IUCN Eastern Africa Programme

Mnazi Bay Ruvuma Estuary Marine Park

GEOGRAPHIC SKILLS

Volume 1: Introduction to GIS, GPS and maps

A training manual for Mnazi Bay Ruvuma Estuary Marine Park

E. van Walsum and R. Verwimp

July 2004

Marine Parks & Reserves

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IUCN The World Conservation Union

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A training manual for
Mnazi Bay Ruvuma Estuary Marine Park

E. van Walsum

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For the UNDP/GEF Development of
Mnazi Bay Ruvuma Estuary Marine Park (MBREMP) Project

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COURSE CONTENT

A course on geographical skills covers a wide range of concepts, tools and techniques for analysing our environment and society in a spatial context. Within this introduction course it is not the intention to teach all these skills in depth. However the course aims at training people that need to be able to transfer real world issues, questions or problems into a geographical database.

In most fields, especially in environmental management and natural resource planning, geographic information has become increasingly important. This is also the case in the field of marine conservation. Marine scientists and politicians are not only interested in the condition of coral reef or the status of fisheries resources; they also want to know WHERE the coral reefs and fish populations are located.

This course is intended for a wide range of people. Whether you are involved in law enforcement, environmental monitoring or social research, this introduction course is for you. The only criterion is that you are interested in the location of the elements you are studying.

This course covers the following topics:

- Geographic Information Systems (GIS)
  - What is GIS?
  - Translating real world problems into a geographical database
  - Using GIS software
- Global Positioning System (GPS)
  - What is GPS?
  - How does it work?
  - Measuring coordinates
- Maps
  - What is a map?
  - Elements of mapping
  - Reading and generating a map

Last but not least we want to warn you! What ever you will be doing after this course, we advise you always to pay a lot, and we really mean a lot, of attention to the quality of your data! ***A decision is as good as the information that goes into it!***

How to use this course

This course is written as a self-study program. It consists of two volumes: this introductory course and another volume containing practical exercises, based on the matter explained in the course. In the theoretical course, each chapter is followed by a quiz containing questions assessing your understanding of the subject matter. Students are expected to study and complete exercises at their own pace. Throughout this learning process, however, there will be continuous support from the GIS team for assistance with more complex topics and for more information.

This course was written in such a way that it is accessible for people without or with a limited background in geography and computer skills. However, by starting with the basics elements and explaining new concepts in an accessible way, it takes people along to a thorough understanding of the basic geographic concepts and the principles of Geographic Information Systems.

The course is not limited by this approach, however. It covers all the information that is needed for working with geographical data and starting up a Geographic Information System. Because of that, this course will not only be useful for GIS novices, but also prove its use at the long term, as a full reference guide for basic and more advance GIS users.

As this course is intended to be an introductory course, not all aspects of geographic skills can be taught in detail. **Info boxes** provide the reader with additional information or explain more complex topics.

The definition of a large number of terms can be looked up in the **glossary** in the appendices at the end of this course.

The **answers to the quizzes** are provided in the appendix of the exercises volume.

1 INTRODUCTION TO GIS

1.1 Geographic Information Systems (GIS)

1.1.1 What is GIS?

In our society, information is becoming more and more important. **Geographic information**, which includes the **location** of objects, has become especially popular, not least in environmental management and natural resource planning. This is also the case in the field of marine conservation. Researchers and politicians do not only want to know the condition of coral reef or the status of fisheries resources; they also want to know WHERE the coral reefs and fish populations are located.

More than 30 years ago, a number of geographers developed a system for the storing and analysis of geographic information in a computer. This technology has come to be known as **Geographic Information Systems** or **GIS**. Rapidly declining computer hardware costs and the increasing importance of geographic information have made GIS increasingly popular during the last decade. In business, government and research institutions GIS has become indispensable.

Definition of GIS:
A GIS is a computer system capable of holding and using data describing places on the earth's surface (ESRI, 1996).

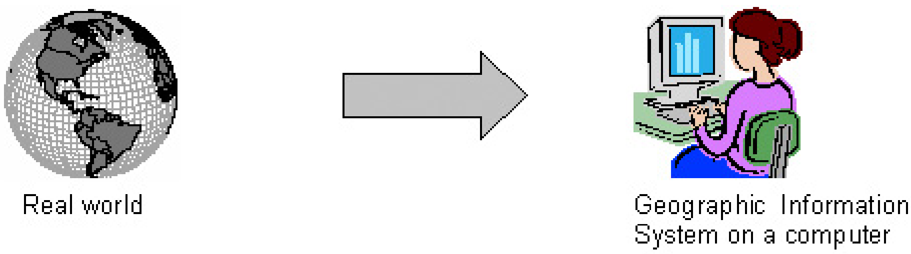


Figure 1: From real world to GIS

Components of GIS

A Geographic Information System is not only made up of a computer or software. There are five components which make up GIS. Of course you need a computer; this is called the **hardware**. On that computer, you need GIS **software**, a program that can handle geographic data. To learn about your area of interest, you need to collect **data**, or to use existing data. But you will not learn a great deal by just looking at the data. To find out relationships, patterns, trends and so on, you will have to perform **analysis** of the data. Last but not least, **people** are needed to make the GIS work. This includes the GIS developers and the GIS users, like you.

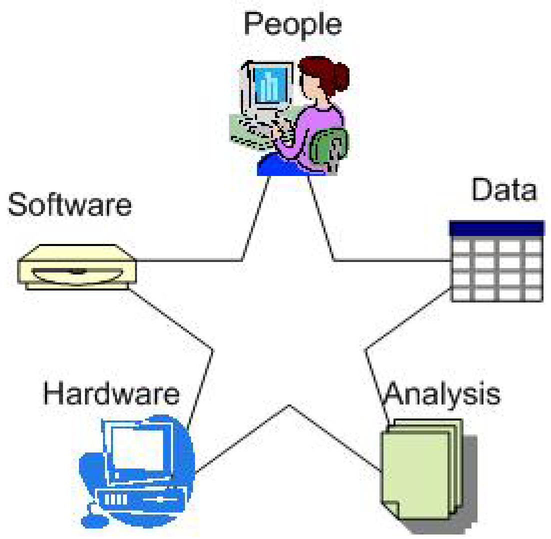


Figure 2: Components of a GIS (adapted from Zeiler, 1999)

What a GIS is not

It is very important to remember that GIS is not simply a tool for making maps. Mapping is only one of the things GIS can do. The major advantage of GIS is that it allows one to **store spatial data** and to **perform spatial analysis**. These concepts will become clear further. A more extensive definition of GIS is given in the glossary at the end of this course.

1.1.2 What can it do?

GIS can store and visualise spatial information, but the most important contribution of GIS is its capability to perform spatial analysis. Because of its capacity of spatial analysis, GIS had become indispensable in **decision making** questions**,** which often imply a spatial component.

Below you can find a typical list of **questions** you can answer with GIS:

Location

- What is at…?

With this question we want to know what or how the circumstances are at a certain location. E.g. the name of a certain village, the depth of a certain location at sea, the crops cultivated at a certain plot.

Condition

- Where is it…?

This question is the opposite of the previous one. Here we start from the conditions or circumstances and we want to know where they are fulfilled. Typical condition questions are for example: “Where are the zones of high ecological value?”, “Where is a certain species of mangrove located?”, “Which places are shallower than 30 metres?”.

Trends

- What has changed since…?

This question might involve both of the first two and seeks to find the difference within an area over time. We could say we add a new dimension here, which is time. Typical questions can be: “Where has the number of fish species decreased compared to 10 years ago?”, “How and where has the condition of coral reef changed over time?”.

Patterns

- What spatial pattern exists?

This question is more complicated. Here we want to see whether a spatial pattern can be recognized in the dataset. Or more so, whether or not the pattern is related to the pattern of another data layer. For example: “Is there a pattern in the distribution of a certain fish species?” and “Does that pattern relate to the distribution of their food?”.

Modelling

- What if…?

This question tries to model what will happen if the circumstances are changing or what should be done to fulfil predefined conditions. For example: “What is the impact of a new road on the surrounding ecosystem?”, “Which regulations have to be put in order to protect a particular species?”.

1.2 Basic GIS concepts

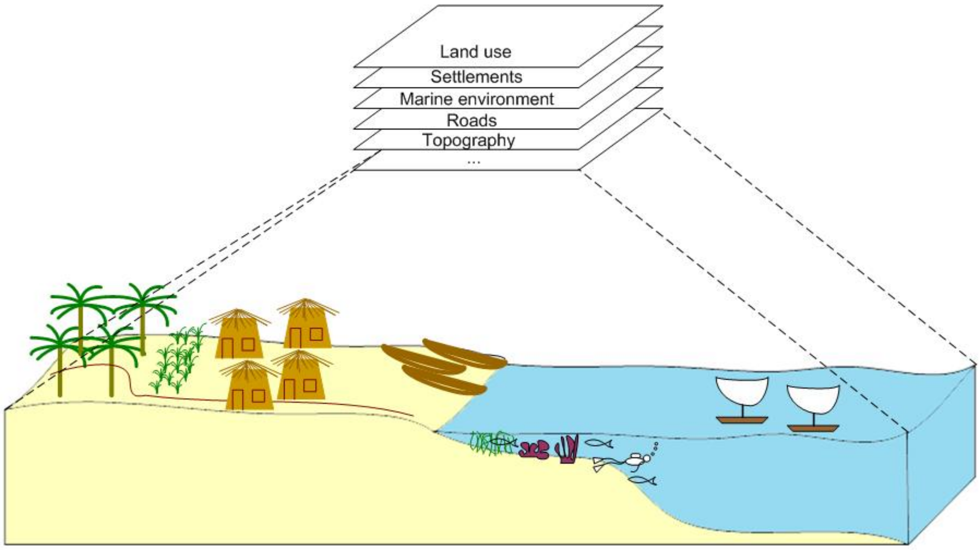
To store information on objects of the real world GIS requires making an abstraction of that world. This means we have to represent the reality by means of abstract symbols or models, much the same as mathematics is a way to represent the reality. In GIS this abstraction exists of two main components. The first one is **thematic abstraction** where the real world is divided into different thematic groups, like land, water, buildings, roads, rivers, forest, cultivated areas, etc. Secondly every thematic group has to be **modelled** according to the data models available in GIS, so that the information can be stored and analysed in GIS. These concepts will now be further explained.

1.2.1 Transferring the world into a database?

Objects are grouped in layers

Our real world exists of many different **objects**. Imagine taking a walk from the coast to the sea. On land you will see houses, roads, agricultural plots, trees, … When you arrive at the sea you’ll see coast, water of different depths, coral reefs, sea grass beds, islands, boats, buoys, etc.

These are all objects that we can recognize in the real world. Every object has certain **characteristics**. However roads have different characteristics (type of surface, length, …) than buildings (type of roof, construction material, …) as have coral reefs (species composition, size, depth, …). All objects that have the same type of characteristics can be grouped together in an object **class**. So roads, buildings and coral reefs are object classes. In GIS we store all objects from the same object class in a **thematic layer** or simply **layer**. In our example, all roads will be in one layer, buildings will be in another layer, coral reef is a third layer and so on. This process is visualized in Figure 3.



Objects at the earth's surface, like houses, roads, trees, water bodies and so on, are represented as layers in GIS

Figure 3: Transferring our real world into thematic layers

1.2.2 Modelling reality

Two basic types of information

It's not entirely correct to say that objects are stored in GIS. In fact **information** on objects is stored. When storing information on objects in a database, several data can be stored. For a coral reef we could store certain **descriptive** data, like size, depth, species composition, health and so on. However, in a Geographic Information System, also the **location** of the coral reef can also be stored.

So there are two types of information:

- **Descriptive** information describing characteristics of objects
- **Spatial** information describing the location and shape of objects

The difference between the two types of information is illustrated in Figure 4.

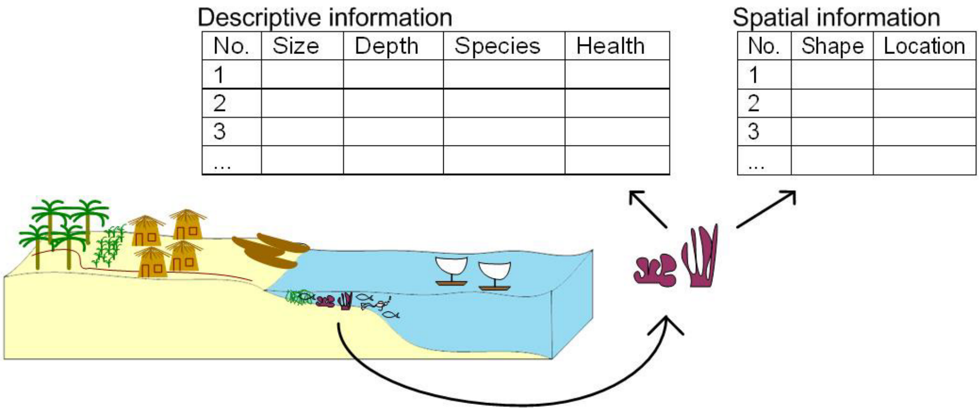


Figure 4: Objects, for example coral reefs, have spatial and descriptive information

The combination of descriptive and spatial information is called **geographic** information. So, geographic information is all information about the object, including location.

No.	Size	Depth	Species	Health
1				
2				
3				

Attribute data: description

No.	Shape	Location
1		
2		
3		

Spatial data: shape and location

Geographic data: description, shape and location

Below, these two types of data are further discussed.

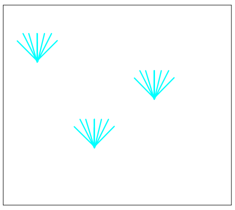
1.2.2.1 Spatial data

As we said higher, spatial information describes the shape and location of an object. In GIS the concept of **features** is used to represent spatial information. You can imagine a feature as the way an object is indicated on a map.

Feature types

There are three types of features:

- **Points**: are features that have a certain location and that are too small to be represented as a line or an area. Points have no width or area.

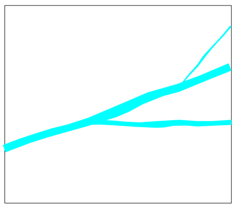


wells

Examples:

Objects like wells, hill tops, antennas,… are often represented on a map as points.

- **Lines**: are features which have a length but are too narrow to be represented as an area. A line is represented as a connection of successive points. Lines have a length but no area.

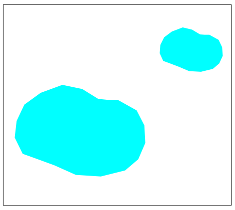


rivers

Examples:

Objects like rivers, roads, contours,… are often represented on a map as lines.

- **Polygons** (areas): are features which are too big to be represented as a point or a line. Polygons are represented by a boundary enclosing a homogeneous area.

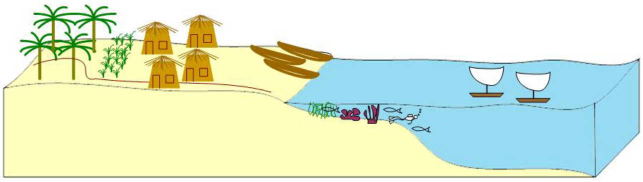


lakes

Examples:

Objects like lakes, forests, protected areas… are often represented on a map as polygons.

If we now have another look at the small piece of the earth's surface that was represented in Figure 4, we will be able to group its objects into thematic layers and to translate them to types of features.



Thematic layers	**Feature type**
▪ land use	polygons
▪ settlements	points
▪ roads	lines
▪ marine environment	polygons
…	

Figure 5: Abstraction of the real world as layers and feature types

Extra info

> The feature type that is used to represent an object will depend largely on the **scale**. When the scale is large (such as on a topographic map) an object like a village will be represented by a polygon. However, the same village will be represented as a point feature on smaller scale (like on a country map). You will learn more on scale in chapter 3 'Working with maps'.

Storing spatial data

Now that we know how spatial data is represented in GIS, we can start with the collection and storage of spatial data. When working with features (you can also work with raster data, see info box below) spatial information is collected and stored as **coordinate pairs**. You will learn more on coordinates in the following chapters. For the moment you just need to know that the location of an object in a flat plane is determined by an **x-coordinate** and an **y-coordinate**, measured along an x-axis and y-axis (see Table 1). Points are always represented by one coordinate pair. Lines and polygons are represented by several coordinate pairs. When collecting coordinates, your information should be organised as in Table 1. One of the most important issues in data collection is the assignment of a **unique identification code** (name or number) or **ID** to every object for which information is collected. This makes it possible, for the data collector and other users, to identify every object in an unambiguous way. The same object always has to be represented by the same ID. Also when more information on the same object is collected later, or by other people, it should be given the same ID, so that the new information can be linked with the existing data.

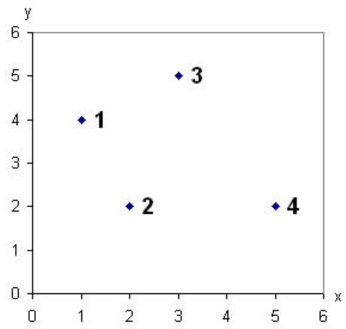
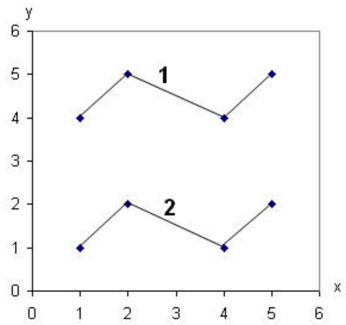
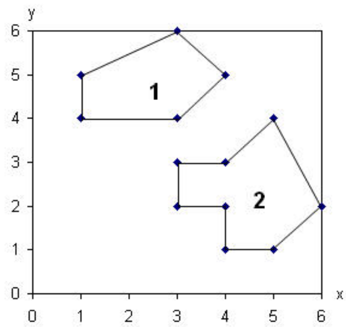
points	ID	x,y coordinates
	1 2 3 4	1,4 2,2 3,5 5,2
lines	**ID**	**x,y coordinates**
	1 2	1,4 2,5 4,4 5,5 1,1 2,2 4,1 5,2
polygons	**ID**	**x,y coordinates**
	1 2	1,4 1,5 3,6 4,5 3,4 3,2 3,3 4,3 5,4 6,2 5,1 4,1 4,2

Table 1: Representing the spatial information of features

Extra info

The model that makes use of features to represent spatial data is called the **vector model**. In fact in GIS there are two different models to represent locations: next to the vector model there is also the **raster model**. In this course we will only deal with the vector model. The difference between both models is illustrated in the figure below.

In the raster model (B) the real-world space is divided in **cells**. Positions are determined by the coordinates of the origin of the reference system, the height, width and number of each cell. Descriptive information is linked to the cells. Images and photographs are examples of raster data.

The vector model (C) makes use of geometric objects or **features** to indicate shape and location of objects (see higher). The position of the features is represented by one or more **coordinate pairs.** Descriptive information is linked to the features.

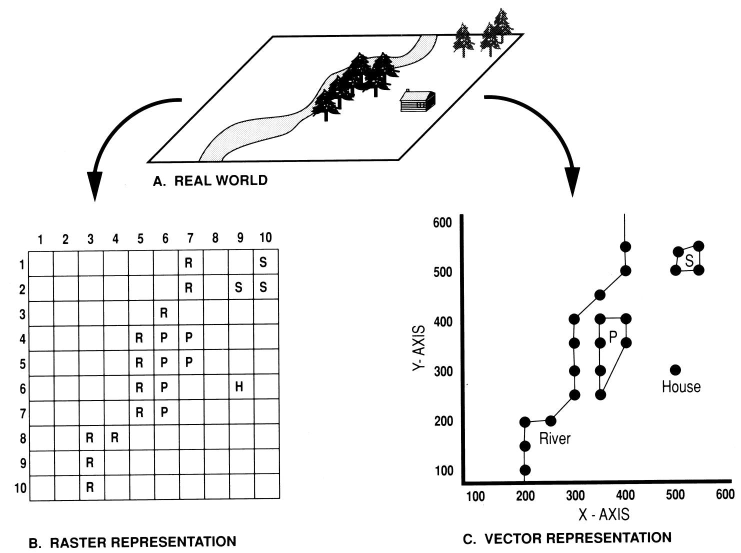


Figure 6: Representation of real world (A) as raster data (B) or vector data (C) (Source: SADL, 2002a)

Both vector and raster models have certain advantages and disadvantages. Therefore, depending on the problem in question, vector data sometimes needs to be restructured as raster data or vice versa. Below are some advantages (+) and disadvantages (-) of both models.

Vector model

- exact representation of reality in a continuous space formed by coordinates (+)
- end products come close to classical cartographic products (+)
- compact data structure (+)
- complex data structure (-)
- complex overlay of data layers (-)
- editing and updating is complex (-)

raster model

- simple data structure (+)
- simple overlay operations (+)
- efficient representation of high spatial variability (+)
- editing and updating is simple (+)
- accuracy depending on cell size results in potential loss of information (-)
- less compact data structure (-)
- graphical end products are less aesthetic (-)

1.2.2.2 Descriptive or attribute data

Storing attribute data

Whatever research you are doing, you will seldom restrict yourself to the collection of spatial data alone. You will certainly want to collect some other characteristics of the objects too.

When you are studying turtle breeding sites for example, you might collect the following characteristics or **attribute data**:

1. depth of the nest
2. number of eggs present
3. number of successful hatchings
4. turtle species

Descriptive information is stored in a **tabular** data file or **table**, as in Figure 7. A **record** represents all the information about one **case** of features (e.g. turtle nest no. 3), and one **field** or column stores one type of information (e.g. number of eggs) measured for all the cases of the feature.

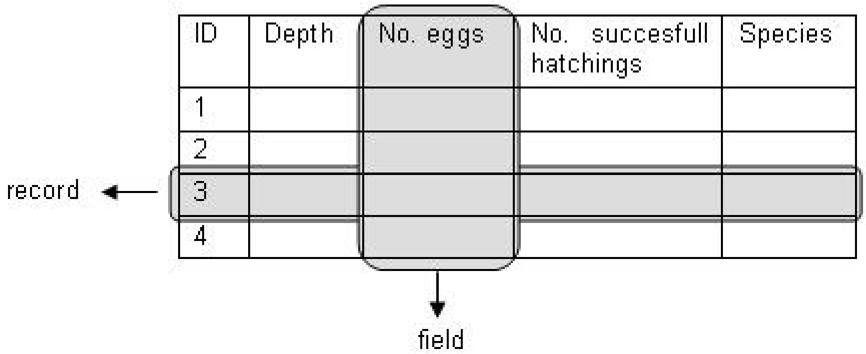


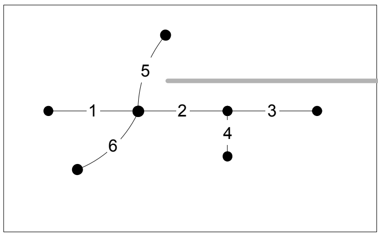
Figure 7: Attributes are stored in a table

When collecting attribute data, make sure you use, for every case, the same ID that has been used in the spatial database. In practice, you will mostly gather spatial and attribute data at the same time. However, there will be occasions when you already have a spatial dataset and you want to collect additional attribute data. Then you have to take care that, for every case, you use the **same ID** for the attribute data as was used in the spatial database.

1.2.2.3 Geo-relational model

In previous paragraphs we have seen that for every object spatial information (describing the shape and location) and attribute information (describing other characteristics) can be collected and stored. In GIS we can now **link** the descriptive and spatial data. The two types of information are linked using relational tables. This means that when two tables have a field (column) in common, both tables can be linked based on this common field. This linking is called the **geo-relational model** and is explained below.

In Figure 8 an overview of the geo-relational model is illustrated. In this figure we can see a small road map. The table next to the map holds the spatial information of all the roads. In this table the coordinate pairs that define every road are stored. Note that every object in this table has a unique ID, going from 1 to 6. In the table below some attribute information is stored for the same road features. To store the attribute data in the attribute table, the **same ID** for the road features is used as in the spatial data table. Because features are known by the same ID in both tables, for each feature in the spatial data table the corresponding record can be found in the attribute table. In that way, spatial and attribute data of the same feature can be linked. In the figure below this is illustrated for road feature no. 5. The path followed by the geo-relational model to link both tables is indicated by the grey line.



Spatial data table

Feature ID	X,Y pairs
1	1,3 4,3
2	4,3 7,3
3	7,3 10,3
4	7,1 7,3
5	4,3 ... 5,6
6	4,3 ... 2,1

Attribute table

Feature ID	Road type	surface	name
1	5	tarmac	R678
2	5	tarmac	R678
3	5	tarmac	R678
4	2	sand	-
5	1	gravel	-
6	1	gravel	-

Figure 8: Geo-relational model

This geo-relational model is one of the fundamental concepts of GIS. The understanding of this geo-relational model is thus of major importance for making good use of GIS software. When going through the next chapters keep this model in mind. The main added value of GIS systems over traditional database management systems is the availability of tools to work with attribute and spatial data of the same object simultaneously.

1.3 A GIS project

Now that you understand the model GIS is using to represent objects on the earth's surface and the basic concepts of GIS, we will give attention to how a GIS project is undertaken.

In a typical GIS project, five basic steps can be recognized:

1. determining the framework
2. getting the data
3. performing the analysis
4. presenting the data
5. definition of metadata

1.3.1 Determining the framework

Starting a GIS project is not an easy task. In the course of the process several decisions have to be made. In the beginning of the project decisions on budget, manpower, time frame, objectives and so on are under discussion. It is very important to take these decisions before the development of the GIS project is started, because they will influence the design of the GIS and the data that will go into it. In what follows we will discuss these issues in details.

The objectives

One of the most important steps is the definition of the objectives of a GIS project. What will the GIS be used for? Why is it needed? Which questions does it have to answer?

During the defining of the objectives the accuracy and precision of the information have to be determined. This implies the geographical extent of the data: is data required on a local or on a national level? Next, existing databases have to be taken into account. Maybe you will have to synchronize your datasets with existing national or regional datasets. Figure 9 illustrates which aspects have to be taken into account in developing a GIS project. Aspects are:

1. the tasks the GIS will have to perform,
2. the data that will go into it,
3. the users that will make use of the system.

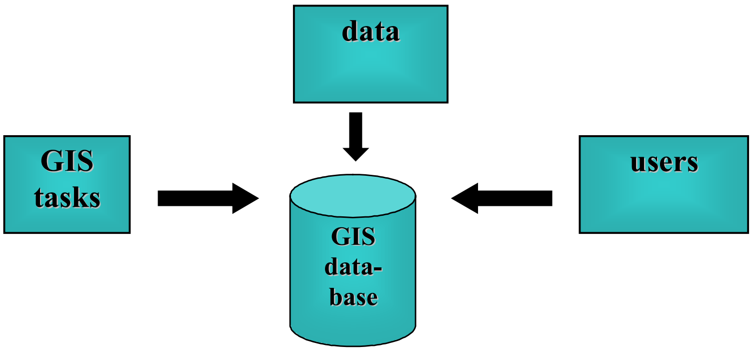


Figure 9: Factors that determine the scope and size of a GIS project

Defining the objectives is often an **iterative process**. Many new but even advanced users are not always able to estimate the potential of a GIS system or dataset from the beginning. Therefore it is better to define only general objectives in this stage. The tuning of the objectives towards the organization or other practical issues has to be done in a later phase. This means that everybody in a GIS project has to be aware of the fact that the objectives can shift. However, you have to stay honest to your objectives, budget, time frame and so on.

Time frame

Based on the objectives a time frame has to be worked out. The time needed to set up the GIS has to be taken into account. This is an iterative process with successive stages of launch and adjustments. Next, the elements of data collection can largely affect the time frame. Not all data can be collected throughout the year. A lot of relevant data can only be collected at a specific moment, for example in a specific season.

Manpower

After you have set the objectives and time frame, you have to estimate the amount of manpower you probably need to reach the objectives within the defined time frame.

Budget

A very important issue is the budget that is required for a GIS project. There are several components that have to be taken into account:

- **Hardware**: Although prices have decreased enormously over the last few years, to buy one or more computers is still a high cost. For basic GIS tasks a regular personal computer will do. For enterprise applications (projects where you have many users or a very high amount of data) one might need a central computer or a server.
- **Software**: Most of the GIS software packages are only available on a commercial basis and are very expensive. To reduce the price most companies sell their GIS products in packages. Every package has a number of functionalities that often corresponds to thematic fields. Most companies have free viewers. GRASS is the only mature GIS software that is available for free. It can be downloaded from the internet (at http://gras.itc.it).

- **Labour**: Developing a GIS project requires manpower. People have to go into the field. The computers have to be set up. Data entry takes time and mapping can be a laborious job.
- **Data**: Although you might collect some new data, you are usually not able to collect all data yourself. That means that you will have to buy existing data. Specialized companies are selling raw or processed data. The cost of data is often the largest cost in the development of a GIS project.
- **Maintenance**: The cost of maintenance is not always the largest component but definitely the most forgotten budget of all. Computers and software have to be renewed every few years. Data and information have to be updated. Furthermore you need to be able to buy supplies for equipment (ink cartridges, paper,…).

1.3.2 Getting the data

Once you have set the framework of your GIS project you have to start thinking of getting the right data. You can either buy existing data from certain companies or create your own data. A mixture of both is also possible.

1.3.2.1 Getting new data

Many GIS projects have a specific goal that requires customized data. Therefore new data often have to be collected. Usually a large part of GIS users will be involved with data collection.

New attribute data

As you have seen before, GIS holds both spatial and attribute data. The collection of new attribute data often is a major part of the GIS work. Mostly spatial information is collected only once, while attribute data has to be collected regularly, like every year.

When collecting attribute data, every attribute has to be defined properly. In order to store the information in an efficient way, the GIS needs to know what kind of information you are storing in each column of the database. You have to define:

- Attribute name
- Precision: number of decimal places (in case you work with real numbers)
- Data type. An overview of common data types is given in the table below.

Type	**Details**
Text	This can be a description of the quality of an object, like poor – moderate – good. When your data is described as text you will have to specify the number of text characters you want to store for every record. This needs a little thought in advance. The definition can not be updated afterwards. This means you should foresee enough characters for all possible text. On the other hand every empty space is also taking up disk space on your computer. This means you have to balance efficiency and flexibility.
Number	Different types of numbers can be stored. Also here you have to define the range of numbers you want to store. When the number type is ‘long integer’, the potential range of numbers is from -2,147,483,648 to 2,147,483,647.
Date	If you want to store a date, you have to specify this as the type of data.

Table 2: Data types

New spatial data Creating new spatial data is not always simple. Spatial data can be collected in two ways:

- Measuring new information in the field with Global Positioning System or **GPS** (see chapter 2).
- **Hardcopy maps** are still an important source of data for GIS. These maps are a synthesis of many surveys and data compiled into a single document. Converting analogue data, for example from a map, to digital data is called **digitising**. To digitise information from a map a digitising table is used. By means of a kind of mouse, analogue data is 'scanned' and brought into a computer.

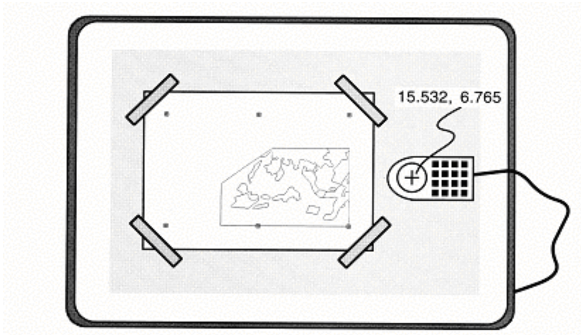


Figure 10: Digitising table

For the use of GPS we refer to chapter 2. The other digitising work is out of the scope of this introduction course.

1.3.2.2 Using existing data sources

All data that has a geographical component is suitable for use in GIS. Once they are in digital format they can be processed by means of GIS tools. Data always has to be projected in a reference or coordinate system (see later).

The main data sources are:

- **Aerial photographs** which are analysed in an analogue or digital way.
- **Land surveying**, in which is made use of analogue or digital equipment to measure distance, angle and altitude differences.
- **Field surveys** (soil, geology, vegetation…). These survey data can be inserted directly into a geographical database or they can be first synthesized into a thematic map and then inserted into GIS.
- **Satellite images** of the earth surface. These images contain digital data which mostly has to be structured properly and interpreted with specific software packages, before it can be used in GIS.
- **Digital positioning** based on GPS measurements.
- **Data campaigns** where attribute data is collected and afterwards linked with spatial objects. An example is a census.

1.3.3 Analyse the data

In the first part we have seen what types of questions GIS can answer. Here we will have a closer look on how GIS is implementing these questions. How do we ask the GIS these questions once our data is inserted? In the first paragraph we explain the difference between spatial and non-spatial analysis. The second part will explain what type of operations GIS can do to analyse data.

1.3.3.1 Spatial versus non-spatial analysis

We have explained that the contribution of GIS is that it can handle spatial data. Other programs, such as Excel, can also store spatial data. Why then aren't these programs GIS? What makes a certain software GIS? The difference with GIS is that it permits **spatial analysis** of the data. This term will become clear in the example below.

Non-spatial analysis

The table below is an example of a database on villages. As attribute data, it holds the name of a number of villages, together with some socio-economic data: number of households, number of fishermen and number of cashew farmers. Based on these data, a number of questions can be answered.

No.	Name	No. of households	No. of fishermen	No. of cashew farmers
1	Litembe	323	34	221
2	Msimbati	296	203	152
3	Madimba	453	137	196
4	Mngoji	434	313	234

Table 3: Village attribute information

The following questions can be asked:

"What is the average number of fishermen in the villages?"

or

"Are there more cashew farmers in those villages where there are less fishermen?"

These are **non-spatial** questions. They don't require any information on the villages' location to be answered.

Spatial analysis

However, questions like:

"How far is every village located from the ocean?"

or

"Is the distance of the villages to the sea related to the number of fishermen?"

are **spatial** questions. Such questions can only be answered if we have information about the location of the villages. Knowing the location of these villages will allow us to answer these questions in GIS and to locate the villages on a map.

The database below also holds the spatial information about the villages: their coordinates.

No.	Name	No. of households	No. of fishermen	No. of cashew farmers		Location	
						X-coord	Y-coord
1	Litembe	323	34	221		644317,8125	8846935
2	Msimbati	296	203	152	+	656278,4375	8855817
3	Madimba	453	137	196		642385,25	8849957
4	Mngoji	434	313	234		646191	8853045

Table 4: Village attribute information, including spatial information

On the map below, the villages can now be located.

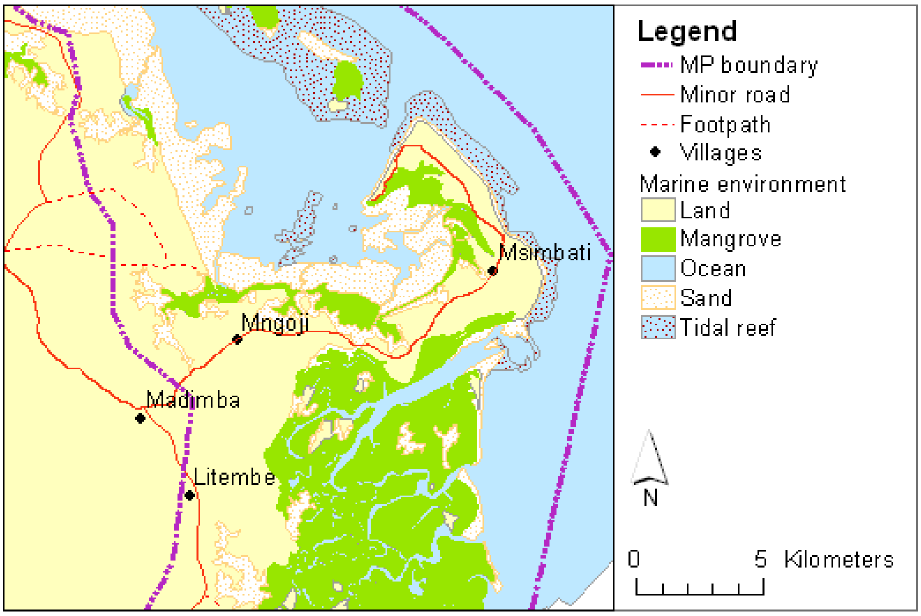
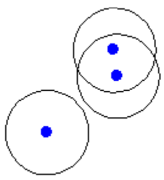


Figure 11: Map illustrating the position of the villages

1.3.3.2 GIS operations for spatial analysis

If you want the GIS to answer your questions, you will have to translate your question into a language the GIS can understand. You will have to reformulate your questions in terms of the basic **operations** GIS can do. Table 5 gives an overview of the most important operations.

Type of operation	Characteristics
Buffer	▪ Calculates a distance around objects ▪ Objects can be point, line or polygon  ▪ *Example: People are not allowed to build or farm within 100 metres of a well. To know these areas you can create a buffer of 100 metres around every well.*

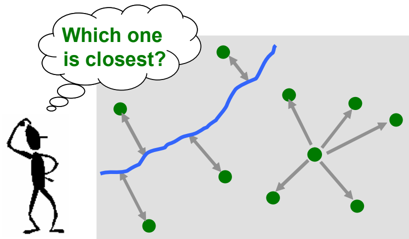
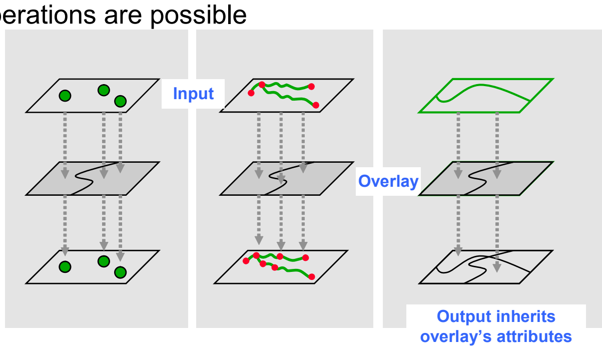
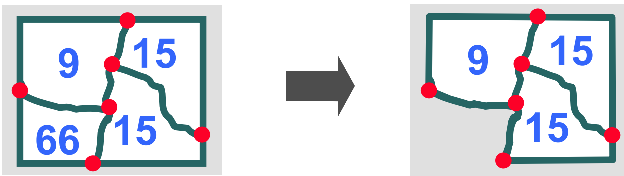
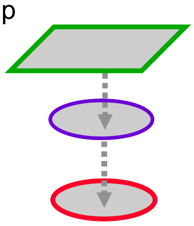
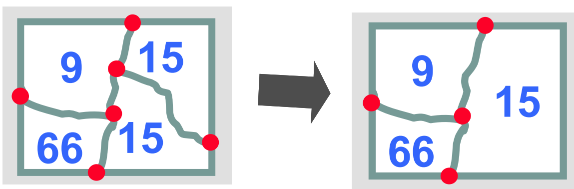
Nearest neighbour	▪ Based on distance calculations ▪ The distance to objects in the same or in different layers can be calculated  ▪ *Example: Which village is located the closest to the ocean?*
Overlay	▪ Data transfer from one layer to another based on location ▪ Point in polygon, line in polygon and polygon in polygon operations are possible  ▪ *Example: To define coastal zones for fishing and for conservation, you can make an overlay of fish density data with data on the condition of coral reefs in the same area.*
Spatial extraction	▪ Extract features  ▪ *Example: A polygon with a certain value is extracted from the data layer.* ▪ Clip  ▪ *Example: From your data on villages, you only want to see those that are located in the national park.* ▪ Dissolve  ▪ *Example: Two neighbouring polygons with the same value are joined.*

Table 5: GIS operations for spatial analysis (Source illustrations: SADL, 2002b)

Now you know which operations exist, you only need to be able to translate your questions into these operations. For simple questions and smaller datasets this is not really difficult. However, when you work with larger datasets (with a larger extent and more features) this can become quite complicated. It becomes even more difficult if you have to combine different operations and different feature types. However, translating questions into the right operation terms is the big clue in geographical analysis! **You have to understand these operations before you can fully use the power of GIS tools.**

1.3.4 Presenting the data

During or at the end of a GIS project, you will mostly want to present your analysed data in one way or another. In general there are three different ways of presenting data in GIS: as **maps**, **tables** and **charts**. GIS systems with extended cartographic functionality allow even the use of charts and tables on maps. Below data on a bathymetry survey is presented in three different ways.

The following map (Figure 12) gives a clear geographical overview of the location of the mangrove survey sites in the Mnazi Bay – Ruvuma Estuary Marine Park. Moreover, it shows the geographical distribution of the aesthetic value estimated at the different sites.

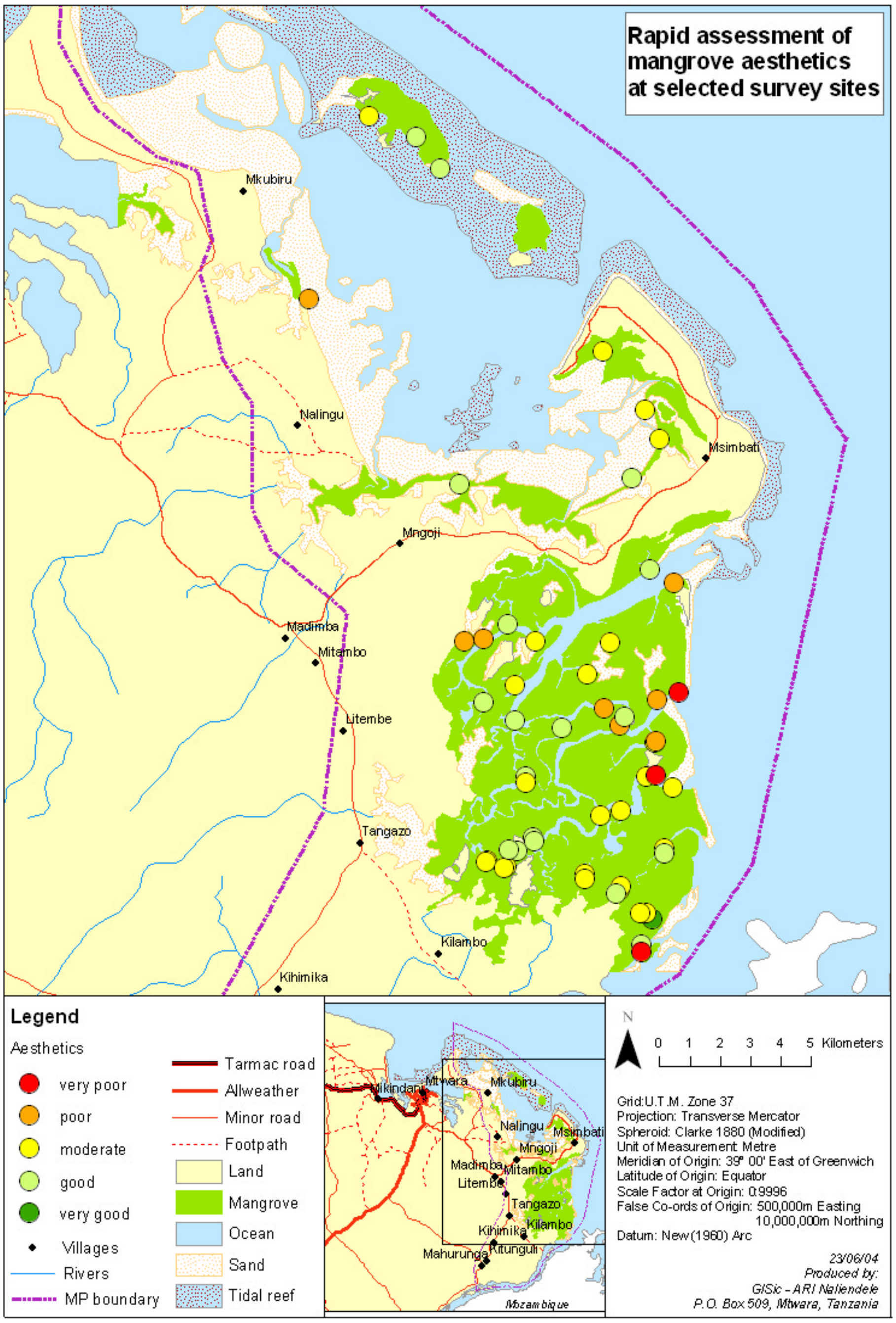


Figure 12: Map showing aesthetics (5-point scale) for a selected mangrove survey sites in Mnazi Bay – Ruvuma Estuary Marine Park (data collected by Greg Wagner)

A table doesn't give a clear view on the distribution, but can give an overview of all the parameters measured for the different sites.

ID	Name	Dn	Hg	S	Hl	Dg	St	A	E
33	Near Site L	3	3	2	4	0	0	4	0
34	Nakolachi	4	3	4	3	1	2	4	0
35	Site in southern branch of upper Nganje River	4	3	2	3	0	1	3	0
36	Nahake	3	3	3	3	1	2	3	0
37	Chui-village Mgoji	3	3	3	3	2	2	2	0
38	Mabomwe	4	4	2	4	0	0	4	0
39	Chui	4	2	2	2	0	0	2	0
40	Nahake	4	4	2	4	1	1	4	0
41	North side of Nganje River	4	4	1	4	1	1	4	0
42	South side of Nganje River	3	3	1	2	3	2	2	4

Table 6: Qualitative parameters measured for a number of mangrove survey sites in Mnazi Bay – Ruvuma Estuary Marine Park. Dn = Density; Hg = Height; S = Seedlings; Hl = Health; Dg = Degradation; A = Aesthetics; E = Erosion (Data collected by Greg Wagner)

A chart can illustrate relative values very well. Of the three presentation options, the chart below shows best the relative values of the parameters measured at different sites.

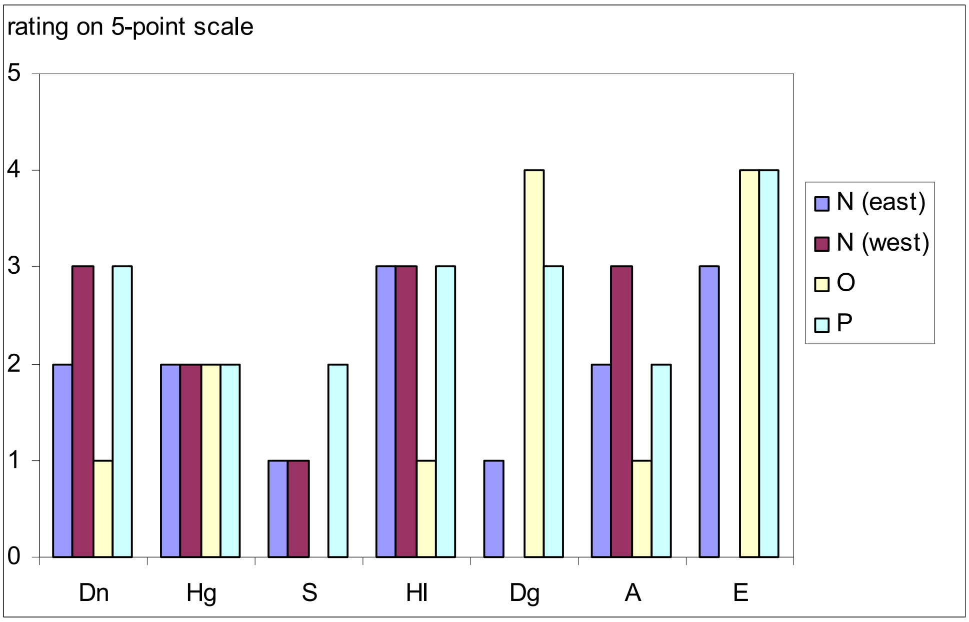


Figure 13: Rapid assessment of condition of mangroves at sites N (east side of river), N (west side of river), O and P along the lower Lugue River in Mnazi Bay – Ruvuma Estuary Marine Park. Dn = Density; Hg = Height; S = Seedlings; Hl = Health; Dg = Degradation; A = Aesthetics; E = Erosion (Data collected by Greg Wagner)

1.3.5 Metadata

One of the last steps in the GIS project is the definition of the **metadata**. Many people ignore this step, although it is one of the most crucial steps in the entire GIS project. We explain why:

Metadata is very simply defined as ‘data about data’. What is more difficult to answer is the question which data has to be collected about the data. Today a few standards about metadata exist and an ISO norm for geographical metadata will be developed soon. One of the main purposes of metadata is to inform other users, outside your organization or people that will come after you, about the data that is present in every layer. Furthermore, metadata allow setting up catalogues and search engines on data available in your organization.

Without going too much into detail, some elements of metadata are given in Table 7. This information should be provided for every data layer.

Topic	**Description**
Title	Give your data layer a proper title that already indicates the contents of your dataset.
Contents	Specify the contents of the data.
Time	Specify when the data was collected. When was the last update? If possible indicate until when the data is valid.
Quality	What is the quality of your data? How detailed was the survey and have you any idea on the accuracy of the data?
Scale	How was the data collected? On which scale?
Attributes	List all the attributes that come with your layer. For every attribute, give the data type and explain the different categories that are used.
Spatial extent	Explain the spatial extent the area is covering. Is it only a specific area or does it cover the region, the country?
Format	Any information a user has to know about the format of the data. This can indicate a software format, a database type… Specify also the location of your documents.

Table 7: Basic metadata elements

For now it is enough that you know that metadata exist and that you need to generate it whenever you create a new data layer.

1.4 Introduction to a GIS program: ArcGIS

You have now learned the most important principles in GIS. To become fully aware of the power and potential of GIS, a lot of practice is needed. After some time you will become better in translating questions into GIS operations. To work with GIS you need a GIS program or software. Below, the ArcGIS software package is described.

1.4.1 What is ArcGIS?

ArcGIS is one of the most popular GIS software tools on the market. It is the latest PC desktop GIS software from the Environmental Systems Research Institute (ESRI). ArcGIS is actually a group name for the different desktop products ESRI has on the market and it covers a wide range of packages.

First of all ArcGIS is scaled in terms of data management functions: it starts with simple packages that provide the basic functions up to more extended ones for more complex operations. The different packages within ArcGIS desktop are listed in Figure 14: these are ArcView, ArcEditor and ArcInfo.

Figure 14: ArcGIS desktop packages

The main difference between these three packages is their capacity to handle spatial data. The more extended packages, ArcEditor and even more so ArcInfo, can handle more types of spatial data and have more extended database management capacities. One of the big advantages of these three products is that they all have the same interface. This is explained below.

1.4.2 ArcGIS components

We already mentioned that all packages (ArcView, ArcEditor and ArcInfo) have the same interface. This means that all packages consist of three main components, a viewer, a file manager and a toolbox, each of which has specific tasks. The three components have the same menu, buttons and tool boxes in all packages. They are introduced in the following paragraphs.

1.4.2.1 ArcMap

The core component of ArcGIS desktop is **ArcMap**. This **viewer** is used for visualizing data, cartography and a broad array of analysis functions. In each ArcMap session you can load as many data layers as you want, but you can store only one single map.

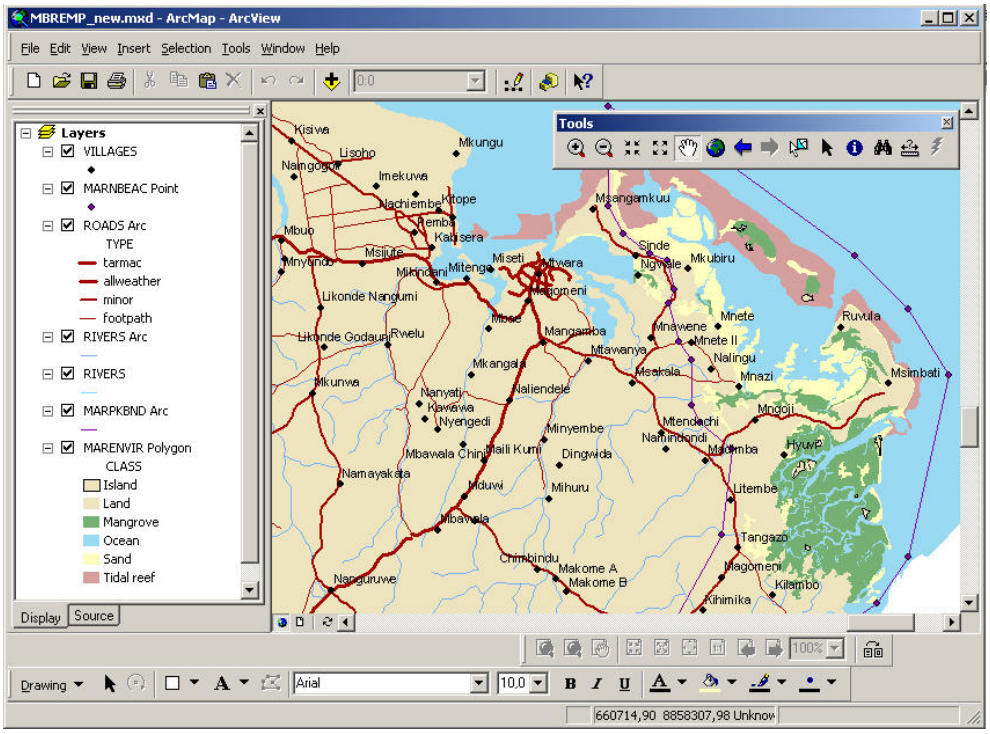


Figure 15: ArcMap component

Extra info

ESRI is also providing a free viewer, called ArcExplorer. This small software tool allows you to visualise and query data. The tool can be found at the following URL: http://www.esri.com/company/free.html.

1.4.2.2 ArcCatalog

In the **ArcCatalog** component, the user can **manage** all the files and databases that contain the spatial and attribute data. New datasets and updates of existing datasets have to be defined here.

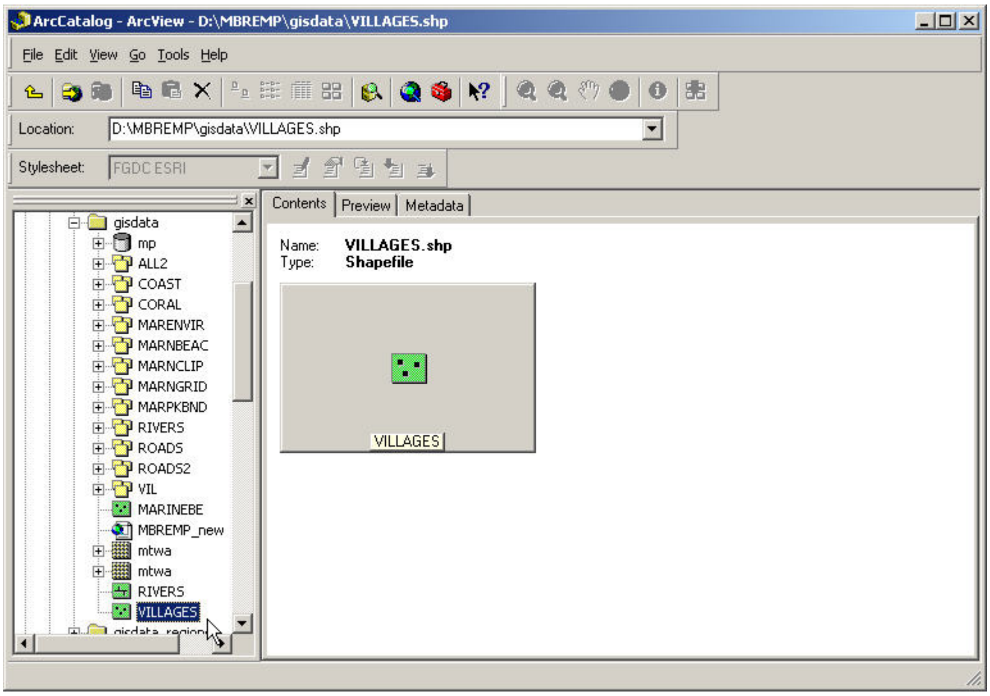


Figure 16: ArcCatalog component

1.4.2.3 ArcToolbox

As the viewer component takes up quite a lot of memory on the computer some users prefer to have access to **analysis tools** without visualizing the data itself. This can be done with the **ArcToolbox** component. It is a list of wizards that can be used to manipulate and analyse geographical data without actually visualizing it.

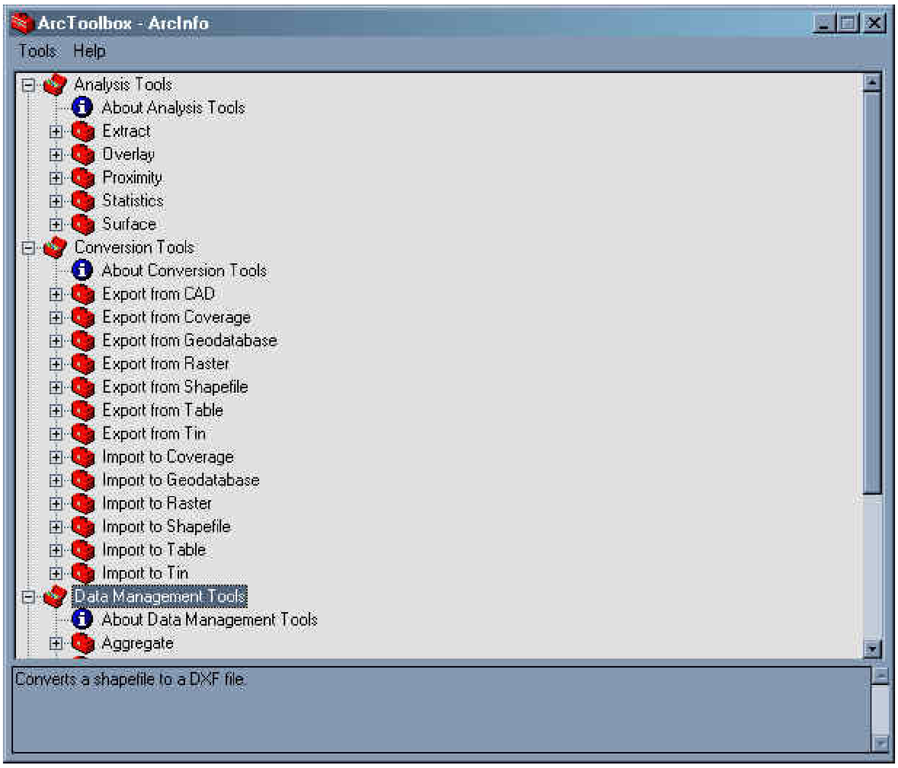


Figure 17: A list of wizards in the ArcToolbox component

Extra info

The analytical capacity of the three GIS packages (ArcView, ArcEditor and ArcInfo) can be still be extended with a number of ArcGIS extensions. A number of the available extensions are listed in the table below.

Extension	**Use**
Spatial analyst	ArcGIS Spatial Analyst adds a range of cell-based (raster) GIS operators to ArcGIS. The raster data structure provides the richest modelling environment and operators for spatial analysis.
3D analyst	3D Analyst is the three-dimensional (3D) visualization and analysis extension to ArcGIS.
Survey analyst	Geographic Information Systems (GIS) technology allows large amounts of thematic information to be stored for discrete features. There is often little information about the quality of the mapped locations of these features. ESRI Survey Analyst adds a set of measurement-based processing and analysis tools for improving the spatial accuracy of vector-based features and determining the spatial quality of feature locations.

Quiz

In this quiz you can test whether you have understood the basic concepts of this chapter correctly.

1. What are the components of GIS?
2. Which questions can GIS answer?
3. How is information about real-world objects represented in GIS?
4. What is the difference between spatial information and geographic information?
5. Which are the three types of features in GIS?
6. How can spatial and attribute data be linked in GIS?
7. Which components define the budget of a GIS project?
8. How can you collect new spatial data for your GIS?
9. What makes GIS different from a spreadsheet program like Excel?
10. What are metadata?
11. Describe the three components that make up the interface of each ArcGIS package.

2 DATA COLLECTION WITH GPS

As we have seen in the previous chapter, it is often necessary to collect new spatial data in the field when you are going to start a GIS project. GPS is a system that allows you to determine the location of objects on the earth's surface. This chapter explains what it is and how it has to be used to determine the spatial data of an object.

2.1 Introduction

2.1.1 What is GPS?

The **Global Positioning System** or **GPS** is a system to determine positions on earth. In that way, the **locations** of objects on the earth's surface can be determined. Locations can be determined for:

- fixed objects, like roads, forests, infrastructure, parcels, buildings, …
- moving objects, like migrating animals, boats, cars, …

GPS can also be used to determine the **speed** of a moving object, for example a car or a boat. Moreover, GPS is nowadays used a lot as a real-time **navigation** system in planes, boats and even cars.

Figure 18: Real-time navigation in cars

GPS was developed by the U.S. Department of Defence in the late 1970's and early 1980's as a worldwide navigation and positioning system for both military and civilian use. Much the same as sailors in the last century used the stars to navigate, GPS makes use of **satellites** as reference points.

The Global Positioning System consists of three **segments** (see Figure 19):

- **space**: 24 satellites orbiting the earth
- **control**: ground stations that accurately monitor the position and functioning of all satellites. The headquarters is located in Colorado Springs (U.S).
- **user**: the GPS receiver

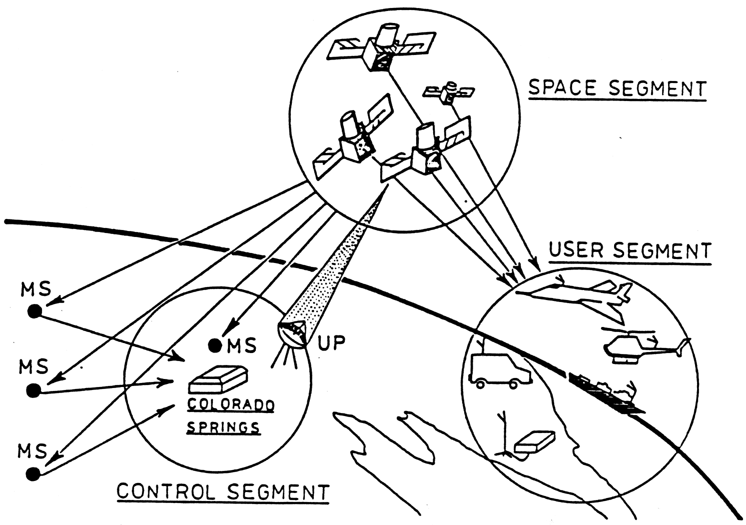


Figure 19: Segments of GPS (MS=Master Station) (Source: GfG, 2000)

2.1.2 Advantages of GPS?

It is everywhere

A constellation of 24 satellites orbit the earth every twelve hours. This should ensure that at least four satellites can be observed **continuously from any point** on earth. So, everywhere you go with a GPS receiver, you can determine your position.

It is precise

Because all satellites are constantly monitored and corrected from the ground stations, the system always works. Cheaper GPS units can measure a location within a few **metres** precision while more advanced units can measure precision to within a few **centimetres**.

Extra info

In the past an error was purposely inserted to the signal to allow the U.S. Defence department to disturb the positioning system when necessary. Therefore, two GPS receivers had to be used to determine exact positions. One receiver was kept at a fixed and known location, while the second receiver was taking measurements. Based on the information of the first receiver it was possible to correct the measurements of the second. This type of measurements is called **differential GPS**. For a few years now the error on the signal has been removed and locations can be measured very accurately with a single receiver.

It is free

Except for the purchase of your GPS receiver, the system is entirely **free** for everybody to use.

Most important of all, GPS makes it possible to collect customized spatial information as required. There is a lot of spatial information already available, but in many projects people still have to go out and collect coordinates of objects in the field. In that way, GPS has contributed tremendously to the collection of geographic data and the use of geographic analysis. It is an **important source of spatial data for GIS**.

2.2 How does it work?

If you have used a GPS receiver before, you will know that the use of a GPS is not difficult: you hold your GPS receiver close to the location you want to measure and after some seconds the coordinates of the location will appear on the screen. Later on in this course we will explain you more in detail how to measure coordinates as correctly as possible.

Although not essential to operate it, it is useful (and also interesting), however, to know how GPS works. This will be explained in this chapter. This part might be a little difficult to grasp at first, but when you read it again and try to imagine how it works, you will realise the basic principle is not so complex.

Basically, GPS determines a position on earth based on the measurement of its distance to a number of satellites. For the purpose of GPS, 24 satellites circle around the earth at an altitude of 20 000 km. These satellites transmit radio signals that can be measured on earth with a GPS receiver.

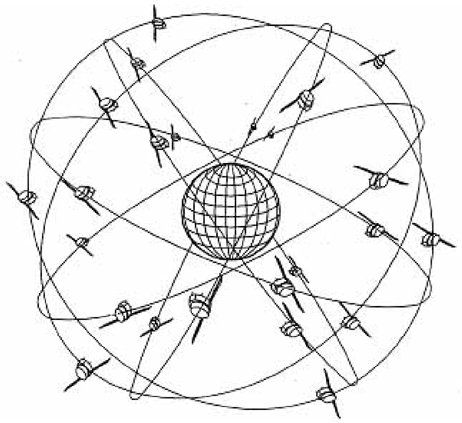


Figure 20: 24 satellites are circling around the earth (Source: GfG, 2000)

The basic principle of GPS measurement is very simple and is based on the following facts:

- with the signals of **three satellites** a position on earth can be determined,
- the travel time of signals transmitted from the satellites gives their **distance**,
- the **position of the satellites** is exactly known (act as reference points).

2.2.1 The three satellites

How can the satellites help us to determine our position? Imagine you are standing on a place on earth and you want to know your exact position. Assume that you know that satellite A is 17 600 km away from you. Next, draw in your imagination a sphere which has the satellite as the centre and a radius of 17 600 miles. If you are 17 600 km away from the satellite, then you must be standing on the perimeter of that sphere. However, that doesn’t tell you much about your position because your location can be anywhere on the perimeter of the imaginary sphere.

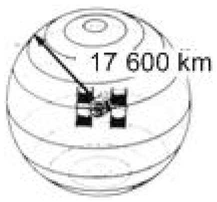


Figure 21: Imaginary sphere around satellite A (Source: Hurn, 1989)

Now there is a second satellite around, satellite B, which is 19 200 km apart from you. Now imagine a second sphere, with satellite B at its centre and a radius of 19 200 km and you standing on the perimeter. To fulfil the condition that you are 17 600 km away from satellite A and 19 200 km form satellite B, your position must be somewhere on the place where the perimeters of the spheres, made up by the two satellites, touch each other. Now you already know your position somewhat better: it is where the two spheres are overlapping.

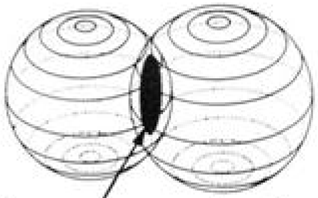


Figure 22: Imaginary spheres of satellites A and B and their overlapping plane (Source: Hurn, 1989)

When there is a third imaginary sphere, made up by a third satellite, satellite C, which is 20 800 km away, only two possibilities for your exact location remain: the two places where the three spheres overlap (see Figure 23).

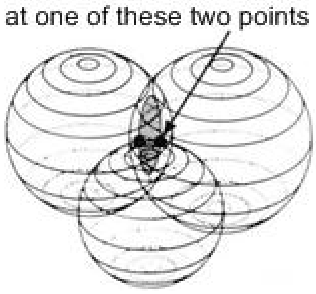


Figure 23: Only two positions are left if three spheres are overlapping (Source: Hurn, 1989)

Logically, when you know the distance to a fourth satellite, you could determine exactly which of the two locations your correct position is. However, this is mostly not done in reality. In practice, three satellites are sufficient to know which location is yours because one of the two potential positions you get with the three satellites is mostly very unlikely, for example a location far from earth. A GPS receiver has a program that allows it to recognize and filter out such unlikely locations. In that way, only one location remains: the exact one.

The basic principle of GPS is this simple and still remains the same. More advanced receivers will use more than three satellites, only to calculate positions even more accurately. It allows them to compare the qualities of the signals they receive from the satellites and to use only the clearest signals.

2.2.2 Measuring distance

The principle explained above is based on the distance between us and the satellite. When we know the distance between each of the three satellites and us, then we can determine our position. But how can we know the distance to these satellites? The answer is simple. We can measure the **distance** of a satellite by measuring the **speed of the signal** it transmits. This is based on the following well-known equation:

speed x time = distance

Figure 24 below illustrates this principle. Imagine a car driving at a speed of 80 km/hour for two hours. At this speed, after two hours the car will have travelled 160 km: 80 (speed) x 2 (time) = 160 (distance).

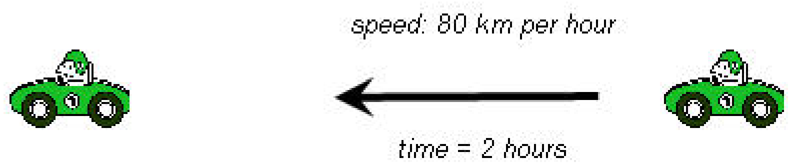


Figure 24: A car driving at 80 km an hour has travelled 160 km after 2 hours

Based on the same principle, the distance of satellites can be measured. All GPS satellites transmit radio signals to the earth. The GPS can measure how long a radio signal travelled from the satellite to the GPS receiver (time). Taking into account that the speed of radio signals is 300 000 kilometres per second (speed of light), the GPS can calculate the satellite's distance. So, when the travel time of the radio signal, travelling at the speed of light, is 0,067 seconds, it has travelled 20 100 kilometres. This is illustrated in Figure 25.

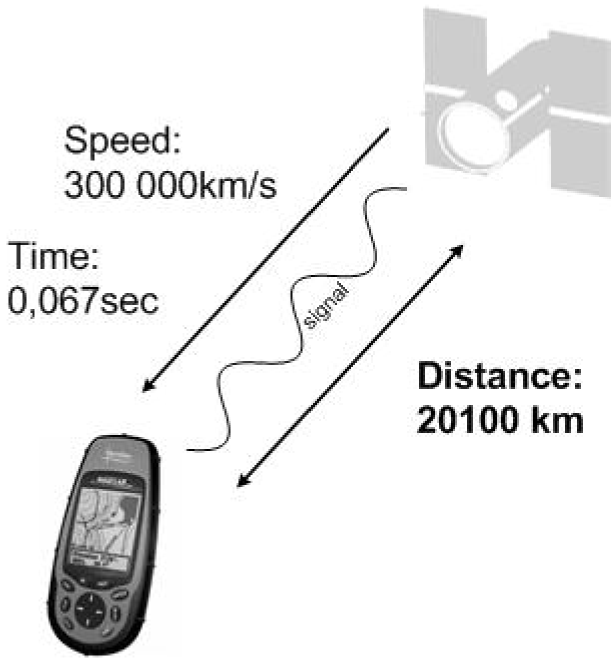


Figure 25: Distance is calculated from the travel time of the radio signal

Now the next question is: how can the GPS determine the travel time of a radio signal? The answer is again quite simple. When the GPS can determine exactly:

1. the moment when the satellite started transmitting, and
2. the moment when the GPS receives the signal,

it can calculate how long the signal has been on its way. For example, when the satellite started transmitting at 04:55:30 and the signal arrives at 04:55:30,067 then the signal has travelled 0,067 seconds from the satellite to the receiver. I you want to know how a GPS receiver can determine when a satellite started to transmit the signal, read the info box below.

Extra info

Radio signals travel very fast, so they arrive at the GPS receiver in just a short time after they were transmitted by the satellite (a few hundreds of a second). To measure such short periods exactly, very precise **atomic clocks** are needed.

Another problem is to know when the satellite starts transmitting the signal. To measure this, the satellite and the GPS receiver were so developed that they transmit the same **code** at the same time. The GPS receiver can calculate how long the signal was underway by determining the shift in code between the satellite and the receiver (the signal needs a short time to arrive at the receiver).

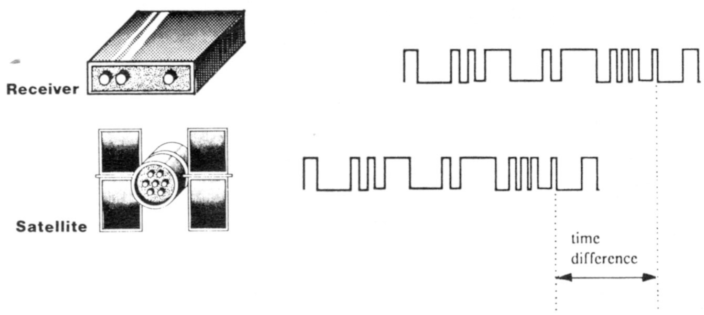


Figure 26: Code transmitted by satellite (source: Hurn, 1989)

2.2.3 Position of the satellites

To calculate our position we do not only have to know the distance to the satellites, but also their exact location. The exact location of each satellite is known from an 'almanac' and status report, both which the satellites also transmit as a signal. Their orbital position is constantly monitored by ground stations so that their instantaneous position is always known with great precision.

2.2.4 Sources of error

As ingenious and accurate as the system is, there are still a number of sources of error that are hard to eliminate. They are mostly related to the transportation of the radio signals through the different layers of the atmosphere. The most important error sources are:

1. the ionosphere (charged particles) and atmosphere (water vapour) of the earth slow down the radio signals,
2. "multi path error", when the signals transmitted from the satellites bounce around before they get to the receiver,
3. small deviations of atomic clocks.

These disturbances can partially be corrected. Differential GPS (see earlier) can be used to reduce the impact of these disturbances. This makes it much more accurate than ordinary GPS. Differential GPS is therefore used for land surveying and precision uses.

Extra info

How to choose a GPS receiver?

Over the last two years GPS has become affordable for many more people and projects than ever before. Several companies have brought GPS receivers on the market ranging in price from 200 to 500US$. These GPS receivers often have a limited number of functions and can measure locations with a precision of 3 to 5 meters. They are mostly tuned for navigation of smaller boats, off road driving and hiking and are also sufficient for most environmental monitoring.

These units can not be compared to the more advanced GPS receivers that are used by land surveyors. Those units can measure with a precision of up to a few centimetres. Their price ranges, however, between 3000 and 5000US$ or even more. The advantage with these advanced units is that they have a large memory and can automatically store coordinates with a certain frequency (seconds). Furthermore they allow you to preset the minimum required quality of the satellite signals.

2.3 Coordinates

Now you know how you can measure locations on the earth's surface by means of a GPS receiver. However, to compare locations with each other, and to communicate about them, a reference system is required. The reference system used to determine positions on earth makes use of **coordinates**.

2.3.1 The coordinate system

Just as we have kilos to express weight and metres to express length, we need a reference system to express locations.

Coordinates

Coordinates are used to represent locations on the earth's surface relative to other locations. A **coordinate system** provides a kind of network which is used to express these locations. In a flat plane, we use an x-y coordinate system to express where a point is. This system is also used for making statistical graphs.

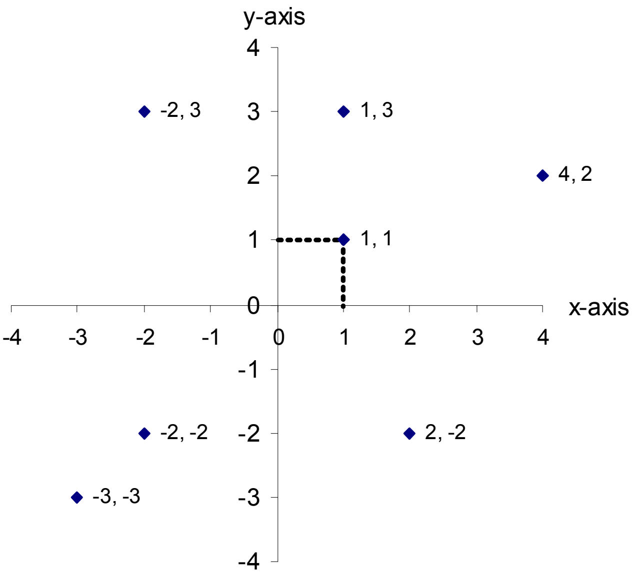


Figure 27: Example of the x-y coordinate system

In Figure 27, you can see that every point is assigned two values. The two numbers are called a **coordinate pair**. The first number was determined by drawing a straight line from the point towards the x-axis (parallel with the y-axis) and reading the value where it meets the x-axis (see point 1,1). The second number is derived by drawing a straight line towards the y-axis (parallel with the x-axis) and reading again the value it reaches on the y-axis.

Geographic coordinate system

To express locations on the earth's surface, a similar coordinate system has been developed. The coordinate system for the earth is formed by lines of **latitude** (comparable with x-axis) and lines of **longitude** (comparable with y-axis). The lines of latitude are parallel to the Equator, which is the line of zero latitude. The lines of longitude are parallel to the Prime meridian, which is in Greenwich, England. The system of all the lines together is called the graticular network.

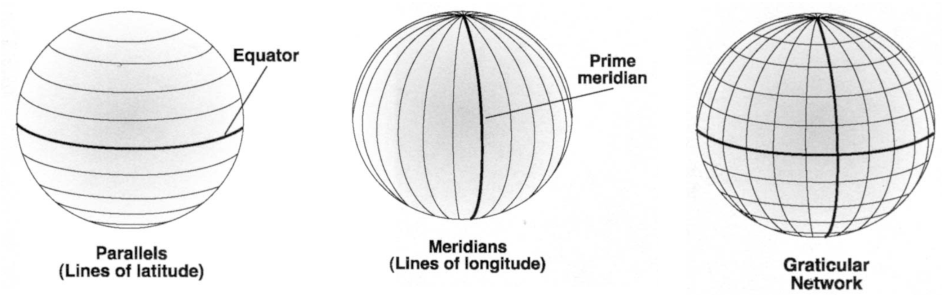


Figure 28: Parallels and Meridians form the graticular network (Source: Kennedy, Kopp, 2000)

A network system used to determine positions at the earth's surface is called a **Geographic Coordinate System (GCS)**. The longitude and latitude values of a point are called its coordinates. Because the earth is round (a sphere), locations on the earth's surface are measured in **degrees**. Latitude values range from -90° at the South Pole to +90° at the North Pole. Longitude values range from -180° when travelling west to +180° when travelling east. This geographic coordinate system based on latitude and longitude measurements is called the **Lat/Lon** Geographic Coordinate System.

Figure 29 illustrates how to determine the latitude and longitude values of a location. The place indicated in the figure is located in the northern hemisphere and east of the prime meridian of Greenwich and has the following coordinate pair:

- latitude: 55°N
- longitude: 60° E

(This point is located somewhere in Russia.)

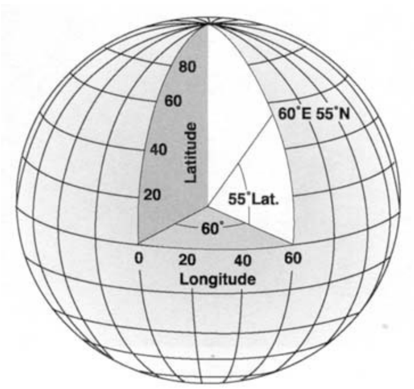


Figure 29: Example of a position on the earth's sphere (Source: Kennedy, Kopp, 2000)

Spheriod and datum

To establish a Geographic Coordinate System for the earth, geographers had to know its shape and size. There they were confronted with the problem that the earth is not exactly round. Actually the earth is flattened off at both poles. Geographers call the shape of the earth therefore a **spheroid**, rather than a sphere.

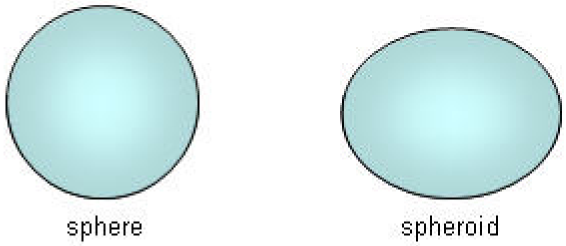


Figure 30: Difference between a sphere and spheroid

Geographers have estimated the earth's spheroid shape several times during the last two centuries. Of those estimations **WGS84** is the latest and most accurate. It is nowadays used as the global standard. Based on these estimations, different frames of reference are defined for measuring locations on the surface of the earth, these are called **datums**. For different places at the earth's surface different datums have been developed, so that in each area of the world locations can be determined in the most accurate way. In other words, datums are modifications of the spheroid calculations based on local circumstances, like mountain areas, depressions and so on.

Extra info

WGS84 stands for **World Geodetic System** (geodetic means earth like). It was calculated in **1984**.

Below some of the estimations of the earth **spheroid** are given.

Name	Date	Radius a (metres)	Radius b (metre)	Polar flattening
WGS84	1984	6378137	6356752,3	1/298.257
WGS72	1972	6378135	6356750,5	1/298.26
Clarke	1880	6378249,1	6356514,9	1/293.46
Everest	1830	6377276,3	6356075,4	1/300.8

Table 8: Some estimations for the earth's spheroid (adapted from Robinson et al., 1995)

2.3.2 Collecting coordinates with a GPS

Now that you are aware of all the theoretical concepts and principles of GPS, we will explain how you have to use your GPS receiver to measure the coordinates of a location correctly.

Step 1: the settings

When measuring coordinates of a location with a GPS receiver, a coordinate system and datum (and related spheroid) have to be set first. Most GPS receivers have the **Lat/Lon** coordinate system set as default. Next, the user has to select whether he/she will measure coordinates in **degrees, minutes and seconds** or in **decimal degrees**. By default, the datum is mostly the **WGS84** datum (which is immediately based on spheroid WGS84) but it depends on where you have bought your GPS. Wherever on earth you are measuring, these setting are always appropriate, since they are the latest and most universal estimations of the earth's shape. Other settings, such as the time, screen setting, the north reference and so on have to be set too. This is all described in your GPS receiver's manual. Normally these settings are set when the unit is used for the first time, but better check them if you start measuring yourself.

Extra info

When setting up the Geographic Coordinate System (GCS) the user is presented a choice of several possibilities. The advantage of the Lat/Lon GCS is that it is appropriate for the whole world and that data can be transferred to all other projection systems. Another option is to choose a GCS that takes into account a **map projection system (see chapter 3)**, for example UTM. When measuring coordinates in Kenya and Tanzania, **ARC 1960** has to be selected as datum. This is also the projection system used in the topographical maps. This has the advantage that GPS data can directly be overlaid with data from topographical maps.

Decimal degrees are computed using this formula: Decimal degrees = degrees + minutes/60 + seconds/3600. As an example: 73°59'15" longitude is equal to 73,9875 decimal degrees.

Step 2: holding the GPS, waiting for proper signal

Once you've adjusted or checked the settings, you are ready to measure coordinates. Remember a GPS receiver determines locations based on radio signals transmitted by the satellites. When measuring, care must be taken that there are a minimum of objects, like the roof of a car or a house, trees and so on, in between the receiver and the satellites. So hold out your GPS through the car window or go outside and look for an open space in the canopy. The GPS receiver should have an **unobstructed view to the sky**. If the view to the sky is poor, the GPS might still be able to determine a position, but it will take longer or the result will be less accurate. Before you start measuring, check the quality of the signal. The **signal strength** is indicated on the screen.

GPS receivers are designed to fit comfortably in the user's hand. They should be held in the palm of the hand with the antenna (or the top of the receiver) pointing towards the sky.

Figure 31: Hold the GPS in front of you while you are waiting for a proper signal

Step 3: measuring coordinates

When you have chosen an object or landscape element you want to determine the position of, stand on or next to it **as close as possible**. This means that you have to measure a relevant position for the object and avoid the insertion of additional measurement errors.

To measure the location of a turtle nest (= point location), stand close to it (not on it!) and not 2 metres away. When you are measuring the coordinates of a village (= point location), measure the position of the village centre. When you want to know the track of a river (= line), you will have to measure coordinates at regular distances or time intervals for the section you're interested in. If you want to know the size or the shape of a coral reef (= polygon), you will have to measure coordinates along the reef. The number of coordinates you have to measure depends on the accuracy you want to reach.

Step 4: recording and organizing coordinates and attribute data

When you have measured the coordinates for a certain point, you can **save** the data in the GPS, or **write** them down in a notebook. During saving, each point is given a unique ID. Also, when writing coordinates down, give every coordinate pair a unique ID (code) and make sure you know what the ID stands for.

Whatever the goal of your project or research is, you will almost certainly not be only interested in the location of the objects. When you are going to study breeding sites of turtles for example, you will also want to know how many eggs are present in the nest, how deep the nest is, whether it is guarded and so on. This non-spatial information is called **attribute data**.

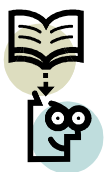
Below an example is given on how a fill-in form for a survey of turtle nests could be organized. The ID of the nests are composed of the first two letters of the site (here RU for Ruvula) followed by a number. In the second column the coordinate pairs of each nest are recorded. The following columns hold the attribute data.

ID	**Lat/Lon coordinates**		**Species**	**No. of eggs**	**Date of laying**	**Date expected hatching**	**Comments**
	x coord	**y coord**					
RU_1							
RU_2							
…							

Table 9: Survey form for turtle nests

remember this!!

- Check your settings: select **ARC 1960** as datum if you are measuring coordinates in Tanzania.
- Position yourself as close as possible to the object your measuring and measure relevant positions.
- Assure an unobstructed view to the sky (check the signal strength).
- Save your coordinates in the GPS or write them down. Remember to give each an unambiguous ID.
- Use a form to write down attribute data.



Quiz

In this quiz you can test whether you have understood the basic concepts of this chapter correctly.

1. What can a GPS be used for?
2. Why are three satellites needed to measure a location?
3. How can a GPS determine the distance of satellites?
4. Describe the Lat/Lon Geographic Coordinate System.
5. Which steps are taken when measuring coordinates with a GPS?

3 WORKING WITH MAPS

Although, in this GIS era, the analysis of geographic information means a lot more than just making maps, understanding how to make and read maps is still a very important skill. Most of the concepts that are important in cartography and map making are also used in GIS.

3.1 Cartography and maps

The use of geographic information, which describes locations and characteristics of objects, is becoming more and more computerized now, but it is not new.

The role of drawings

Already in prehistoric times people had to determine, remember and communicate locations, for example areas where game could be found for hunting. Also, to visualize and communicate information, ideas, plans and so on, prehistoric people made **drawings**. These drawings can be thought of as early versions of what we now know as maps.

Drawing was probably the first way of communicating information, even before the development of language. Drawings are especially good to capture spatial information. Locations, distances, shapes and so on, can often be expressed more easily in a drawing than by means of description. This is because people can interpret spatial structures and relationships more easily if they can see them.

Figure 32: A prehistoric drawing

Maps

A graphical representation of a spatial setting is called a **map** (Robinson et al., 1995). During the process of mapping the spatial characteristics of a larger area are reduced to make it observable. However, a map is more than a mere reduction. It is a carefully designed instrument for recording, calculating, displaying, analyzing and understanding the relationships that occur between things. Properties like distances, directions, patterns, networks, adjacency and so on, can be identified from a map. A map is therefore a very powerful tool for spatial analysis. For example:

- A city plan showing roads, junctions, important buildings, green areas, rivers and so on is a means for orientation and route planning.
- A regional map which shows landforms, soil types, vegetation, population, roads and so on is a tool for land planning.

Cartography

Cartography is the making and study of maps. The following definition expresses the essence of cartography.

Cartography is concerned with reducing the spatial characteristics of a large area and putting it in map form to make it observable.

However, cartography is more than making maps. There are four processes in cartography:

1. selecting and collecting the data for mapping,
2. manipulating and generalizing the data, designing and constructing the map,
3. reading or viewing the map,
4. interpreting the information.

The effectiveness of a map depends on the ability of the **map maker** to represent information clearly and on the skill of the **map user** to understand the map.

The role of GIS

Information technology has led to the rise of **digital mapping**. **Geographic Information Systems (GIS)** have completely changed the way of thinking about data collection and mapping. The conventional map is no longer the ultimate product of the cartographic process. More focus is now paid to the collection and management of geographic information in **databases**. These geographic databases allow for a tremendous increase in the **possibilities for analysis** of geographic information.

3.2 Basic characteristics of maps

As discussed in chapter 1 ‘Geographic Information Systems’, geographic information includes two types of information: **spatial information** about locations and **descriptive or attribute information**. These are also the types of information represented on each map:

- **Locations** are positions on the earth’s surface, like the position of mangrove survey points presented by the dots in the map below.
- **Attributes** are qualities or magnitudes, like the status of health in mangrove survey points.

On the map below (Figure 33) a number of mangrove survey sites are indicated. Each dot on the map represents the location of a survey site. The value of the attribute ‘health’ for every survey site is indicated in the legend.

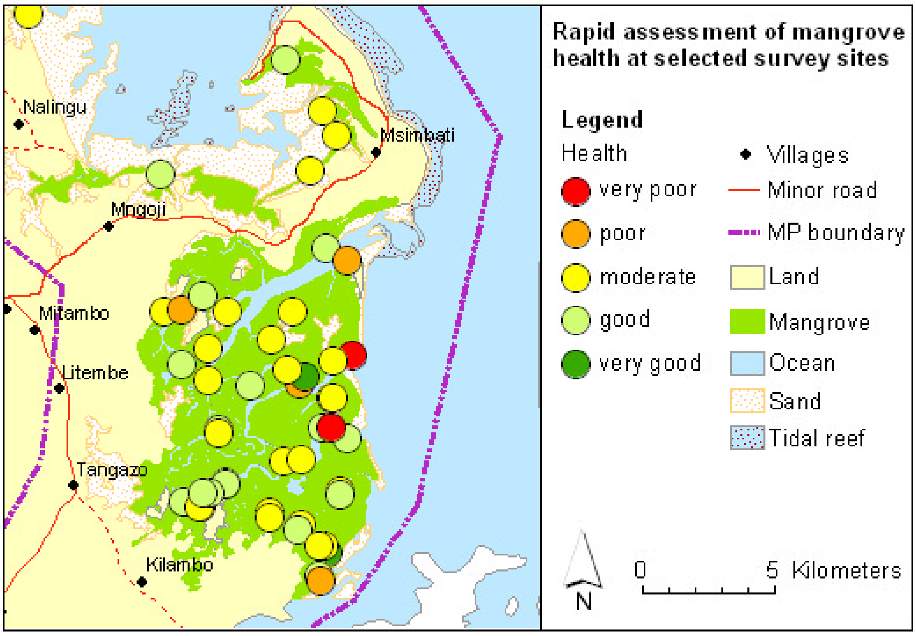


Figure 33: Map showing the location and the attribute 'health' for a number of mangrove survey sites (data collected by Greg Wagner)

All maps have some basic characteristics. To represent the three-dimensional reality of the earth's surface on a two-dimensional map, a transformation is needed, which is called a **map projection**. All maps are **reductions**: the map is smaller than the area it represents. The relationship between reality and the map is called the **scale**.

Maps are **abstractions** of reality: if all elements of the world would be represented the map would become too complicated. Therefore, only a **selection** of information is represented. **Symbols** are used to indicate elements of reality. Therefore various kinds of marks are used: colours, lines, dots, patterns, and so on. The meaning of the symbols is expressed in a **legend** or key.

The different components of the map are discussed in the following paragraphs.

3.2.1 The projection

As the earth is approximately round (or spheroid, to be more correct), the best way to represent it would be on a **globe**. In that way only the size is reduced, while other characteristics such as relative distances, angles and areas stay the same. However, globes are not very practical to handle.

Map projections

More practical is the presentation of the map on a flat surface, like a piece of paper. This is not easy however. Compare it with flattening the peel of an orange on a flat surface – it will rip. So, to represent the earth on a map the three-dimensional surface of the earth needs to be **transformed** or **projected** into a two-dimensional flat surface. The mathematical formula and related parameters that are used for such a transformation are called a **map projection**.

During the transformation from spherical to flat surface the geometric characteristics, like shape, area and distance, are modified. These modifications are called **distortions**. Different map projections cause different types of distortions. In general you can say that the distortions are bigger at the edges of the map.

Below two map projections of the world are given. The first one is the **Mercator** projection. This is a conformal projection, which means that the transformation preserve the local shapes. This projection was originally created to display accurate compass bearings for sea travel, for which it is still used. A drawback of this projection is that areas may be greatly distorted in the transformation process. When we look at Brazil and Alaska for example (indicated in light grey), they appear about the same size on the map. In reality, however, Brazil is five times larger than Alaska.

Figure 34: Mercator projection

The **Peters** projection, which is an equal area projection, preserves areas. With this projection, the areas of Alaska and Brazil are in the correct proportion. The area of the continents of South-America and Africa comes out much larger than with the Mercator projection. But while area is preserved, other properties like shape, angle and scale, are distorted.

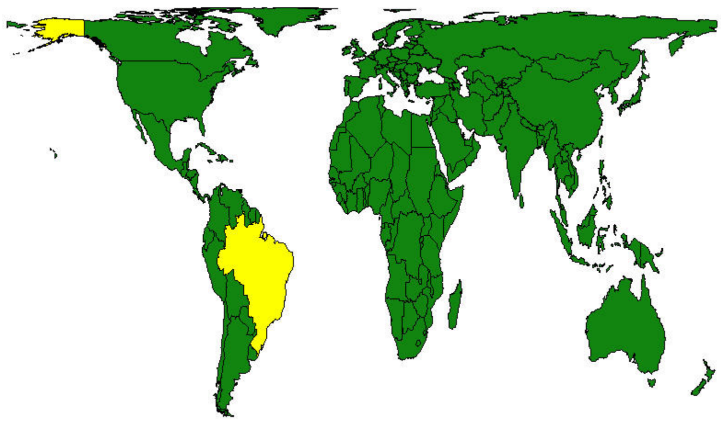


Figure 35: Peters projection

The **Universal Transverse Mercator** or **UTM** projection is an adapted version of the Mercator projection. Because the UTM projection preserves local shapes, it is the most appropriate system for large-scale mapping (smaller areas, with a lot of details). The projection system preserves local shapes because the transformation formulas are **adapted according to local zones**. This means that every area has its own local projection system with limited distortions.

Projected coordinate systems

In chapter 2 'Data collection with GPS' we have already described the reference system that is used to determine or describe locations on earth: the **Lat/Lon Geographical Coordinate System**. Also on a map a system of coordinates is used to describe locations of features. On maps, this is an x-y coordinate system. Because all maps are projections the coordinate system used on a map is called a **projected coordinate system**. For example, a map produced by means of a UTM projection will have a UTM coordinate system.

Figure 36 shows a part of a topographical map for the Mnazi Bay-Ruvuma Estuary Marine Park area. The details of the projection system are described at the bottom of the map (Figure 37). The projection system used to make this map is UTM zone 37 (East-Africa). The arrows on Figure 36 indicate how the location of a feature on a map can be determined. In this example, the coordinates of a lighthouse are determined. Along the edges of the map, the x- and y-coordinates of the projection system are indicated. To determine the x-coordinate, a line has to be drawn from the lighthouse towards the x-axis, parallel with the y-axis. This line reaches the x-axis at 635 800 metres. In the same way, the value of the y-coordinate can be determined at 8 871 600 metres. The coordinate pair of the lighthouse is therefore 635 800, 8 871 600.

Figure 36: How to determine coordinates on a map

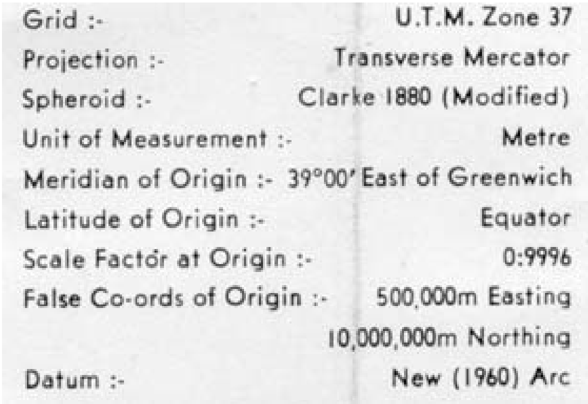


Figure 37: The details of the coordinate system are indicated on the map

3.2.2 Scale

To be useful, maps are necessarily smaller than the area they represent. Therefore the area of interest and its features have to be reduced in size when mapped. Every map must indicate the ratio between a map distance and the corresponding distance in reality. A distance of one centimetre on a map might represent a distance of one kilometre in reality. This ratio is called the map **scale**. The map's scale may be expressed in different ways. We describe the two most common ones.

Representative fraction

The scale can simply be indicated as a fraction, called the **representative fraction**. The distance on the map is always expressed as 'one'. It can then be shown as 1:100 000 or 1/100 000. This means that 1 millimetre on the map represents 100 000 millimetres (100 metres) on the earth's surface or 1 centimetre on the map corresponds to 100 000 centimetres (1 kilometre) in reality.

On older maps the ratio might be indicated with a **verbal statement**, like "one centimetre represents 1 kilometre".

Bar scale

The **graphic or bar scale** is a symbol, subdivided in units, for comparing how a distance on a map relates to a distance on the earth's surface. One end of the bar can be subdivided further to provide more precise estimation of distances.

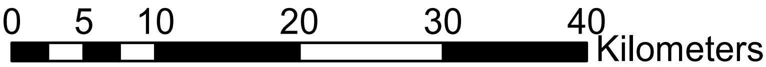


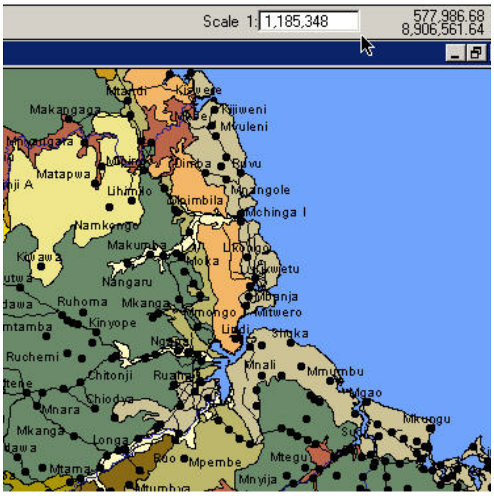
Figure 38: Example of a bar scale

Scale in GIS

On classical maps there was a relation between the scale of the map and the accuracy of the data. For example, when a map with scale 1/20 000 was to be produced, surveyors would only include elements that would visible on the map, which means not smaller than about half a millimetre. This means only elements of 10 meters or larger would be included in the survey. So a scale of 1/20 000 would mean an accuracy of 10 metres in reality.

However, when working with GIS, you will frequently zoom in and out on a map displayed on a screen. This means the scale is changing all the time. Although data are collected with a precision of 10 metres, you will be able to zoom in to a much larger scale, maybe up to a scale of 1/10 000 or even more. However, the accuracy of the data will not change: you will not see more details when you zoom in. This means that in GIS the scale will no longer give information about the precision of the survey. Therefore it is more and more important to indicate the survey methodology. An indication of the accuracy of information that was collected to draw the map is nowadays more important than an indication of the scale itself. Even in GIS, scale is still used, for example, to compare map distances with distances in reality.

Map zoomed in to scale 1/1,185,348



Same map zoomed in to scale 1/606,898

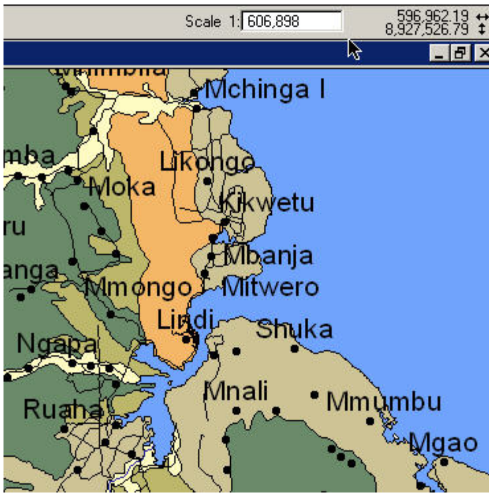


Figure 39: Zooming in and out maps in GIS

3.2.3 Other map elements

3.2.3.1 Legend

Since maps are a reduction of reality, different kinds of symbols have to be used to represent all kinds of elements from the real world. On a good map all the symbols that were used are explained, so that all users read the map in the same way. The area on the map where all the symbols are explained is called a **legend**. Symbols used for points, lines and areas are mostly grouped together.

3.2.3.2 North arrow

If you want to take a map in the field and try to recognize the objects drawn on the map it is always good to have a reference on how to position the map. For most maps this reference is the north. Maps are mostly drawn in such a way that the top of the map is north. However, there are exceptions to this rule. To make sure the user knows where the northern part of the map is, it is indicated with a north arrow.

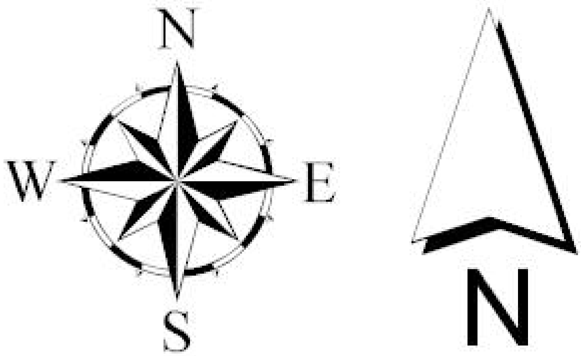


Figure 40: Examples of north arrows

3.2.3.3 Publisher and year

Besides all the graphical components on a map the reader of the map might also be interested to know who made the map, why it was made and when. This information is not really obliged but it can help people to locate the producers of the map and contact them if they want a reproduction of the map or if they want to make use of some of the data that is in the map.

3.2.4 Reading special symbols

3.2.4.1 Topography

A special kind of symbol represents the topography of an area. **Topography** is the configuration of the land's surface, simply called the relief. On topographic maps the relief is shown by means of graphic devices, like shading, altitude colours and contour lines. Of these types of graphic devices, **contour lines** are the most useful because they provide information on the elevation above sea level and the steepness of slopes.

In addition to the relief of the land's surface, on marine maps the depth below sea level of the coastal waters, or **bathymetry**, can be indicated. To indicate levels of the same depths, the same system of contour lines is used.

Contour lines

Contour lines are imaginary lines on the map, every point of which is at the same elevation above sea level. You can better understand the principle of contour lines when you imagine a small island illustrated in Figure 41. Above the island is shown; below it is a map showing the contour lines. The shoreline is the line of zero elevation because it is at sea level, so it is given the value 'zero'. Imagine that the sea level now rises exactly 10 metres. The water level now forms a new line that connects all points that are exactly at 10 metres above sea level. This water line represents the 10 metre contour line. It the water rises another 10 metres, it forms the 20 metres contour line, and so on.

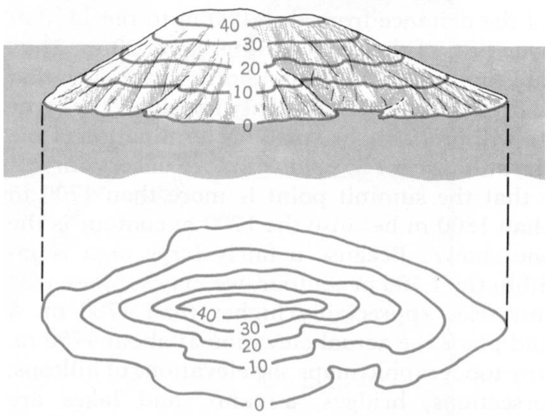


Figure 41: Island with mapped contour lines (Source: Strahler & Strahler, 1992)

Contour interval

The **contour interval** is the vertical distance separating successive contour lines. In the example above it is 10 metres. This means that on a map the distance between two successive contour lines represents a 10 metres height difference. This brings along a very important principle of topographic maps. Because the vertical distance between contour lines if fixed (here 10 metres) a close crowding of contour lines on a map represents a steeper slope. Contour lines that are widely spaced represent a gentle slope. This is clearly indicated on the figure below. From point A to point B on Figure 42, the slope is **steep**, represented by **close** contour lines on the map. If you walk from point C to point B, the slope is more **gentle**, resulting in more **widely** spaced contour lines.

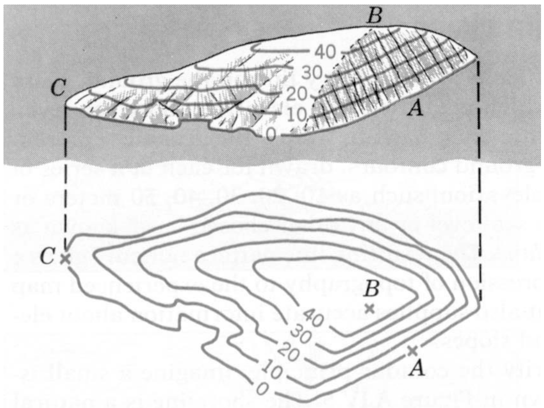


Figure 42: The closeness of contour lines gives information about the steepness of slopes (Source: Strahler & Strahler, 1992)

The selection of the contour interval depends on the relief of the land and the scale of the map. Topographic maps of areas with strong relief (mountains) might show intervals up to 100 metres or more.

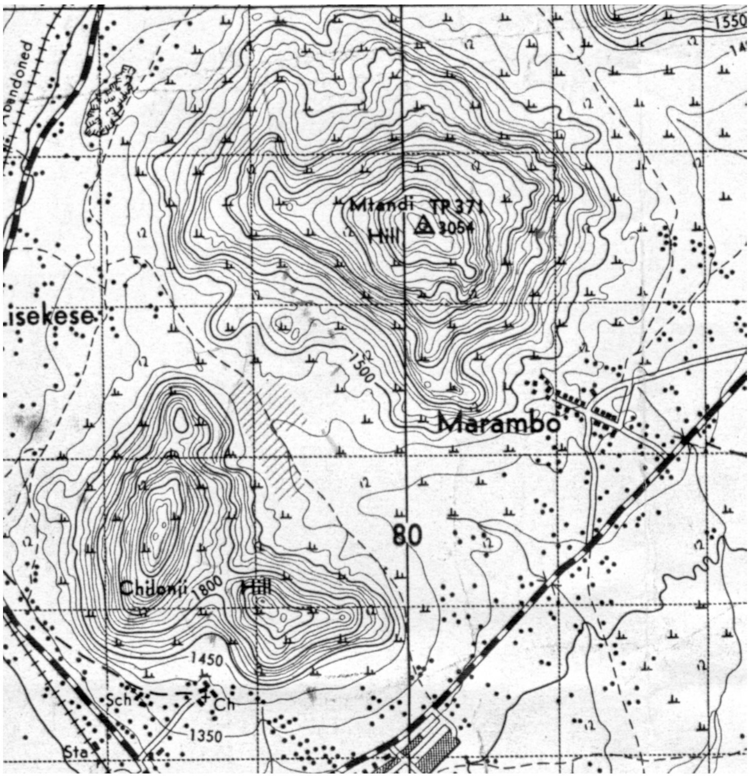


Figure 43: Close contour lines representing insel bergs close to Masasi

On the copy of the topographic map in Figure 43 close contour lines represent insel bergs. On this map the contour interval between successive contour lines is 50 metres.

Contour lines can also be used to indicate depth below sea level. In Figure 44 contour lines were calculated based on depth values digitized from an old chart for Mikindani Bay, Mtwara. The resulting map gives a clear picture of the depth profile of the bay, with the light colours showing shallow areas and dark colours representing deeper parts.

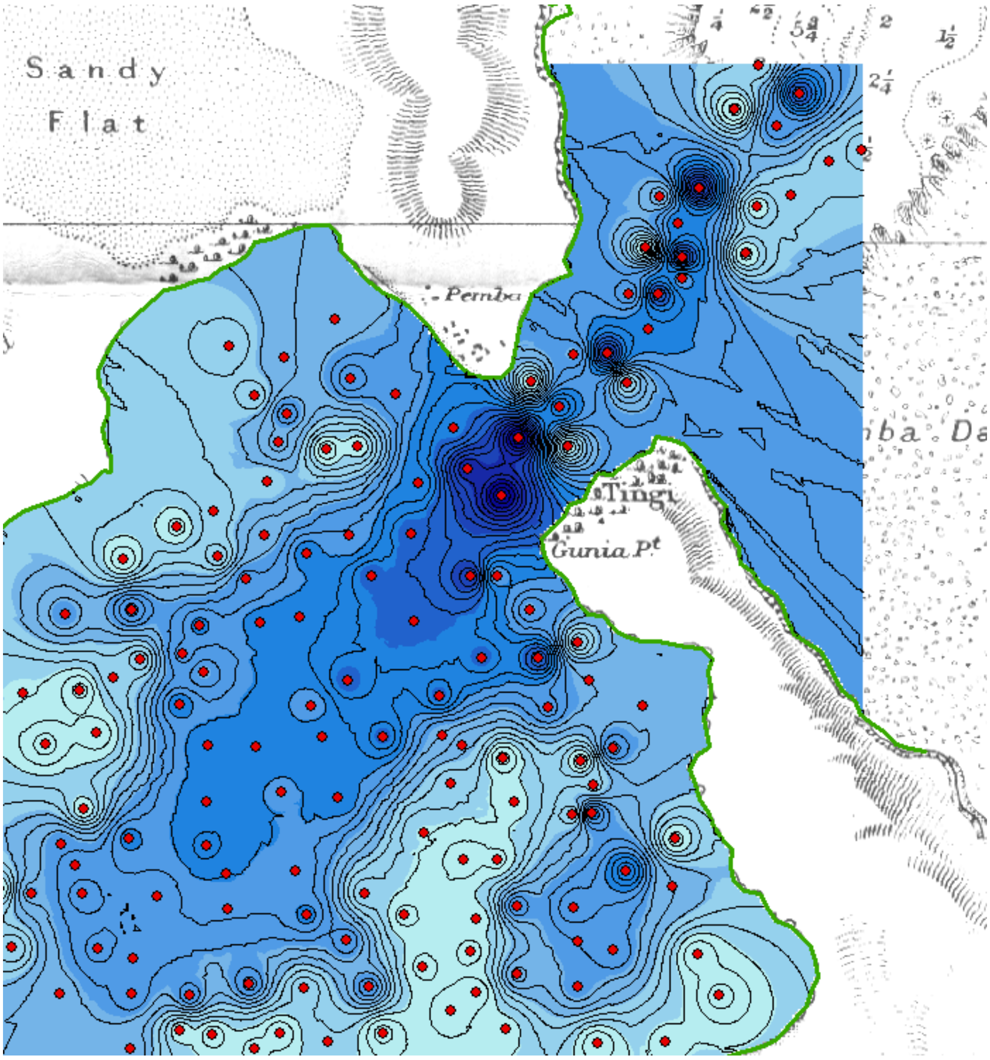


Figure 44: Contour lines connecting points of similar depth for Mikindani Bay

Determining elevations

Figure 45 illustrates how you can determine the elevation of a point by means of contour lines. Point B is easy to determine as it lies exactly on the 1300 metre contour line. Point C requires interpolation. Because it lies midway the 1100 and the 1200 contour line, its value is estimated at 1150 metre. Point D lies at one-fifth of the distance between the 1000 and the 1100 contour lines. We can estimate that the point has an approximate elevation of 1020 metre. Elevations of key points like hill tops are mostly printed on the map. This is illustrated by point A, situated at the hilltop at 1750 metres.

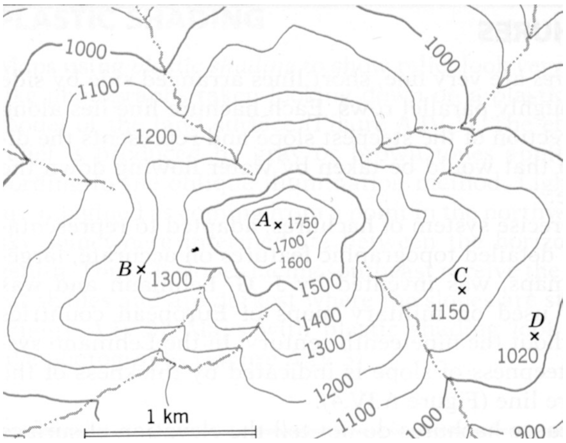


Figure 45: Determining the elevation (Source: Strahler & Strahler, 1992)

3.3 Categories of maps

Because scale, objectives and subject matter of maps differ widely, there is a huge variety of maps. Nevertheless they can be grouped together into some categories according to their characteristics. Maps can be classified by scale or by function.

3.3.1 Classified by scale

As mentioned earlier the scale of the map is the ratio between a distance on the map and the corresponding distance in the real world. Large areas, such as a continents or even the world, have to be greatly reduced to fit on map of limited size. Such maps are called **small-scale maps**. **Not much detail** can be shown on such a map. On a world map, just the countries and maybe the location of major cities can be represented (Figure 46). However, when the map shows a smaller area, like an individual city, many **more detail** can be given. A city map will show streets, buildings, rivers, and so on (Figure 47). These maps are called **large-scale maps**. Whether a map is small or large-scale is often relative. Cartographers agree that a map with a scale of 1 to 50 000 or less is large-scale; maps with ratios of 1 to 500 000 or more are considered as small-scale maps.

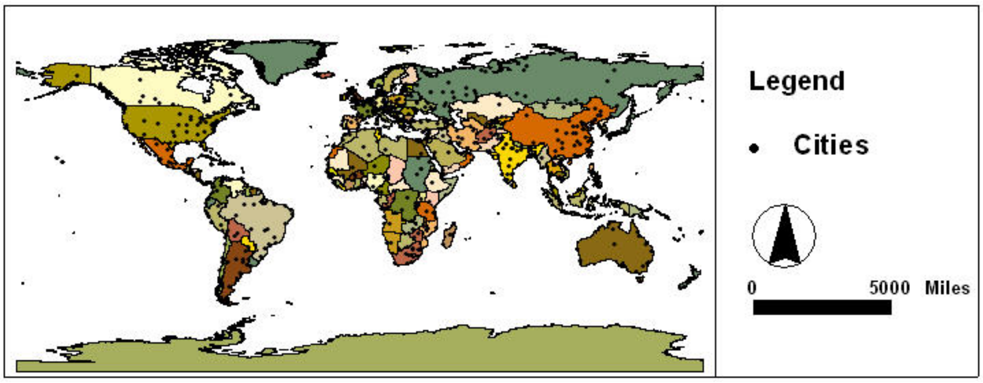


Figure 46: Small scale map of the world

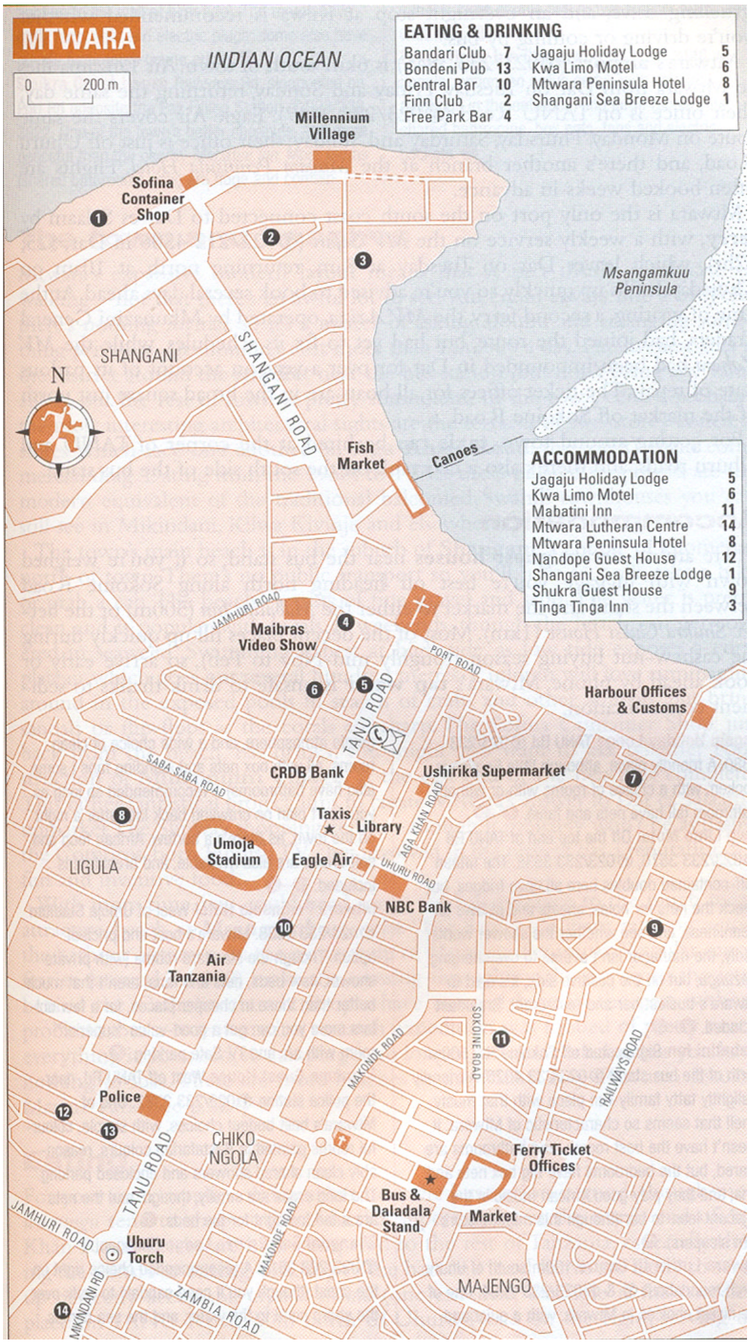


Figure 47: Large scale map of Mtwara town (from Rough Guide Tanzania)

3.3.2 Classified by function

When classified by function, three main categories of maps can be recognized: general reference map, thematic maps and charts.

3.3.2.1 General reference maps

When the objective of the map is to show the location of a variety of different features, this kind of map is called a **general reference map**. Examples of small-scale general reference maps are topographic maps. The town plan shown in Figure 47 is an example of a large-scale general reference map.

3.3.2.2 Thematic maps

Thematic or **special purpose maps** concentrate on the distribution of a single attribute. Examples are maps of precipitation, temperature, population, average annual income etc. When maps are classified according to their **subject matter**, there is no limit to the number of classes. Thus, there are soil maps, climatic maps, population maps, economic maps, pollution maps, transportation maps, oceanographic maps and many more.

3.3.2.3 Charts

Charts are maps that are not only meant to look at, but also to work with. This kind of map is frequently used in Participatory Rural Appraisal (PRA). Examples are sketches of villages made in cooperation with villagers on which comments can be added. Maps that are designed for navigational purposes are also called charts. On charts navigators write down comments, mark positions, work out routes and so on. Sailors make use of charts, but also aircraft pilots use them.

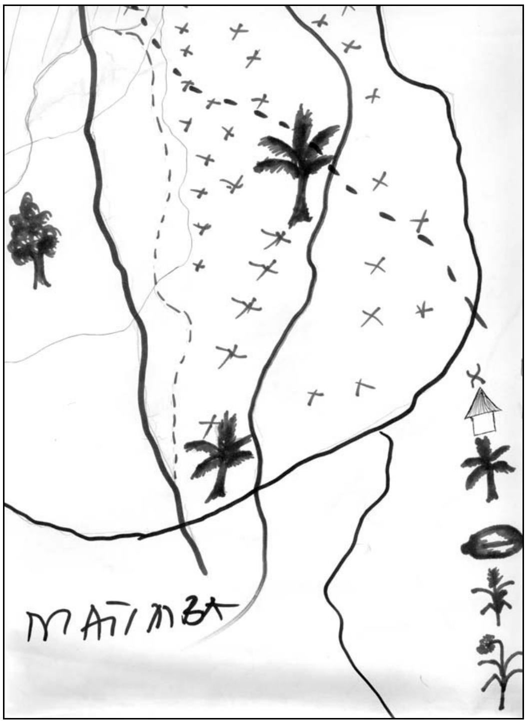


Figure 48: A PRA map is an example of a chart

Quiz

In this quiz you can now test whether you have understood the basic concepts of this chapter correctly.

1. How would you define a map?
2. Which elements can be found on a map?
3. What is a map projection? Could you give an example?
4. What is the scale of a map and how can it be represented?
5. What is a contour line?

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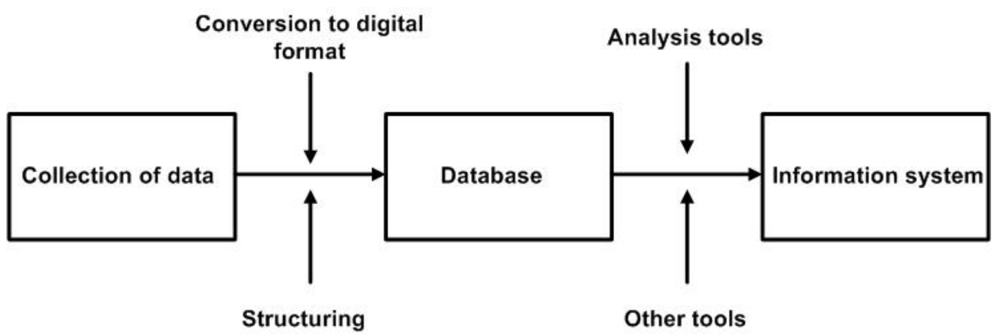
APPENDIX

Glossary

Analogue data	Non-computerized data, for example on paper or on a map.
Analysis	An operation that examines the data with the intent to extract or create new data that fulfil some required conditions.
Atomic clock	Clock based on vibrations of atoms to measure time.
Attribute	A characteristic of a map feature. GIS stores attributes in tables and links them to the corresponding features.
Attribute data	Tabular or textual data describing the characteristics of map features. Also called **descriptive** data.
Cartography	The art of studying and making maps.
Contour interval	The vertical distance separating successive contour lines.
Contour line	Imaginary line on a map, of which every point is at the same elevation above sea level.
Coordinates	Values used to express a location relative to other locations. They describe a location in terms of a distance from a fixed reference. X,Y coordinates describe a location on a flat surface.
Customized data	Data that is collected or produced according to the buyer's or owner's wishes.
Data	A collection of related facts arranged in a particular format and gathered for a particular purpose.
Database	A computerized collection of related data organized for efficient retrieval of information. A collection of data becomes a database after data have been structured and converted into digital format (see scheme below).



Datum	A frame of reference to measure locations at the earth's surface. A datum is a modification of the spheroid calculations based on the local circumstances.

Descriptive data	See attribute data.
Desktop GIS	A Geographical Information System for use on personal computers.
Digital data	Computerized data. Data represented as a series of bits.
Digitizing	The process of converting locations on a map to a series of coordinates stored in computer files (digital).
Feature	A shape and its associated location, used to represent a real-world object on a map.
General reference map	Map showing a variety of different features. The opposite of a thematic map.
Geographic Coordinate System	A network system used to determine positions at the earth's surface.
Geographic coordinates	Values used to describe locations on the earth's surface, expressed in degrees of latitude and longitude.
Geographic data	The composite of spatial and descriptive data. It holds the locations and descriptions of geographic features.
Geographic database	A database holding spatial data and related descriptive data.
Geography	Study of the earth's surface, physical features, climate, products, population etc. Also means the arrangement of the features of a place.
Geo-relational model	The model whereby spatial and attribute data is linked in GIS, making use of a common data field.
GIS	Geographic Information System. An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. Certain complex spatial operations are possible with GIS that would be very difficult, time consuming or impracticable otherwise.
GPS	Global Positioning System. A technology to determine positions at the earth's surface.
Hardware	Mechanical and electronic parts of a computer.
Information	Data and information are often used as synonyms, but actually information is the *meaning* of data as understood by a user.
Information system	When a number of *analysis tools* are added to the database, it becomes an information system (see scheme above). Functional information can now be retrieved from the data.
Interface	The buttons, windows etc. of a software that appear on your screen and by which you can communicate with the program.
ISO norm	A norm of the International Standardization Organization.
Iterative process	A process wherein certain actions or operations are repeated and hereby lead to improvement.
Large-scale map	A map showing a smaller area (small ratio). Many details can be given. E.g. a city map, a topographic map.

Lat/Lon GCS	A type of Geographic Coordinate System where a location at the earth's surface is expressed as latitude and longitude values.
Layer	A logical set of thematic data described and stored in a geographic database. Layers organize a database by subject matter (e.g. soils, roads, wells,…) and extend over the geographic area of the database.
Legend	A list of symbols appearing on a map. It includes a sample of each symbol and text describing what each symbol means.
Map	A graphic representation of an area, using shapes to represent objects and symbols to describe their nature.
Map projection	A mathematical formula that converts latitude-longitude locations on the earth's surface to x,y coordinates on a map's flat surface.
Map projection	The mathematical formula and related parameters that are used to transform the three-dimensional surface of the earth to a two-dimensional surface.
Metadata	Data about data, describing data type, content, format, accuracy, quality etc.
Parcel	Piece of land.
Pattern	Way in which something happens, moves, developed or is arranged.
Polygon	A polygon or area is a feature represented by a boundary enclosing a homogeneous area, e.g. a lake is represented by a polygon.
Raster model	A data structure to represent geographic information. The structure is composed of cells of equal size arranged in columns and rows. The value of each cell, or group of cells, represents the feature value. Attributes are associated with each cell. Commonly used to store image data.
Relational database	Database where the data, organized in table, can be related by a common field.
Relational tables	Data organized in tabular files that can be related by a common field. In that way, data from different tables can be recombined.
Satellite	Man-made device, e.g. a space station, put in orbit round a planet.
Scale	Ratio between a distance on a map and the distance in the real world.
Server	Usually larger computer, where central database is stored, and that is accessed by different users.
Small-scale map	The area represented on the map has largely been reduced (large ratio). Not much detail can be shown on the map. E.g. a world map, country map.
Software	Data, programmes etc. not forming part of a computer but used when operating it.
Spatial analysis	The study of the locations and shapes of geographic features and the relationships between them.

Spatial data	Information about locations and shapes of geographic features.
Spatial operations	The operations used in GIS to perform spatial analysis.
Spatial overlay	The process of superimposing layers of geographic data that occupy the same space in order to study the relationships between them.
Spheroid	The shape of the earth.
Table	Information organized in rows and columns. Each row relates to a single case; each column contains the values for a single characteristic.
Thematic	Related to a theme or attribute.
Thematic map	A map which concentrates on the distribution of a single attribute.
Topographic map	Map showing surface configuration or topography (relief) by means of contour lines or other graphic devices.
Topography	The configuration of the land's surface, also called relief.
UTM	Universal Transverse Mercator. A map projection which preserves local shapes because transformation formulas are adapted to local zones.
Vector model	A coordinate-based data structure to represent geographic information. Each feature is represented by one or more coordinate pairs. Attributes are associated with the feature
WGS84	World Geodetic System 1984. The latest and most accurate calculation of the spheroid shape of the earth.