and Documentation	95 min.	✓ Create a map with given data ✓ Create data in GIS ✓ Perform a spatial analysis in GIS ✓ Evaluate different GIS use cases

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OPEN MACHINE LEARNING FOR EARTH OBSERVATION (ML4EO)

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WELCOME

to the 1st LIVE SESSION of the ML4EO course

Before we start

- Trainers' team today

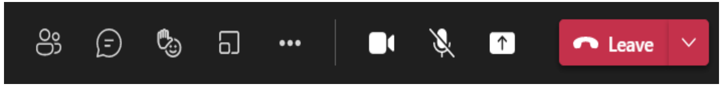
Joseph Tuyishimire
Lecturer CGIS

Clarisse Goffard
Education Expert

Joanne Schuiteman
Moodle Expert

Anselme Ndikuryyayo
Education Expert

- Communication:
  - Please mute your device if you are not speaking, and switch on the camera/video
  - Please post your questions in the chat and we will answer them on the spot, or during the Q&A session
- Material and presentation will be shared



- The presentation will be recorded, we assume your consent

Rwanda Space Agency

ML4EO Training Kick-Off Meeting

Rwanda Space Agency at a glance…

Vision

To develop a globally competitive space ecosystem

Mission

To develop Rwanda's space sector towards social-economic development using space technologies, services and product development.

Foundation(Steps)

- High quality capacity building initiatives – Academically, technically and industrially
- Robust partnership network – Local, regional and international

Rwanda Space Journey

RSA
Rwanda Space Agency

June. 2018

Establishment of a space working group

Nov. 2019

Launch of RWASAT-1, Rwanda's first Satellite

Aug. 2020

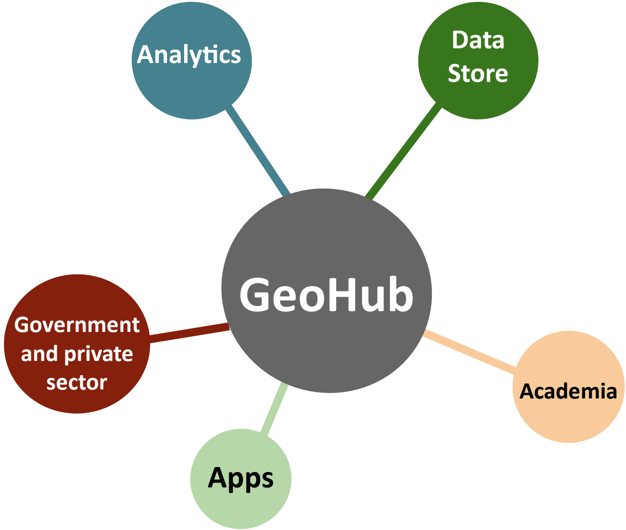
Establishment of Rwanda Space Agency

May. 2021

Utilization of the Geospatial Hub

Geo-Hub: A hub for Geospatial Resources

Geo-Hub: An infrastructure for geospatial resource, data, ready to use apps, intelligent models, and collaborative research resources.



- Machine learning models
- High performance Compute (HPC)
- Ready to use dashboards
- Geospatial data, and databases
- Ready to use APIs and Hosted Services

Roadmap: 2023 - 2026

RSA
Rwanda Space Agency

2023/24

Public Sector

- Urbanization
- Agriculture
- Disaster
- Mining & minerals

2024/25

Academia & Private Sector

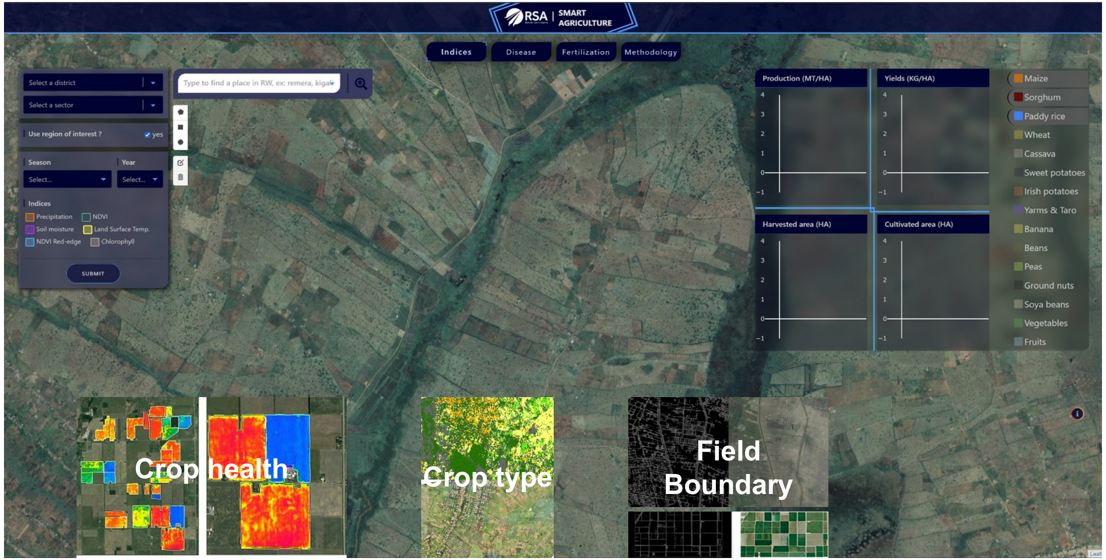
- Startups
- Labs
- Center of Excellence

2025/26

Export of products & Services

- Products on International level
- Services

Agriculture: Prediction and Beyond

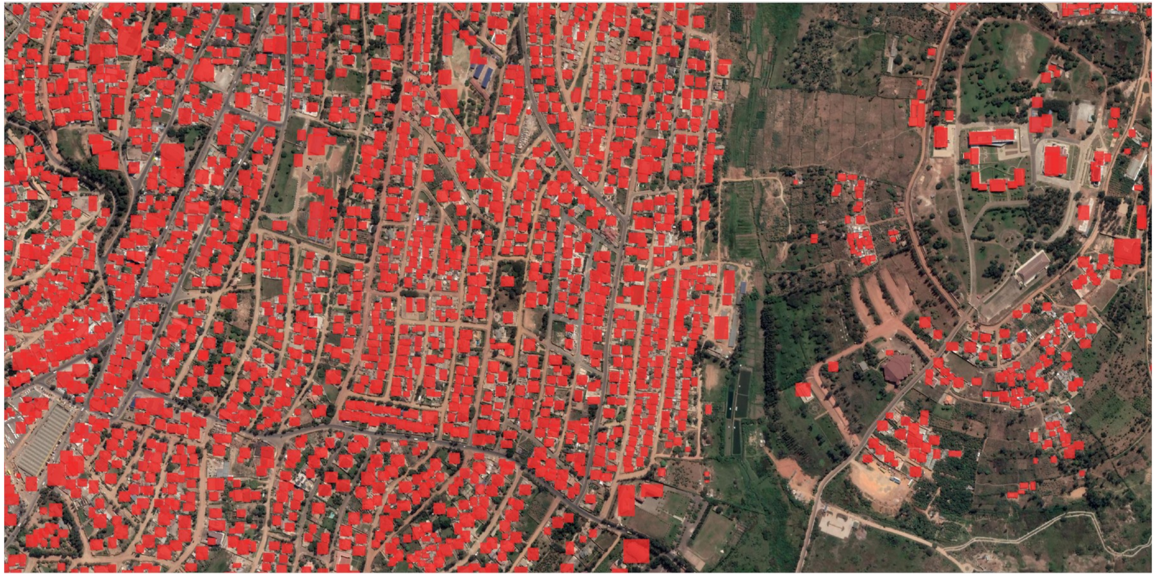


It gives info about :

- Crop health (specifically indices)
- Historical crop yield info.
- Field boundaries
- Crop Classification

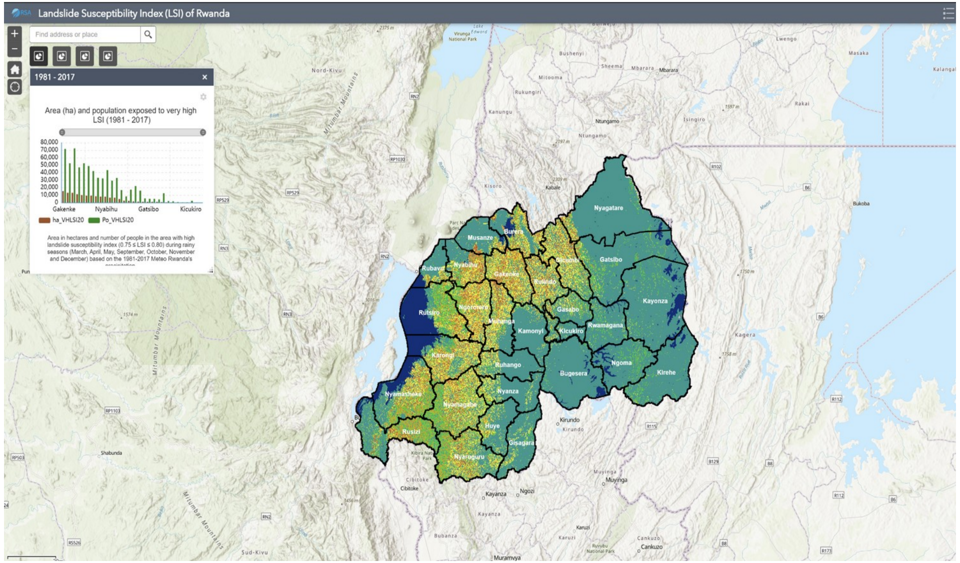
Urbanization : Prediction and Beyond

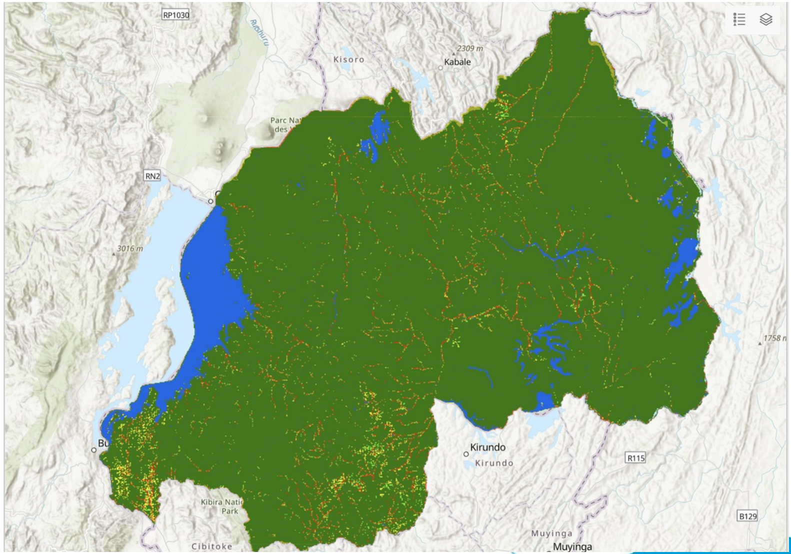
RSA
Rwanda Space Agency



Building footprint extraction: Useful in urban planning and development, insurance, taxation, change detection, infrastructure planning, and a variety of other applications.

Disasters: Mapping Landslide and Floods





- Mapping zones prone to landslide

- Mapped areas susceptible to floods in Rwanda

Summary:

- RSA is a government institution mandated to develop and regulate Rwanda's space sector towards social-economic development.
- RSA is creating an environment that encourages entrepreneurial and industrial development in order to enable the creation of products that are globally competitive for local consumption and export markets.
- RSA provides services/products via Geo-Hub.
- RSA utilizes cutting edge technologies to extract and share insights from Satellite imagery

MURAKOZE

THANK YOU

Digital Transformation Center Rwanda – The Home for GIZ Rwanda‘s Digital Activities

Global Project

Digital & Blended Learning

atingi

Regional Project

Entrepreneurship and

Startup Development

Make-IT in Africa

Regional Project

Supporting the Secretariat

smart africa

Digital Transformation Center Rwanda

Bilateral Project

Solutions Development

Digital Inclusion & Capacity Building

Machine Translation

SSD

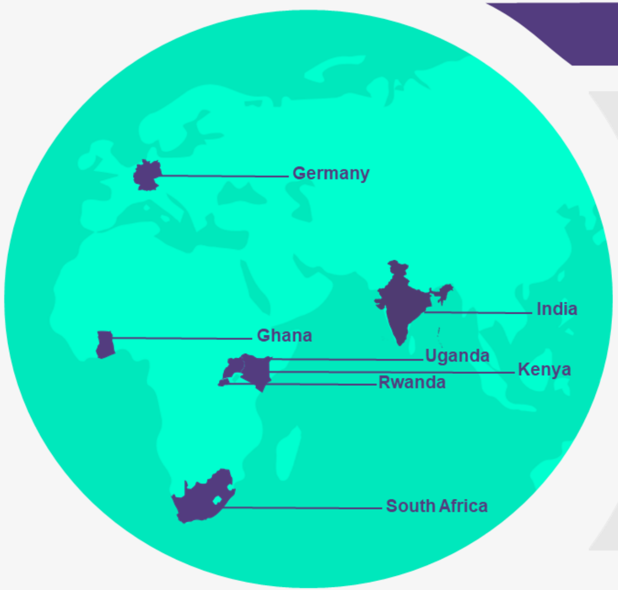
AI Hub Rwanda

Global Project

Foundations of AI & AI Policy

FAIR FORWARD

FAIR Forward –
Artificial Intelligence for All



Main goals of the global initiative

- Improve access to training data and AI technologies for local open innovation
- Strengthen local technical know-how on AI in Africa and Asia
- Develop Policy Frameworks Ready for AI - Ethical AI, Data Protection and Privacy

On behalf of: German Federal Ministry for Economic Cooperation and Development (BMZ)
Implemented by: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Duration: 2019 – 2025
Main partners: Smart Africa, Mozilla, IDRC, UNGP

Welcome of participants – Say Hi!

What you like

- watch sports, tutorial and tech videos
- watch football
- read books and conversate with people
- go to public places like concerts
- listen to music or watch movies or documentaries
- read the news
- read about new breakthrough in Information Technology
- joke and have good time with friends and family
- go for a swim

What you expect

- apply machine learning techniques to earth observation data
- get practical skills on using EO data to solve real world challenges
- interpret geographical data and use it to support decision-making
- analyzing large volumes of data and map them
- fundamentals of ML, data preparation and preprocessing, model building and model selection
- application in different domains such as agriculture for crops mapping and health for disease monitoring
- help me grow my career
- comfortable, activating and engaging learning environment

Structure of today's session

- Official launch of the course ML4EO + Welcome
- Course overview
- Keynote speaker's address
- Introduction to Module 1
- Q&A
- Learner path
- Next steps / assignments
- Closure

Course overview

The course is composed of **11 Modules**

- Module 1: Introduction to GIS
- Module 2: Introduction to Remote Sensing
- Module 3: GIS data collection methods
- Module 4: Introduction to ML and Python
- Module 5: Data curation for ML
- Module 6: Visualization of EO data
- Module 7: Predictive modelling using local RS data
- Module 8: Deploying remote sensing-based models
- Module 9: ML workflows and best practice
- Module 10: Business model generation and value proposition design
- Module 11: Project development

Modules 1-4: online + field work

- MS Teams live sessions
- Self-learning on Moodle

Modules 5-10: face-to-face

- Block 1:April 2023
- Block 2: May 2023

Module 11: online & face-to-face

- Project development
- Pitch event

Keynote Speaker‘s address

Pierre Philippe Mathieu,

Head of the ESA Φ-lab Explore Office,

& Research Fellows

MODULE 1: Introduction to GIS

Digital Transformation Center Rwanda

What do you know about GIS ?

We will collect your current ideas via Mentimeter.

Follow the steps:

- ➢ Either: Click on the link in the chat
- ➢ Or: go to www.menti.com + submit the code (given in the chat)
- ➢ THEN participate by answering the questions

What do you know about GIS ? Give us some keywords!

Mentimeter

global information system
and analyse data
displays geographically
which is a combination
collect geospatial data
geograhical
geographic coordinate
of application and sateli
map
geospatial
geospatial mapping
information that is locat
storing ans analyzing
satellite data
mapping
location
geographique
geographical
ed to one location
analyse
data with a location
analysing
tool
data
system
remote sensing
collecting earth data
a tool for managining
information
data collection
where features are
earth
geographic data
geographical data
earth observation
geospatial data analysis
tes for geo data
algorithm for land cover
sytem that analyze and
it stores geopgrahical
software for mapping
geography
geographic information
geographic information sy

22

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Content: Introduction to GIS

1. WHAT is GIS?

2. WHY is GIS relevant/useful?

3. WHO uses GIS?

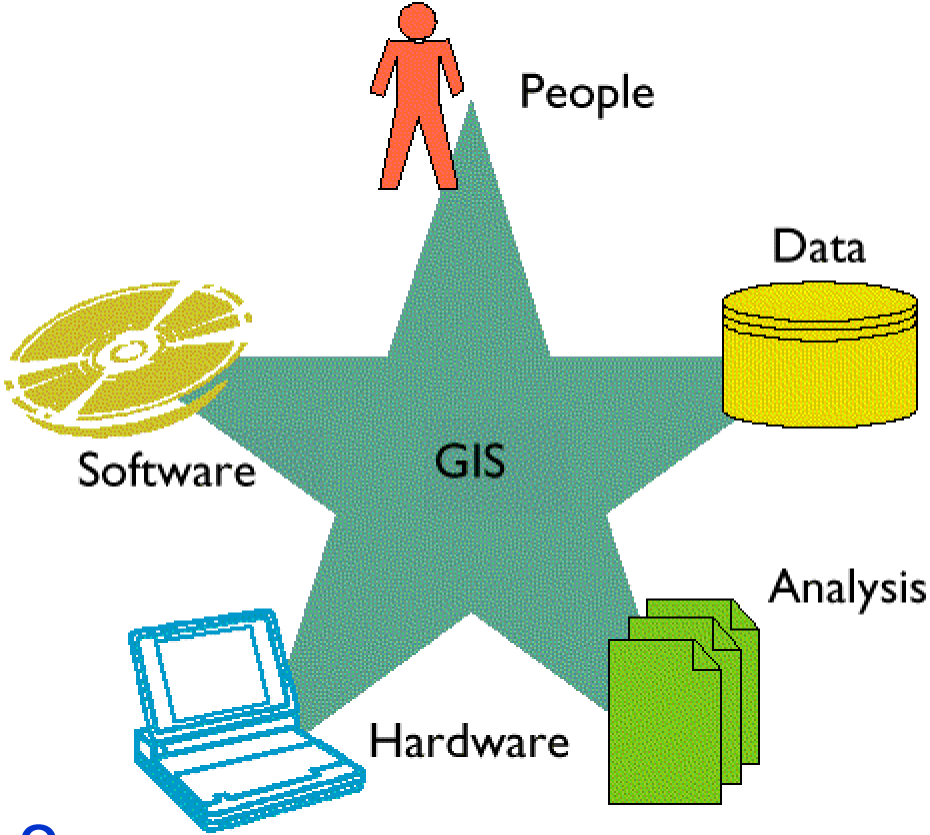
4. FOR WHAT purpose or FOR WHOM is GIS used?

5. Examples of real-life applications of GIS

WHAT is GIS?

- **Geographic;** WHERE something is located on earth
- **Information;** WHAT it is (its size, name, value etc)
- **Systems;** to help MANAGE and use the data.

How? By who? Why?



WHY is GIS relevant/usefu?

GIS provides fundamental operations in order to find solutions to real-world problems

Capture

Data input

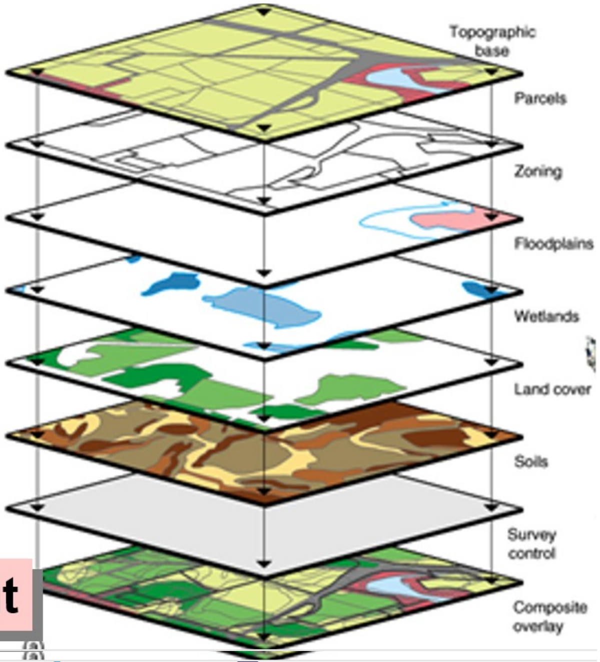
Store

Query

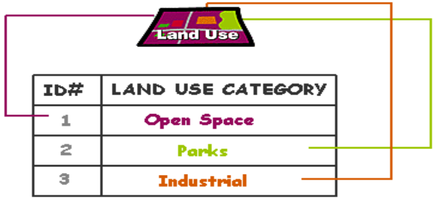
Analyze

Display

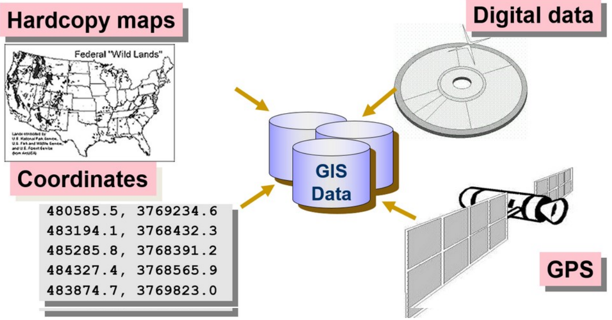
Output



2. Spatial and tubular



3. Database and output

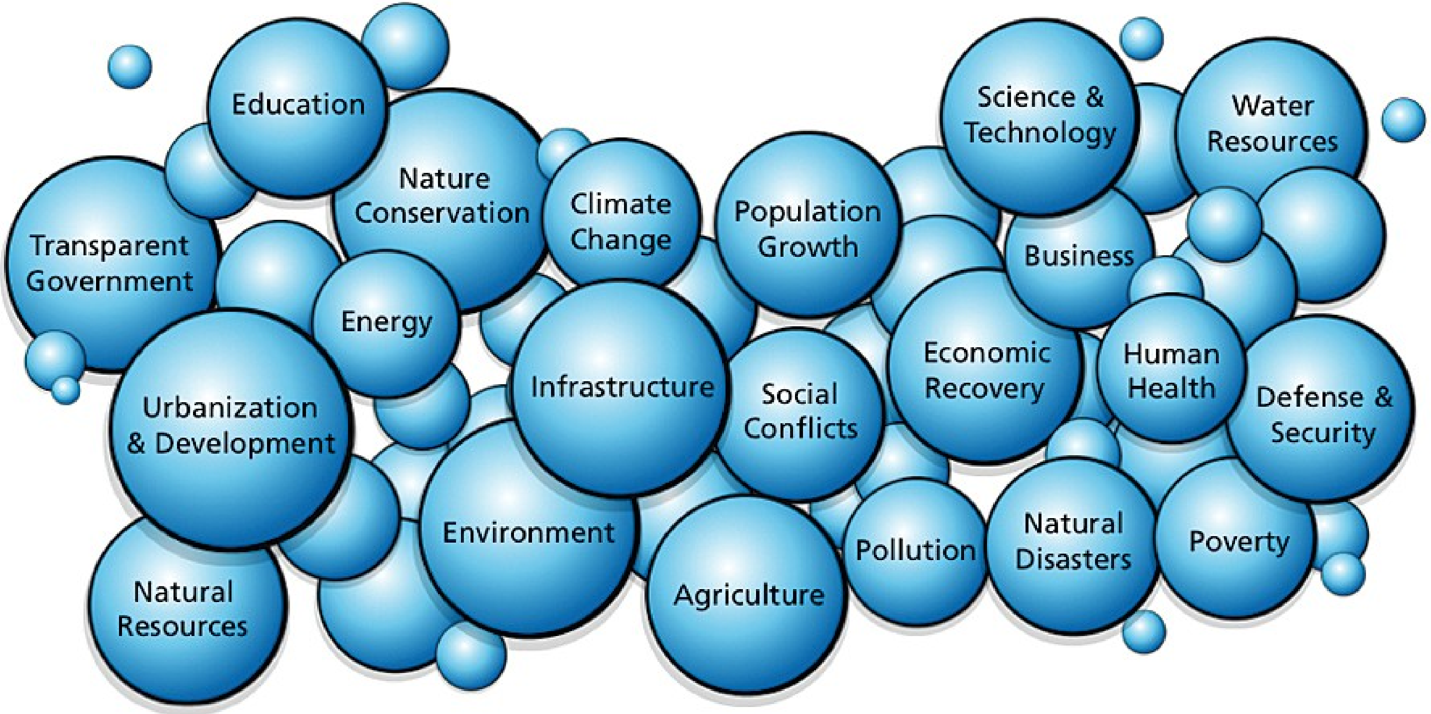


WHO uses GIS?

Everyone needs GIS! What? When? Where?

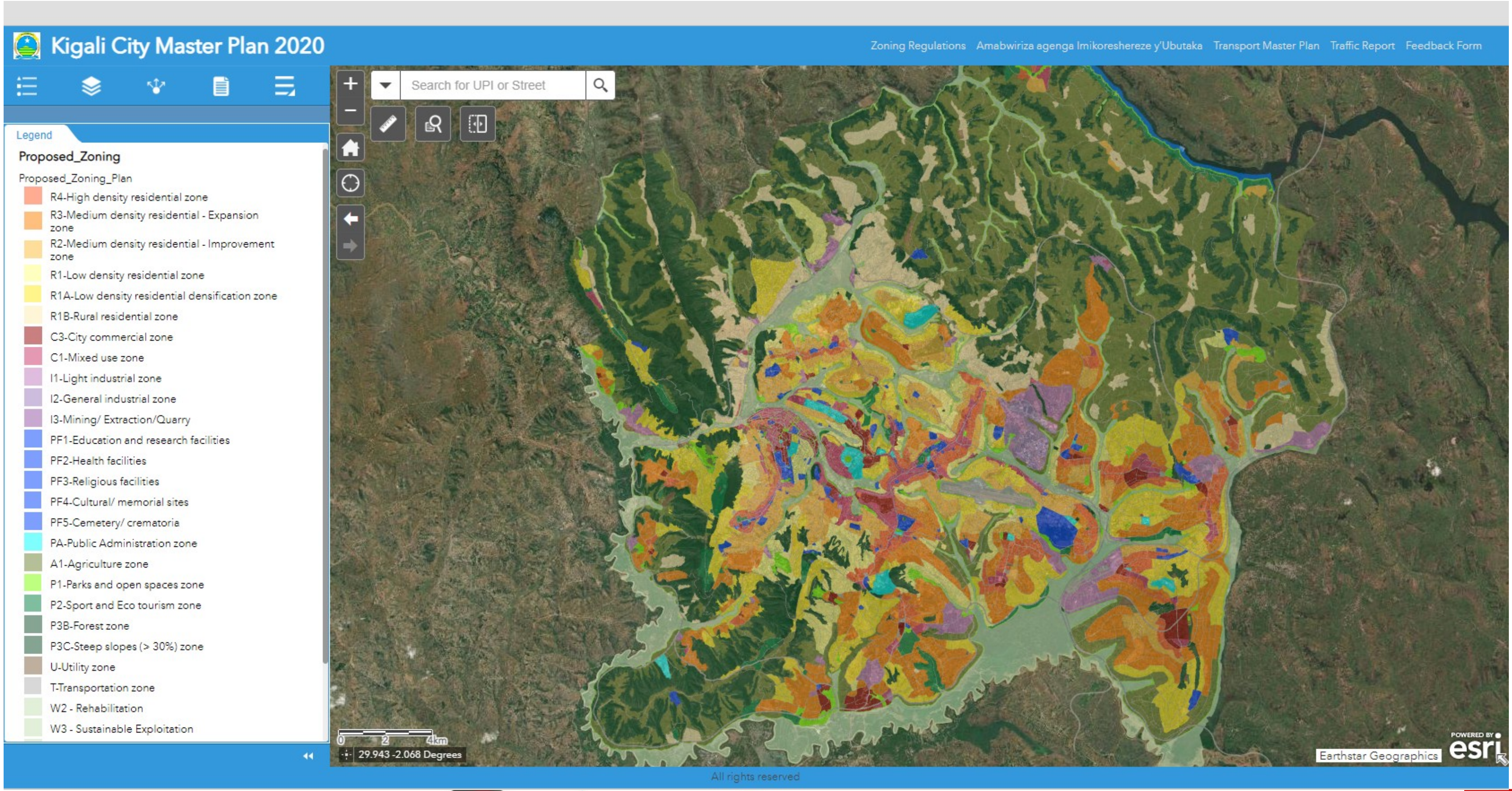
- *Land Managers*
- *Environmentalists*
- *Natural resource managers*
- *Land surveyors,*
- *Mineral experts*
- *Hazards and Disaster Managers*
- *Geologists*
- *Security agents*
- *Civil Engineers*
- *Retailers*
- *Urban Managers/Planners*
- *Agronomists*
- *Marine Scientist*
- *Water Engineers*
- *Health Planners*
- *Soil Scientists…etc.*

FOR WHAT purpose or FOR WHOM is GIS used?



- Crosscutting
- Several areas
- Approaches
- Interfaces
- Classic softwares
- Machine Learning
- Desk
- Cloud

Examples of real-life application of GIS



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Examples of real-life application of GIS

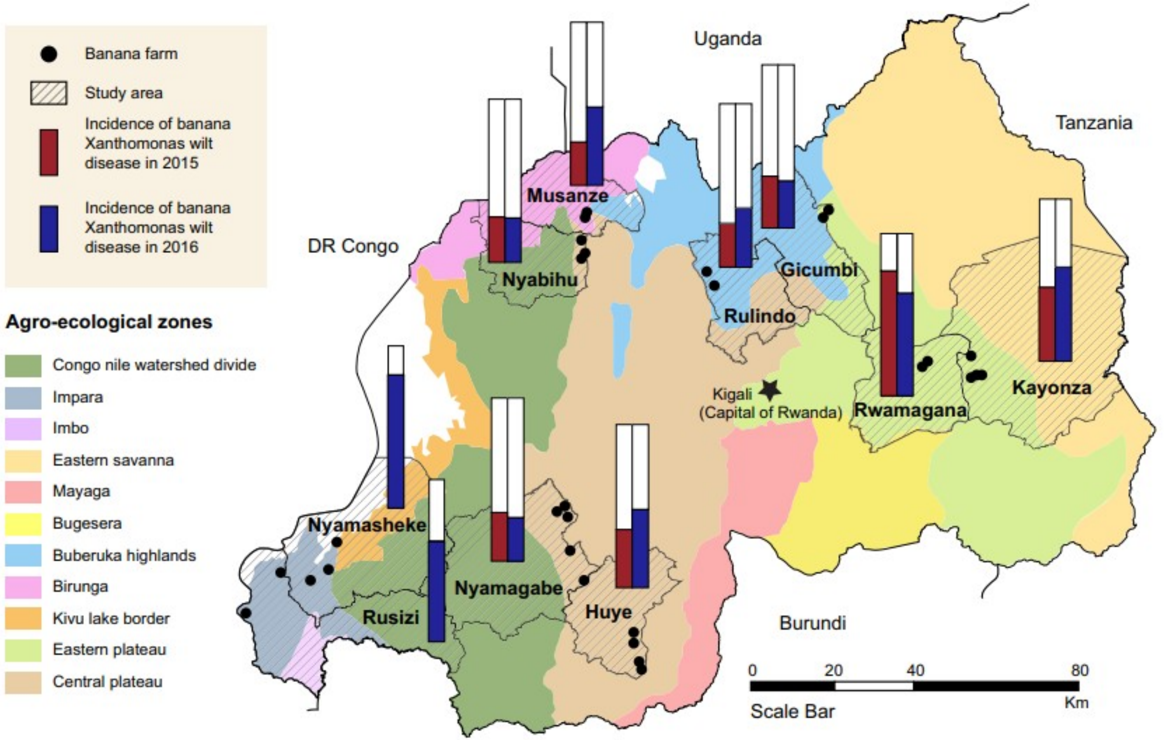

Fig. 2 Agro-ecological zones of Rwanda based on differences in climatic, topographic, and edaphic environment (Verdoodt and Van Ranst 2006) and banana *Xanthomonas* wilt distribution in the surveyed districts during 2015 and 2016. The disease was present in all surveyed districts. Black dots indicate some surveyed farms, and bars show *Xanthomonas* wilt incidence in 2015 and 2016

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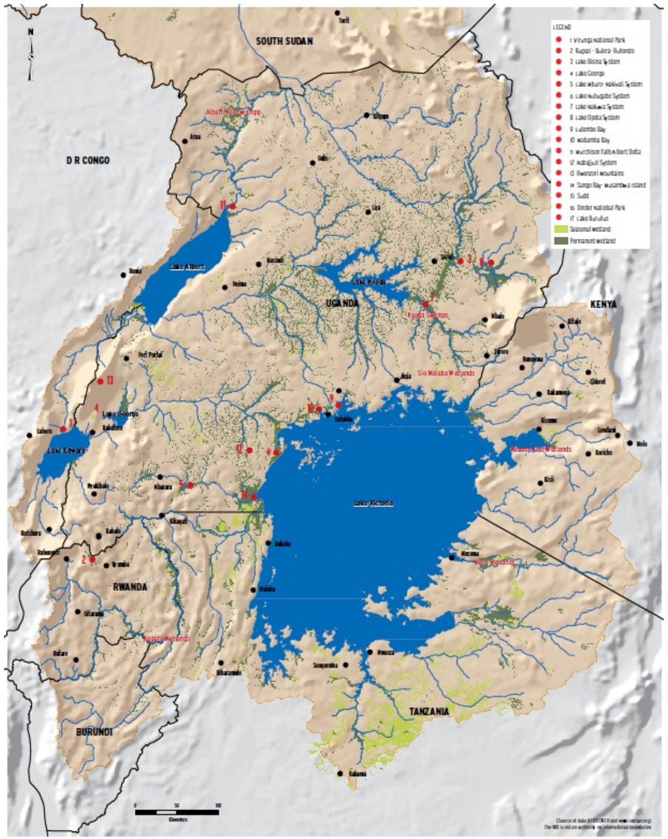
Examples of real-life application of GIS

Wetlands in the Nile Equatorial Lakes Region



LEGEND

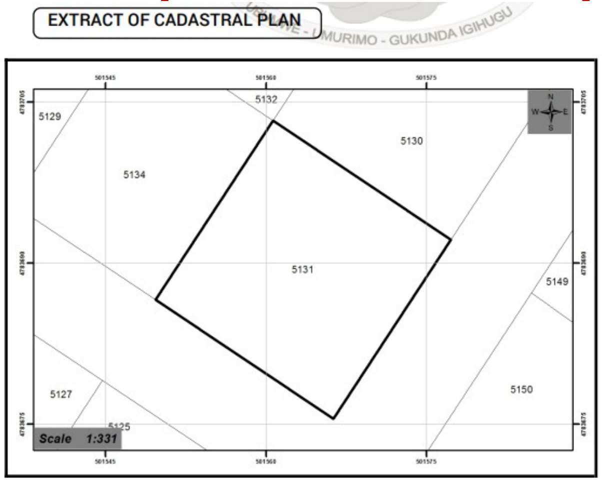
- 1 Virunga National Park
- 2 Rugezi - Bulera- Ruhondo
- 3 Lake Bisina System
- 4 Lake George
- 5 Lake Mburo- Nakivali System
- 6 Lake Nubugabo System
- 7 Lake Nakuwa System
- 8 Lake Opeta System
- 9 Lutembe Bay
- 10 Mabamba Bay
- 11 Murchison Falls-Albert Delta
- 12 Nabajjuzi System
- 13 Rwenzori Mountains
- 14 Sango Bay- Musambwa Island
- 15 Sudd
- 16 Dinder Natiobal Park
- 17 Lake Burullus
- Seasonal Wetland
- Permanent Wetland

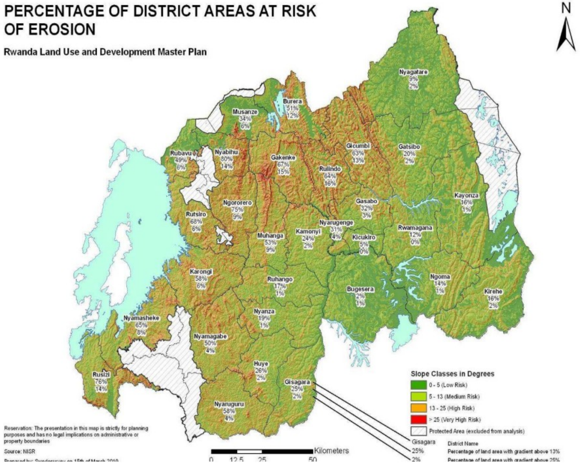
Hydrological functions of major wetlands in the Nile Basin

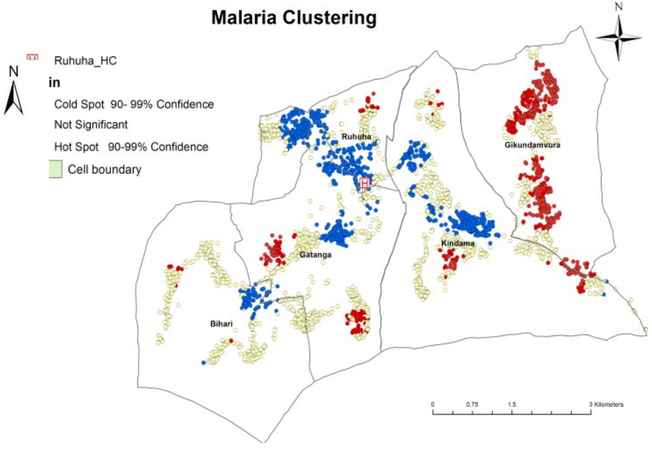
Wetland	Hydrological functions
Wetlands of Uganda	Most of the individual wetlands link to other wetlands through a complex network of permanent and seasonal streams, rivers. and lakes, making them an essential Part of the entire drainage system of the country (UN-WWAP and DWD,2005)
Headwater wetlands of the Baro Akobo	Regulate flow in the Baro Akobo River while believed to play an important role in maintaining downstream dry-season river flows
Lake Albert	Critical link between the White Nile and its headwaters; without the flow regulation of this lake the White Nile would be reduced to a seasonal stream and could play no significant role in maintaining the base flow of the main Nile (Talbot and Williams, 2009)
Sudd, Machar Marshes and wetlands of the Bahr Ghazal	Significantly attenuate flows of the White Nile and its tributaries reducing flood peaks and supporting dry-season river flows, thereby minimizing the seasonal variation in the flow of the White Nile (Sutcliffe and Widgery, 1997; Sutcliffe and Parks, 1999)
Nile Delta	Limits saline intrusion from the Mediterranean Sea, thereby protecting coastal freshwater sources (Baha El Din, 1999)

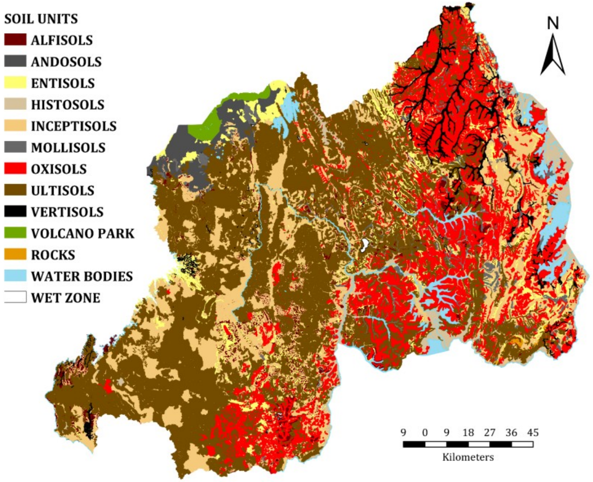
Regional scale planning-Wetlands management

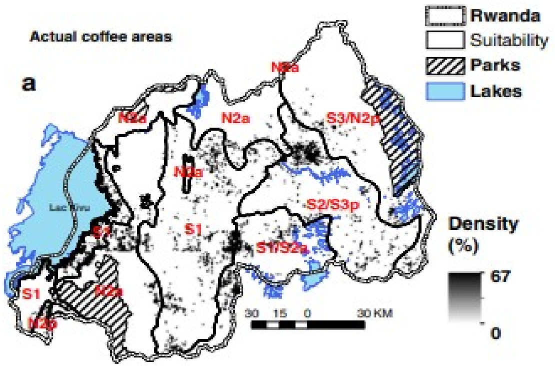
Examples of real-life application of GIS











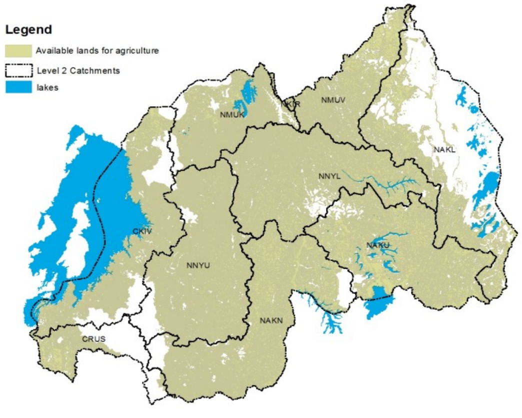


Figure 4-4: Rwanda agricultural lands

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Q & A

DO YOU HAVE ANY QUESTIONS?

Please raise your hand

or write your questions into the chat box!

Structure of today's session

- Official launch of the course ML4EO + Welcome
- Course overview
- Keynote speaker's address
- Introduction to Module 1
- Q&A
- Learner path
- Next steps / assignments
- Closure

Self-study part Moodle – Module 1

- To be completed by Sunday **26.02.2023**
  - Read all contents of all sessions
  - Watch all videos
  - answer all quiz questions after each session (3 attempts)
  - Perform the application exercise on QGIS

Learner Path - assessment method

How to pass the course?

Course work	Written Exam	Practical Task (Business model / project development)
35%	15%	50%

- A total of 75% is required to pass the course

Learner Path - online modules

- **How to pass the online modules (0 – 4)?**

Self-study + individual work	No. of tasks
Participate in tech check (module 0)	optional
Participate in (technical) live sessions	3 / 4
Read text, watch video & solve quizzes (per module)	3 / 4
Application exercise, fieldwork + related questions/ report (per module)	1 / 1

Collaboration + exchange	No. of tasks
Engage in social fora (getting to know the group + expectations) (Module 0 only)	2 / 2
Contribute to discussions in technical fora/ participate in group assignments (per module)	1 / 1

- All tasks receive feedback (personal or automatized)
- Tutoring is available online (on LMS)

- Tutors assess regularly and inform participants about their learning progress
- Badges give orientation

Group Assignment on Moodle – Module 1

- To be completed by Sunday **26.02.2023**

Contribution to the Forum:

- Post your results of the application exercise and your answers to the questions in the forum
- Read the contributions of the other group members
- Answer any question you got in response to your own post

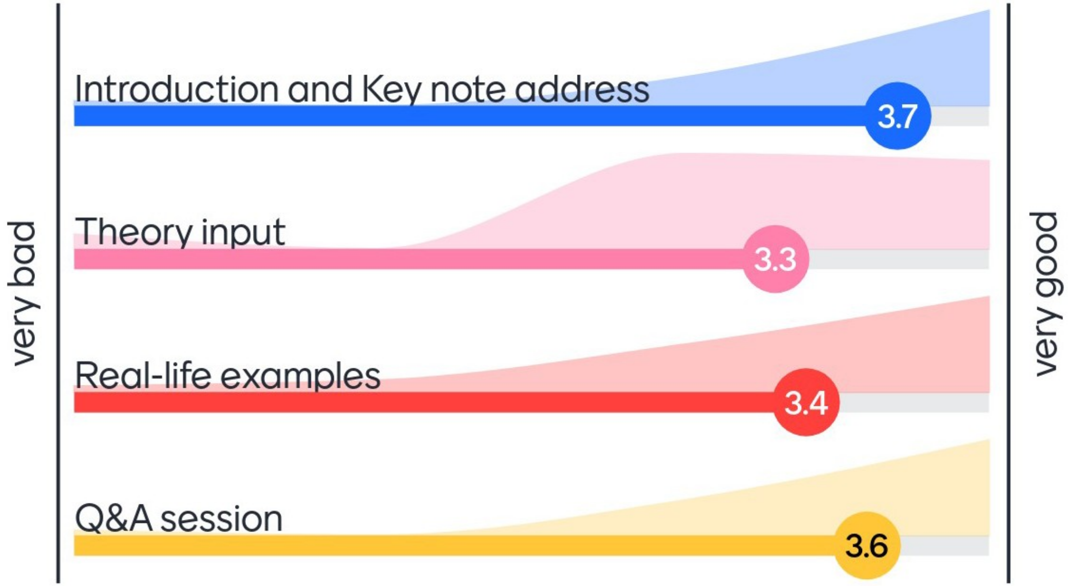
Learning days at the DTC

- At every online lecture (M2, M3, M4), there will be the opportunity to sit in at the **Digital Transformation Center (DTC)** Rwanda for two hours
  - Own devices have to be used for joining the session
  - Physical room for exchange and working on course material

Evaluation of the Live Session

- Before we close… please do a short evaluation of our live session
- Either: Click on the link in the chat
- Or: go to www.menti.com + submit the code (given in the chat)
- THEN participate by answering the questions

Rate the content of todays' live session



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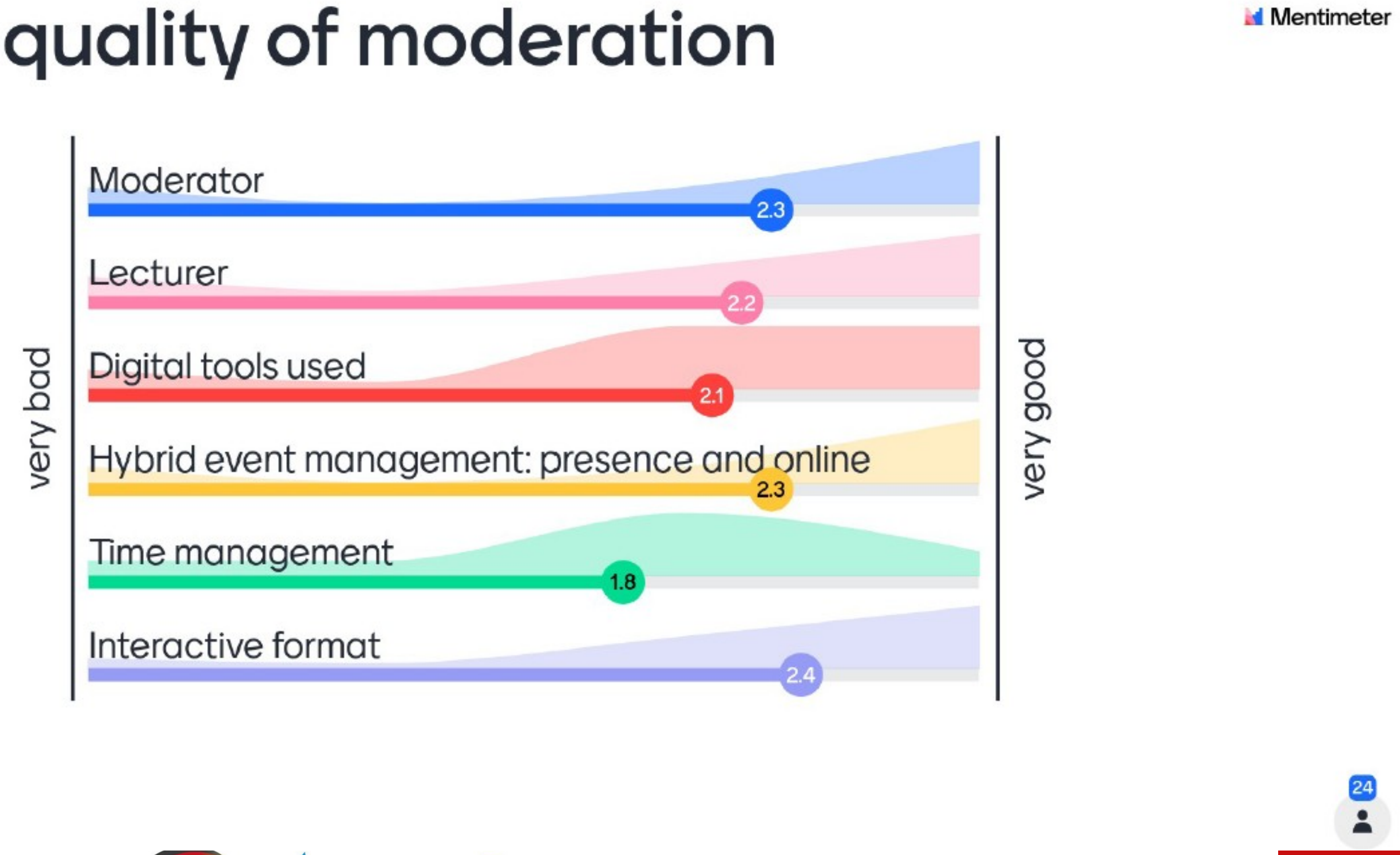
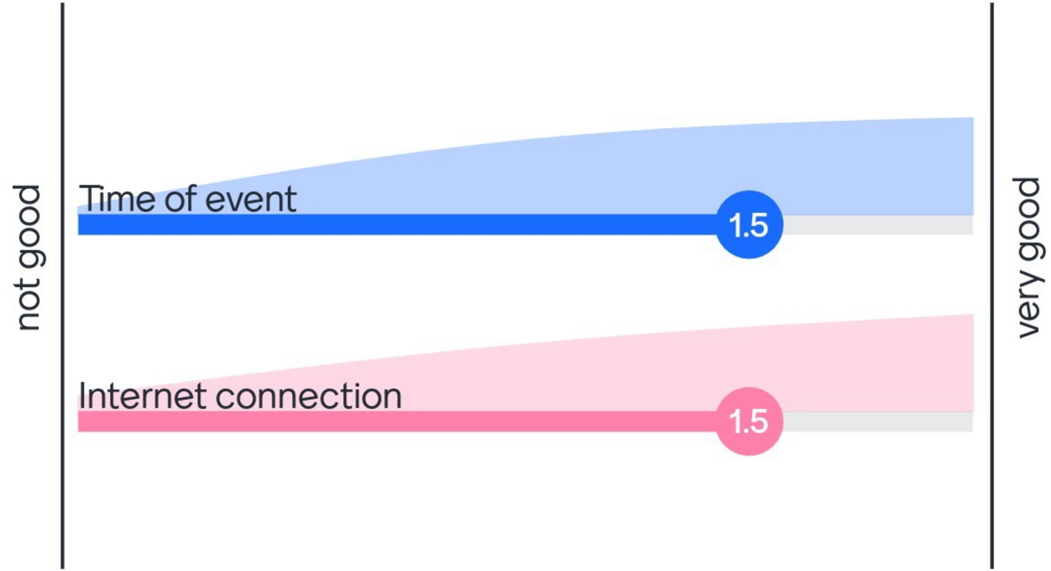
Rate the quality of moderation



How did the logistics work for you?

Mentimeter



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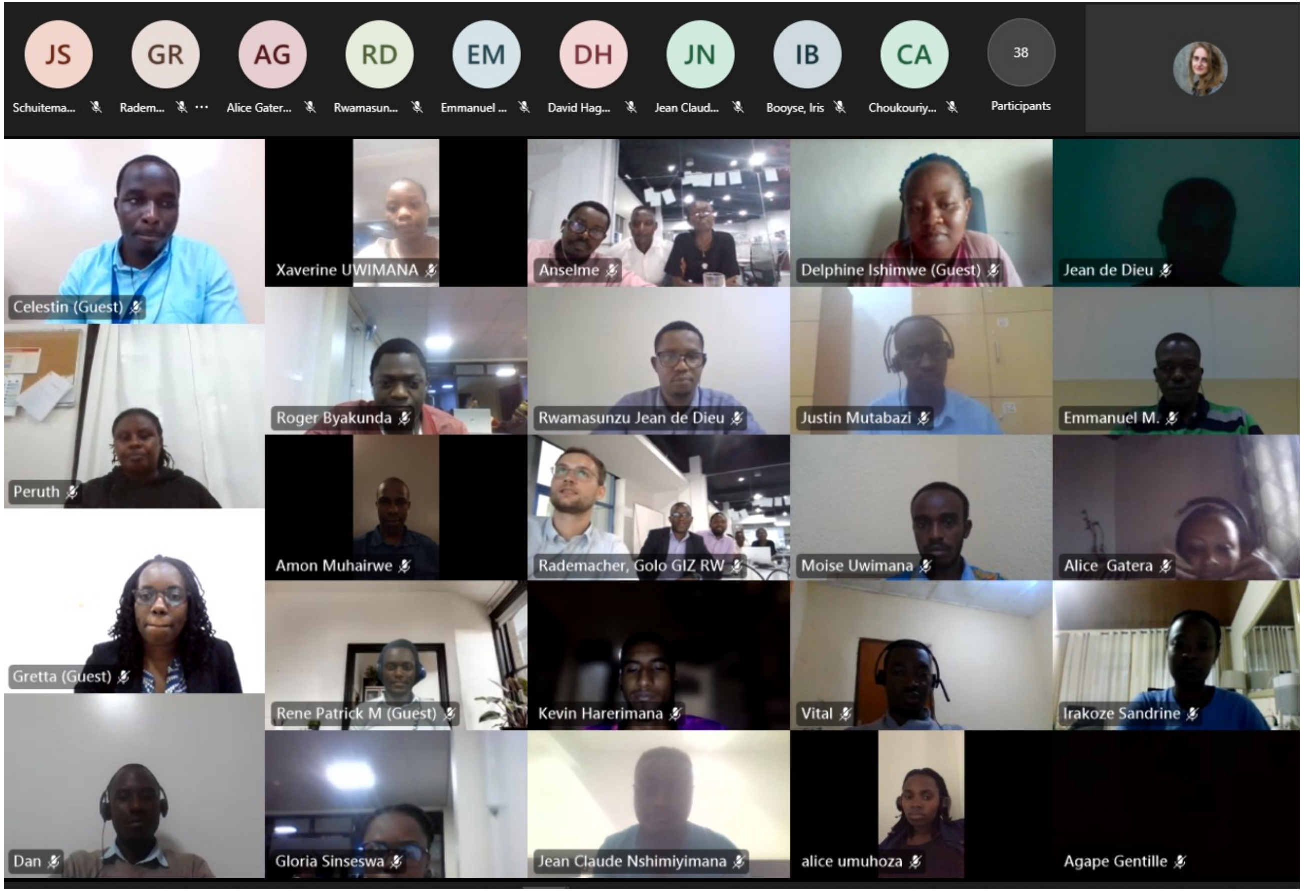

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CLOSING

THANK YOU

for sharing this time with us!

See you next time (Monday, 27.02, 3pm):

Module 2: Introduction to Remote Sensing

1.1 Definition and Key concepts

Reading material

Introduction to geographic information system (GIS) data (data type and structure or vector vs. raster data):

Definition of GIS: A system of hardware, software, and procedures designed to support the capture, management manipulation, analysis, modelling, and display of spatially referenced data for solving complex planning and management problems" (Rhind,1989)

GIS components: it is an integration of five components

- **Hardware**
- **Software**
- **People**
- **Data**
- **Analysis**

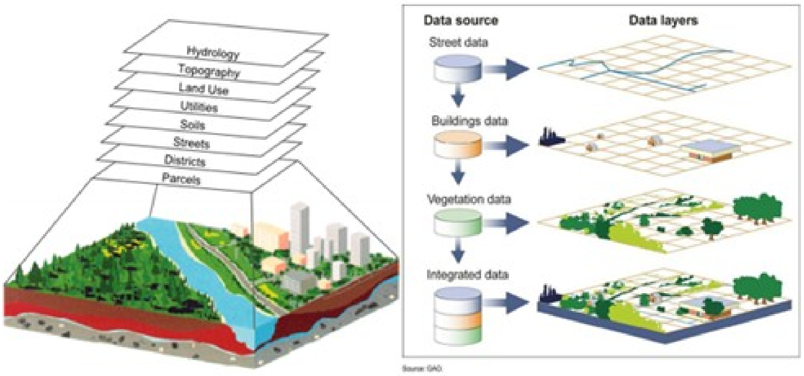
All the components should be in balance, if the system is to function satisfactorily.

Data Model concept: Data represent a simplified view of the real world, physical entities or phenomena are approximated by data in GIS (Spatial location, extent of the physical entities, non-spatial properties). Objects or features are abstractions in a spatial database.

Spatial objects are the objects in a spatial database representing real-world entities with associated attributes

In a GIS system, **Coordinates** are used to define the spatial location and extent of geographic objects and **Attribute/non-spatial data** are linked with coordinate data to define each spatial object in the spatial database.

Most conceptualizations or models view the world as set of layers and each layer organizes the spatial and attribute data for a given set of cartographic/spatial objects (e.g., Lake, river, road, etc.)



Source: Concepts and techniques of Geographic Information system, Book by C.P.Lo, Albert K.W. Yeung (2009)

Definition: Attribute data

Attribute data are the information linked to the geographic features (spatial data) that describe features. That is, attribute data are the "non- graphic information associated with a point, line, or area elements in a GIS." Labels affixed to data points, lines, or polygons.

Attribute data are categorized as nominal, ordinal, or interval/ratio:

- Nominal attributes: variables that provide descriptive information about an object e.g., colour, vegetation type, city name, owner of parcel, soil type etc.
- Ordinal attributes: variables that imply rank order or scale by their values
- Ordinal attribute may also be descriptive (e.g., small, medium, large, low, moderate, high, ranging from 1 to 5 (soil erosion level), etc.
- Interval/ratio attributes are used for numeric items where both order and absolute difference in magnitudes are reflected in the number
- Real number on a linear scale, e.g., area, length, weight, height, depth, value, etc. are represented by interval/ration variables

"GIS" is an acronym for Geographic Information Systems, this is the system that creates, manages, analyses, and maps all types of data. On the contrary to the name itself it does not only include geographic type of problems and data but is applicable to different areas of work. For a better understanding of the principles of GIS you can watch the video below:

https://www.youtube.com/watch?v=P17IRpCXTzs

Exercise materials and tasks

Quiz questions

Instructions: Answer the following five questions to check if you have understood everything so far:

1. What do the letters GIS mean?
   a. Geographical Interpretation System
   b. Geographical Information System
   c. Geographical Interpolation System
   d. Geoscience Information Software

2. GIS is a visualization tool which brings together
   a. Disparate data and information about a phenomenon together with their geolocation
   b. Data and information about activities that take place in time
   c. Disparate data and information

3. What are the components of GIS?
   a. Latitude, Longitude, Height, Speed
   b. Software, Hardware, Methods, People, Data
   c. Polygons, Multipolygons, Lines, Polylines, Points

4. What are the things a GIS can do?
   a. capturing, storing, analysing, and visualising data related to the time of observation
   b. capturing, storing, analysing, and displaying data related to the physical conditions of observation
   c. capturing, storing, checking, and displaying data related to positions on Earth's surface

5. Which of the following is not an example of spatial data?
   a. Polygons showing the area occupied by a particular land use or variable
   b. Lines showing the pipeline network
   c. Points that showing location of cities
   d. Duration of particular events

1.3 Spatial data

Reading material

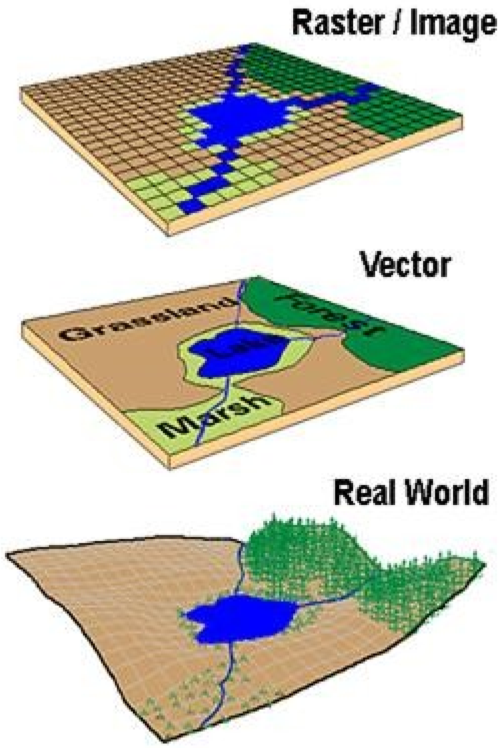
In this session, we're going to learn about several forms of GIS data (spatial data types) and associated properties. We're also going to learn about different sources of spatial data and instruments to collect them with consideration of data quality requirements such as raster data resolutions, GPS receiver accuracies.

Spatial data models

There are two main data models or conceptualizations used in GIS, the vector data model and the raster data model.

1. **Vector data model** uses sets of coordinates and associated attribute data to define discrete objects. Features such as point, lines and polygons to represent the geometry of the real-world entities, discrete entities.
   - Point objects in spatial database represent location of entities considered to have no dimension simplest type of spatial objects, e.g., wells, sampling points, poles, telephone towers, etc.
   - Line objects are used to represent linear features using ordered set of coordinate pairs, e.g., infrastructure networks (transport networks: highways, railroads, etc.): utility networks: (gas, electric, telephone, water, etc.); airline networks: hubs and routes, etc.); natural networks such as river channels.
   - Polygon objects in spatial database represent entities which covers an area, e.g., lakes, Buildings, parcels, etc.
2. **Raster data model** defines the world as a regular set of cells in a uniform grid pattern, Cells are squares and evenly spaced in the x and y directions. Each cell represents attribute values and cell location of phenomena or entities. Raster data represents continuous phenomena that may change continuously across a region. E.g., elevation (DEM), rainfall, temperature, soil moisture, etc.
   - Raster data model may also be used to represent discrete data e.g., land cover: forest, wetlands, urban areas.
   - Rasters are normally digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps.
   - Spatial data models begin with conceptualization, how you will represent the real-world phenomena or entities. E.g., a road can be represented as lines; river as line or polygon; city and towns as point or polygon, etc. the road to include the road type (e.g.: highway, street, etc. or gravel, paved/ asphalted, etc.); width of road.
   - Vector data model and Raster data model can represent the same phenomena, e.g., elevation represented as surface (continuous field) using raster grid or as lines representing contours of equal elevation (discrete objects), or as points of height (Z values)
   - Data can be converted from one conceptual view to another e.g., raster data layer can be derived from contour lines, point cloud.

- Selection of raster or vector model depends on the application or type of operations to be performed e.g., Elevation represented as surface (continuous field) in raster – to easily determine slope, or as discrete contours if printed maps of topography.



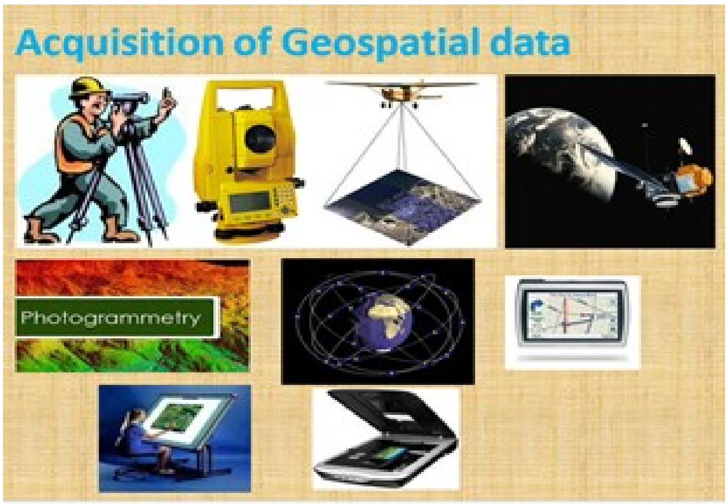
Source: Concepts and techniques of Geographic Information system, Book by C.P.Lo, Albert K.W. Yeung (2009)

What type of graphics do we use every day and what is the difference between them?

GIS data representation: https://rb.gy/vhmmcf (time duration 7:05)

Source: Regents of University of California Davis

Acquisition of Geospatial data



1. Land survey (Field data collection – using Total station, EDM, GPS/DGPS receivers and Mobile Apps such as Cobo collect, survey 123, etc.)
2. Remote sensing Data (Satellites image collection) can be found here:
    - Copernicus global land services
    - Earth Explorer from USGS
    - Open Data Cube for Africa
    - Digital Earth Africa (DE Africa) is providing analysis-ready data in Africa from free satellite imageries namely Landsat and Sentinel as well as continental services such as water observation from space, cloud-free mosaic (GEOMAD), fractional cover and cropland extent.
3. Photogrammetric process (use of Aircraft, UAVs and laser scanners)
4. Scanned maps (Georeferencing & Digitization process)

If you want to find out more about remote sensing image collection, follow the links below:

Copernicus global land services - https://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home

Earth Explorer from USGS - https://earthexplorer.usgs.gov/

Open Data Cube for Africa - https://www.opendatacube.org/

Digital Earth Africa (DE Africa) - https://www.digitalearthafrica.org/platform-resources/services

Acquisition of Attribute data:

- Field investigations, Site Visits (use of questionnaires)
- Remote sensing image interpretation and processing
- Reports
- Thematic/Attribute data are generally collected by sampling method.

Note that the creation of attribute data and the link to non-spatial tabular data will be explored in detail in the next modules.

Exercise materials and tasks

Quiz questions

Instructions: Answer the following five questions to check if you have understood everything so far:

1. What are two main data models that are used in GIS?
   a. **Vector**
   b. Dot
   c. **Raster**
   d. Line

2. Which of the following features would be better represented using the vector data model?
   a. Elevation
   b. **Roads**
   c. **Rivers**

3. What are basic features used to represent the geometry of the real-world entities?
   a. Latitude, longitude coordinate pair and height
   b. Point, Square, Circle
   c. Point, Line and Polygone

4. Which data model is better to represent continuous phenomena that may change continuously across a region? E.g., elevation (DEM), rainfall, temperature
   a. Vector data model
   b. Raster data model
   c. Spatial data model

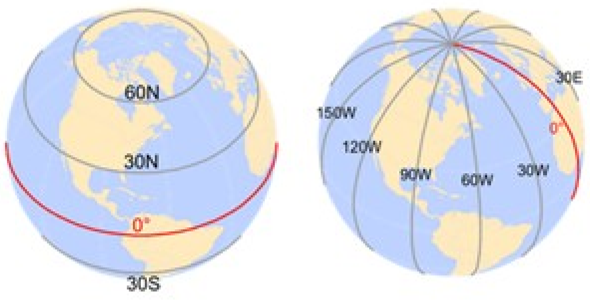
1.4 Mapping references

Reading material

Now that you know more about GIS, the types and models of data and how to collect them, we will dive into Mapping references.

Our planet is round so we can't project it on a plane map without deformations. People in the past used different projections and developed different coordinate systems to display data. In this session you will learn more about geographic coordinate system and projections.

A **geographic coordinate system (GCS)** is a reference system for identifying locations on the curved surface of the earth. Locations on the earth's surface are measured in angular units from the centre of the earth relative to two planes: the plane defined by the equator and the plane defined by the prime meridian (which crosses Greenwich England). A location is therefore defined by two values: a latitudinal value and a longitudinal value.

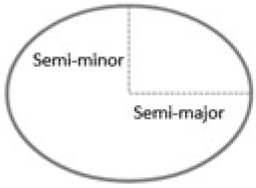


Source : https://mgimond.github.io/Spatial/chp09_0.html

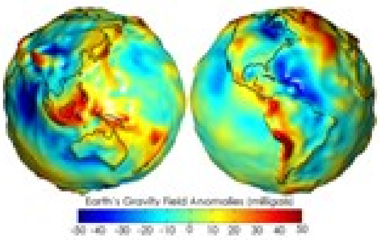
A latitude measures the angle from the equatorial plane to the location on the earth's surface. A longitude measures the angle between the prime meridian plane and the north-south plane that intersects the location of interest. In a GIS system, the North-South and East-West directions are encoded as signs. North and East are assigned a positive (+) sign and South and West are assigned a negative (-) sign

In GIS, a GCS is defined by an **Ellipsoid, Geoid and Datum**.

1. **Ellipsoid:** Assuming that the earth is a perfect sphere greatly simplifies mathematical calculations and works well for small-scale maps (maps that show a large area of the earth). However, when working at larger scales, an ellipsoid representation of earth may be desired if accurate measurements are needed. An ellipsoid is defined by two radii: the semi-major axis (the equatorial radius) and the semi-minor axis (the polar radius).

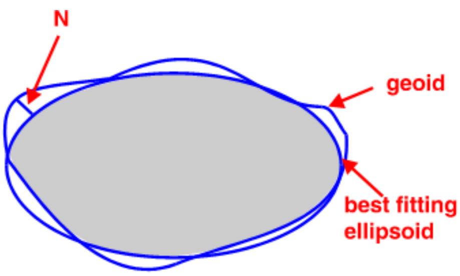


2. **Geoid:** Representing the earth's true shape, the geoid, as a mathematical model is crucial for a GIS environment. However, the earth's shape is not a perfectly smooth surface. It has undulations resulting from changes in gravitational pull across its surface. These undulations may not be visible with the naked eye, but they are measurable and can influence locational measurements. Note that we are not including mountains and ocean bottoms in our discussion, instead we are focusing solely on the earth's gravitational potential which can be best visualized by imagining the earth's surface completely immersed in water and measuring the distance from the earth's centre to the water surface over the entire earth surface.



Source: The COMET Program/ESA

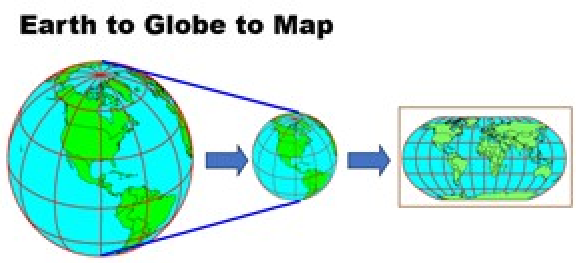
3. **Datum:** So how are we to reconcile our need to work with a (simple) mathematical model of the earth's shape with the undulating nature of the earth's surface (i.e., its geoid)? The solution is to align the geoid with the ellipsoid (or sphere) representation of the earth and to map the earth's surface features onto this ellipsoid/sphere. The alignment can be local where the ellipsoid surface is closely fit to the geoid at a particular location on the earth's surface or geocentric where the ellipsoid is aligned with the centre of the earth. How one chooses to align the ellipsoid to the geoid defines a datum.



Source: The COMET Program/ESA

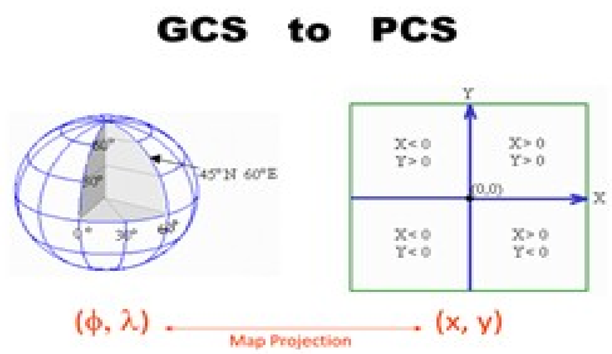
To prepare a map, the earth is first reduced to a globe and then projected onto a flat surface:

The surface of the earth is curved but maps are flat. **A projected coordinate system (PCS)** is a reference system for identifying locations and measuring features on a flat (map) surface. It consists of lines that intersect at right angles, forming a grid. Projected coordinate systems (which are based on Cartesian coordinates) have an origin, an x axis, a y axis, and a linear unit of measure.



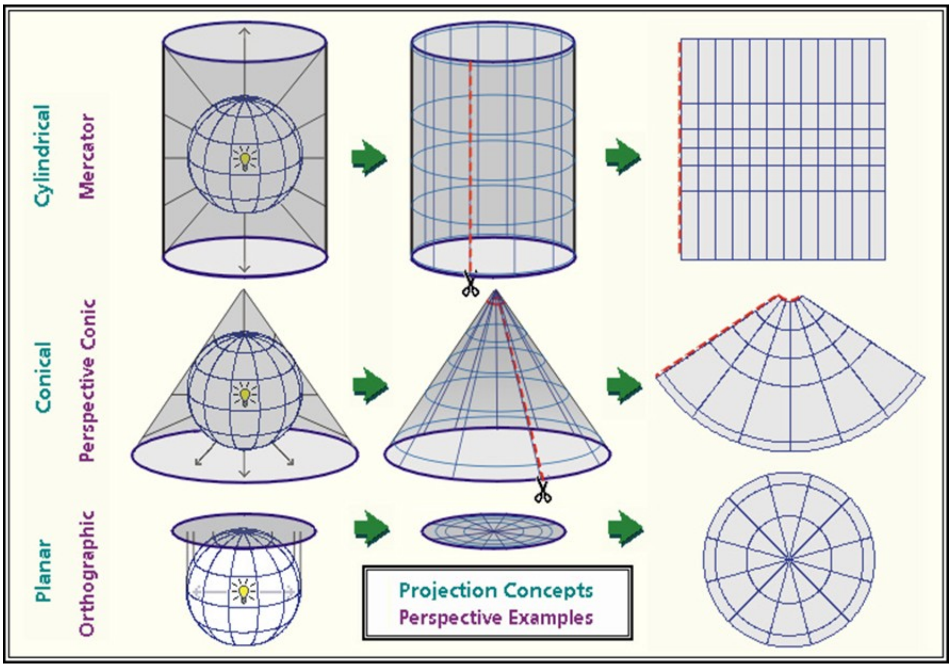
Source: https://kartoweb.itc.nl/geometrics/Map%20projections/mappro.html

Going from a GCS to a PCS requires mathematical transformations:



Source: www.mathworks.com

The myriad of projection types can be aggregated into three groups: **planar, cylindrical and conical.**



Source: **https://kartoweb.itc.nl/geometrics/Map%20projections/mappro.html**

No place for a flat-Earther's here!

We know that understanding of how we get from a ball to a plane map is hard. Here is a short video to better understand how different projections works.

Why all world maps are wrong - YouTube

https://www.youtube.com/watch?v=kIID5FDi2JQ

Exercise materials and tasks

Quiz questions

Instructions: Answer the following five questions to check if you have understood everything so far:

1. What does it mean if you are located at 0° longitude?
   a. I am at the Equator.
   b. I am located on the Greenwich line or prime meridian.
   c. I am located nowhere.
   d. I am located at the Artic circle.

2. How is a geographic coordinate system defined in a GIS?
   a. With Latitude and Longitude
   b. With Elipsoid and Geoid
   c. With Elipsoid, Geoid and Datum

3. Which shape represents the earth's true shape as a mathematical model is:
   a. Spheroid
   b. Geoid
   c. Ellipsoid

4. Which projection is recommended for topographic mapping by the United Nations Cartography Committee?
   a. Transverse Mercator (TM) projection
   b. Universal Tranverse Mercator (UTM) projection
   c. WGS84 projection

5. The distortion properties of map are typically classified according to what is not distorted on the map. What is true for equidistant map projection?
   a. the length of particular lines in the map are the same as the length of the original lines on the curved reference surface.
   b. the angles between lines in the map are indentical to the angles between the original lines on the curved reference surface.
   c. the areas in the map are identical to the areas on the curved reference surface.

1.5 Spatial Data Analysis

Reading material

Before we can try this all out, it will be good to get a more in-depth understanding of Spatial Data Analysis. This session will help you get through the main concepts and tools to make the necessary analysis with the data. By using spatial data analysis, you will work on transforming raw data into valuable insights. While working on data, there's always a question that you need to answer: "which analysis function you want to use to solve the problem".

Let's dig into next session and find out!

Spatial analysis concept

Spatial analysis is the process by which we turn raw data into useful information. Spatial analysis is the crux of GIS because it includes all of the transformations, manipulations, and methods that can be applied to geographic data to add value to them, to support decisions, and to reveal patterns and anomalies that are not immediately obvious. In a narrow sense, spatial analysis has been described as a method for analysing spatial data, while in a broad sense it includes revealing and clarifying processes, structures, etc., of spatial phenomena that occur on the Earth's surface.

GIS Analysis Functions

Once the data input process is complete and GIS layers are pre-processed, someone can begin the analysis stage. GIS analysis functions use the spatial and non-spatial attribute data to answer questions about real-world. Analysing geographic data requires critical thinking and reasoning. When use GIS to address real-world problems, you will come up against the question that which analysis function you want to use and to solve the problems.

GIS analysis functions help look for **patterns, associations, connections, interactions, and evidence** of change through time and over space.

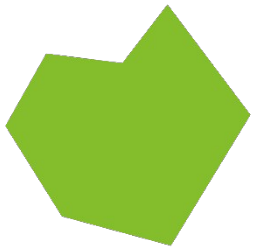
Functionally, GIS provides a sophisticated tool for reporting the results of a database. These reports may be for an entire dataset (or table) or for a portion of the dataset (e.g., based on the results of a query or data summary).

Geospatial data is any type of data that contains a geographic component (it contains a location in any coordinate system). Geospatial data can be a simple point or a more complex shape with lines and boundaries (lines, polygons). Data usually contains not only location but also elevation and other informative attributes, e.g., area, shape, poverty rates, population density, information on traffic, different pixel values (in raster), …

These properties of data allow us to perform certain functions on them. We can divide these functions by their spatial attributes, spatial relationship and creating new geometries.

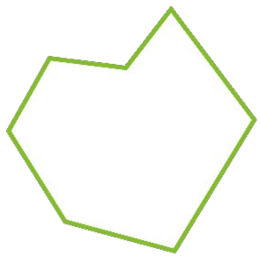
Spatial attributes:

- Area – are attribute tells us about the surface of the spatial data (polygon), measured in different units (e.g., m2, km2, ha, …)



Source: GeoCodis

- Perimeter - continuous line forming the boundary of a closed geometrical figure.

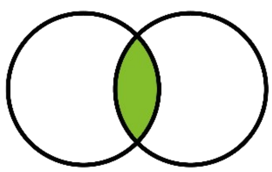


Source: GeoCodis

- Length - gives us the information about longitude of a specific spatial data (line, polyline)
- Min, Max - we can measure, calculate, determine, evaluate or add different minimums or maximum of spatial data. (e.g., lowest or highest elevation)

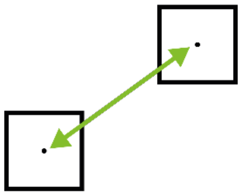
Spatial relationship:

- Intersect - function intersect extracts the portions of features from the input layer that overlap features in the overlay layer. Attributes are assigned to the intersection layer.



Source: GeoCodis

- Contains - a geospatial polygon can contain other geospatial data or different attributes.
- Distance - the length of the space between two points. This also includes distance between point and polygon or between two polygons since geometric centroid is always included in the measuring and not the whole surface.

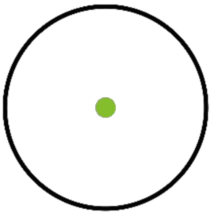


Source: GeoCodis

- Equals - meaning something is the same as another or has the same status or quality.

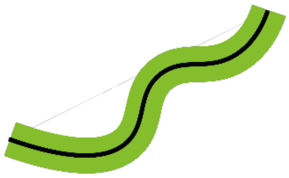
Creating new geometries:

- Centroid - centroid is a centre point of the object (polygon). It is the point where all three medians of the triangle intersect



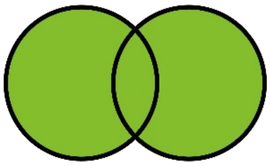
Source: GeoCodis

- Buffer - is an area within the specified distance of a point, line or a polygon



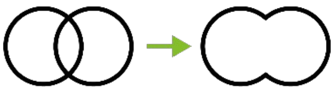
Source: GeoCodis

- Union - is a function that combines different geospatial data into a single composite layer, preserving the attributes and boundaries of both (all)



Source: GeoCodis

- Dissolve - is a function that unifies different geospatial data, while unifying their boundaries. Dissolve is based on the common attribute values and will only be performed when this condition is satisfied



Source: GeoCodis

Analysis FUNCTIONS of GIS Includes:

- Measurements
- Query
- Extraction (clip, select, split etc...)
- Proximity
- Classification
- Overlay analysis
- Topology
- Network analysis …

Tools that are openly available to you:

- QGIS [Welcome to the QGIS project!]

- https://docs.qgis.org/3.22/en/docs/gentle_gis_introduction/index.html
- ArcGIS About ArcGIS | Mapping & Analytics Software and Services (esri.com)
- PostGIS About PostGIS | PostGIS
- PostgreSQL PostgreSQL: The world's most advanced open source database

Exercise materials and tasks

Quiz questions

Answer the following three questions to check if you have understood everything so far:

1. We can perform certain functions on geospatial data. Select all spatial relationship fuctions from the list:
   a. Contains
   b. Perimeter
   c. Length
   d. Distance
   e. Intersect
   f. Buffer
   g. Centroid
   h. Union

2. Geospatial function DISOLVE is:
   a. Geospatial relationship functions that represent geospatial data, which are not intersected at any point
   b. Geospatial function that create new geometry that unifies different geospatial data, while unifying their boundaries
   c. Geospatial relationship function that represent all geospatial data that have the same atributes.

3. Which geospatial analysis is suitable for determining if any road passes within 1000m of a stream?
   a. Overlay analysis
   b. Statistical analysis
   c. Proximity analysis

1.6 Application and documentation

Exercise materials and tasks

Congrats! You made it through first part of theory – introduction to GIS!

Now that you have expanded your knowledge, we will do an exercise on that topic.

Download and install QGIS on your computer.

Go on the following page and check instruction provided below and in the documents on the website:

https://qgis.org/en/site/

1. QGIS is unique among the major desktop GIS software applications in that it can run on Windows, Mac, and Linux computers. For this reason, it is important to select the QGIS version appropriate for your operating system on the Download page. You will also notice that, even once you have selected your operating system you may still see up to 4 options to choose from: for Windows you can select a 32-bit or 64-bit version of QGIS and for both Windows and Mac you can select the latest release of the software or an older, more stable long-term support release. The 64bit version is recommended for almost all users, unless you are attempting to install the software on an older computer that has a 32-bit processor. It is also recommended that you install the latest release rather than the long-term release so that you have access to the latest QGIS features. If you are working on a Windows PC or Mac, click on the QGIS standalone installer link for the software version that is most appropriate for your computer configuration to download the QGIS installation files. If you hoping to load QGIS on a Linux computer, follow the instructions on the Download page to download and install the software on your computer using the software installation method specific to your Linux distribution.

2. Once you have downloaded the most suitable version of QGIS for your Windows or MacOS computer the next step is to actually install the software on your machine. Once you are ready to run the installer, click on the QGIS installer file you downloaded to bring up a wizard that will walk you through the install process in a few easy steps. For most users the default options offered in each step will be fine, but you should read the contents of each page in the wizard carefully to see if you think any adjustment to the default settings is required for your particular use case. Once you reach the end of the installation wizard, click the Install button to start the installation process which should take just a few minutes to complete on a typical computer.

Now that you have installed QGIS on your computer. Open the attached file (***Data _practices-it contains District_boundaries, province_boundaries, health_facilities, school_locations, Roads_network, powerlines_network, aquatic_land and LULC_2009)*** for Rwandan data and follow the below instructions.

Get familiar with QGIS interface and tools:

- First of all, locate the table of content, standard menu, Zoom and other tools, Data sources browser, map area etc.
- Then import shapefile into QGIS environment (browse the file named ***data_practices*** and add all vector layers located in that file)
- From the table of context try to explore attribute tables for displayed data, ***from the attribute table select secondary schools of Eastern province (Hint: use select by attribute tools)***
- Select and Export the Eastern province of Rwanda as polygon from the ***province_boundaries.shp***
- Using the ***created Eastern province.shp*** clip following data ***health_facilities.shp, roads_network.shp, aquatic_land.shp and powerlines_netowrk.shp***
- Create ***multiple-buffer (of 100, 300 and 500 m)*** along the powerlines_network of Eastern province
- With all extracted data of Eastern province, create a map layout (include all key element of map)
- Create another separate map of population distribution by Rwandan districts

Answer the following three questions on the application exercise.

1. How many attributes does secondary schools of Eastern province data layer have?
   a. 0
   b. 3
   c. 5

2. How many health facilities objects intersects with 100m powerlines network of Eastern province?
   a. 40
   b. 13
   c. 523

3. What is the total length of roads in Eastern province of Rwanda?
   a. 453 km
   b. 513 km
   c. **494.5km**

Additional resources and material

Before we move to the next module on Remote Sensing, below are a few more resources available to you if you wish to go deeper on GIS.

If you feel like diving into depth on **QGIS for beginners**, these videos provide all the info. Note that they are long to watch and only optional:

- An absolute beginner's guide to QGIS: https://youtu.be/NHolzMgaqwE

- https://courses.spatialthoughts.com/introduction-to-qgis.html
- https://courses.spatialthoughts.com/advanced-qgis.html
- Make a map from areal image in QGIS: https://www.youtube.com/watch?v=ttwb4OrRpFE
- Complete Tutorial - How to Make a MAP from ZERO: https://www.youtube.com/watch?v=9seReuWjZUg
- More about map projections: https://kartoweb.itc.nl/geometrics/Map%20projections/mappro.html

Raster terrain analysis: Using DTM we calculate aspect, hill shade, slope, relief:

- Raster analysis — https://docs.qgis.org/3.22/en/docs/user_manual/processing_algs/qgis/rasteranalysis.html
- Raster terrain analysis — https://docs.qgis.org/3.22/en/docs/user_manual/processing_algs/qgis/rasterterrainanalysis.html
- Vector analysis — https://docs.qgis.org/3.22/en/docs/user_manual/processing_algs/qgis/vectoranalysis.html
- Vector geometry — https://docs.qgis.org/3.22/en/docs/user_manual/processing_algs/qgis/vectorgeometry.html