

Understanding Plantation and Natural Forests A Handbook for Forestry Practitioners

 Vision Publishing Limited

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Editors:

J.M. Abdallah; J.Z. Katani; S.N. Augustino;
D.A. Woiso; R.C. Ishengoma

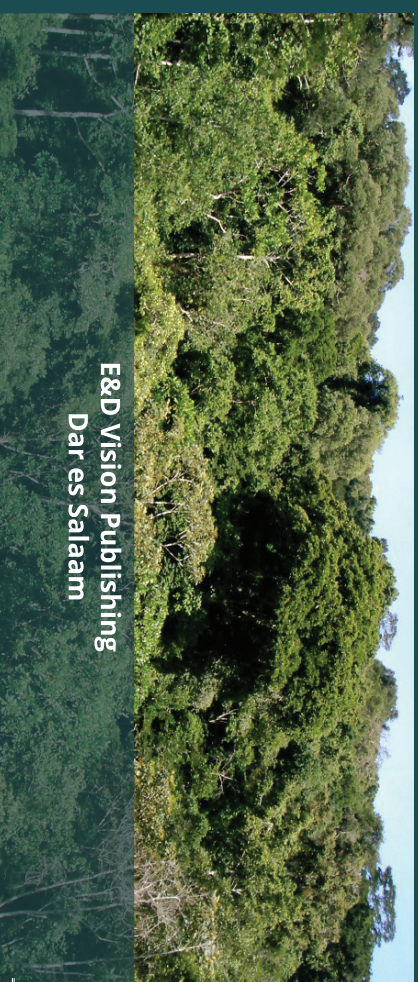
Understanding Plantation and Natural Forests: A Handbook for Forestry Practitioners is written purposely to support the forestry practitioners and other experts in the field of forestry in order to effectively implement their duties. It covers topics such as silviculture, botany, protection, utilization, forest resources assessments, harvesting and economies.

Areas of coverage organized in chapters include Introduction to forestry; Silvicultural practices in plantation and natural forests; tree morphology, taxonomy, physiology and ecology; Plantation and natural forests; Survey and resources inventory in the field of forestry; Harvesting techniques and utilization of forest and forest products and Economics of forest products utilization.

Generally the book is an important reference book about forestry and forestry practices in Tanzania. It can be used as reference materials in training, research and forest management practices in different locations throughout Tanzania and worldwide.

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Forest Resources Assessment

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Concepts

Forest Resources Assessment

Forest assessment aim to provide status, development, changes or progress of forests. This information is required for planning and decision-making. The assessment facilitates a multifaceted analysis and study of forests that infer economic, social and environmental roles of forests. The basic objectives of forests assessment are: to establish forest inventory (an accounting of trees and their related characteristics of interest over a well defined land area), monitor developments and assess overall progress. Information from forest resource assessment should be used for management planning of the forest, and where possible integrated into broader development plans and strategies at national and regional level. The basic approaches to forest resource assessment are complimentary; they include ground based survey techniques and remote sensing.

Surveying and Mapping

Surveying is the science (and art) of taking measurements to determine relative positions of point and/or object details above, on, or beneath Earth's surface and to present them in usable form, or to establish the position of points and/or details. In simple terms, surveying deals with

determination of the size and shape of a portion of the Earth's surface and its delineation into the horizontal plane in a map or plan. The map shows relative positions of physical features in horizontal or vertical plane. Surveying consists of: taking measurements in the field; and calculations, plotting, and drawing of maps. Surveying also includes levelling which is about comparison of heights of points on a surface located at different locations. Other basic terms used in chain surveying are:

- Survey station: is a point at the beginning and the end of a survey/chain line. It can also be at any convenient point on the survey line. Survey stations may be: main stations, subsidiary and tie stations.
- Main stations: these are control points; they are taken along the boundary of an area. Usually the main survey lines will cover the whole area under survey.
- Subsidiary stations: these are intermediate stations which are found on the main survey lines or any other survey lines. These stations are normally taken to run subsidiary lines when dividing an area into triangles, for the purpose of checking the accuracy of triangles formed and/or for locating interior details.
- Tie stations: these are stations taken on the main survey line. They originate from tie lines. Tie lines are mainly taken to fix the directions of adjacent sides of the chain survey map.
- Base line: it is a line on which the entire framework of survey depends on. It is the longest and most important line of the survey, measured accurately and carefully through a reasonably level ground. Its magnetic bearings are taken to fix the north line of the map.
- Check Line: this is the line joining the top of a triangle to a fixed point on the base of the triangle. It is measured to check the accuracy of triangle formed in the survey and locating interior details.
- Offset: side or lateral measurement taken from an object to the survey line. They usually locate objects with reference to the survey line. During offsetting one has to note whether it is on the left or right of a survey line. An offset could be perpendicular or oblique. Perpendicular offsets are lateral measurements taken perpendicular (right angle) to the survey line. Oblique offsets are lateral measurements which are not perpendicular (not at right angle) to the survey line.

Survey Applications and Principles

Surveying can be used for various applications including:

- Topographical map showing various features e.g. hills, valleys, rivers, villages, towns and forests;
- Vegetation maps showing various vegetation types such as woodlands, forests, bushlands, grasslands;
- Cadastral map showing the boundaries of fields, plot/houses, land parcel and other properties;
- Engineering map showing details of various works such as roads, railways, reservoirs and irrigation canals;
- Military map to show various strategic infrastructure of the country for purpose of defence including bridges, railway communications, electrical installations and transport; and
- Geological map showing areas where various mineral resources exist.

During surveying, one has to observe the following fundamental principles:

- To work from the whole to the parts. The whole area is enclosed by main stations and survey lines, the area should then be divided into a number of small triangles (well-conditioned); and
- To locate a new station by at least two measurements (linear or angular) from fixed reference points. When fixing any survey station one has to make sure at least two measurements are taken as a means of counterchecking errors that might have occurred during measurement.

Classification of Surveying

Surveying is divided into two major categories, namely, plane and geodetic surveying. These categories differ mainly in the assumptions on which the computations are based.

- *Plane surveying*: This category considers an area under surveying as a plane. It is applicable for small areas by assuming that the error from the curvature of the Earth is insignificant. Computations in plane surveying are made using trigonometry principles, algebra and geometry.
- *Geodetic surveying*: It considers the curvature (the shape and size) of the Earth. This type of surveying is suited for large areas and long

distances (e.g. surveying the whole country or continent or sub-continent) and is used to find the precise location of basic points needed for establishing control for other surveys.

Surveying can also be classified based on other criteria such as nature of the field of survey, purpose, instrumentation and approaches as follow:

- *According to nature of the field of survey:* land surveys for lands, hydrographic, marine or navigational surveys for large water bodies and astronomical surveys for positioning movements of celestial bodies;
- *According to the purpose for which the survey is conducted:* control, topographic, engineering, geological, mining and cadastral surveys;
- *According to instrumentation:* chain, compass, plane table, levelling, aerial, photographic, theodolite; and
- *According to approaches used:* traverse, triangulation.

Surveying Equipments

The common tools used during surveying are chain or tape, ranging pole, measuring rod, plumb bob, spirit level, compass, arrows and pegs. The functions of the tools are:

- *Chain and Tape:* They are used in measuring distances; they are made of different types of materials. The chain is made of steel; usually with connected segments of steel with a total length of 20 m including the two end of the handle. The measuring tape is made of steel, linen or synthetic fibre materials. It ranges from 20 m to 100 m depending on the needs. It is normally graduated on small units of millimetres or centimeters;
- *Ranging pole:* The ranging pole is a straight rod (sometimes jointed) made of either wooden, plastic or steel material which is 2 to 4 cm thick and 2 m long used in marking areas and/or setting out a straight line during surveying. It is usually painted with alternate red and white or black and white bands to increase visibility. They can be made locally (home-made) using bamboo or tree branches that are straight;
- *Plumb Bob:* Is used to check whether the object is vertical. It consists of a piece of metal typically bronze or copper like material which is

called bob attached to a string. A plumb bob will always be pointing downwards when is hanging free;

- *Arrows*: Are steel pins used for marking measurements points on the ground. It is a set of 10 pieces each of 35cm long;
- *Pegs*: Are wooden pieces usually locally collected and used when permanent marking is required. They vary in size (40-60cm long) depending on the type of soils and survey work. The pegs are normally vertically driven into the soil and the top has to be clearly visible;
- *Spirit level*: Is used in checking whether objects are vertical or horizontal. The instrument is made of metal rugged curved glass tube which is partially filled with liquid (alcohol or paraffin) with air bubble which determines whether the object is level. An object will be considered levelled when the bubble is just on the middle;
- *Measuring rod*: A straight board with length ranging from 2 to 5m. It is usually graduated and marked the same way as the measuring tape in centimetres, decimetres and metres; and
- *Other advanced instruments*: These instruments measure distances by means of radio or light waves. Possible to measure distances from a maximum of 1km up to 100km with high degree of accuracy. The instruments are expensive, so a considerable amount of survey work is required before investment in such instrument should be considered. The use of GPS (Global Positioning System) also is common now days where satellite signals are used to compute position.

Usually, two basic measurements are taken during surveying i.e. distance and angle measurements.

Distance Measurements

In surveying, there are several ways of measuring distances i.e. pacing, taping, tacheometry and electronic. The distance is the horizontal length between two points. If the points are at different elevations, then the distance is the horizontal length between perpendicular lines at the points. When conducting surveying, especially during distance measurement it is important to ranging out the survey by marking out any physical features in the survey line. Before measuring distances it is important to ranging out so that no detail is left out.

Ranging Out

A straight line is the shortest distance between two points on a survey line (Figure 5.1). Before measuring distance, ranging out is done by erecting two ranging poles at each end of the line (Figure 5.2). When carrying out surveying, measure straight horizontal lines between points.

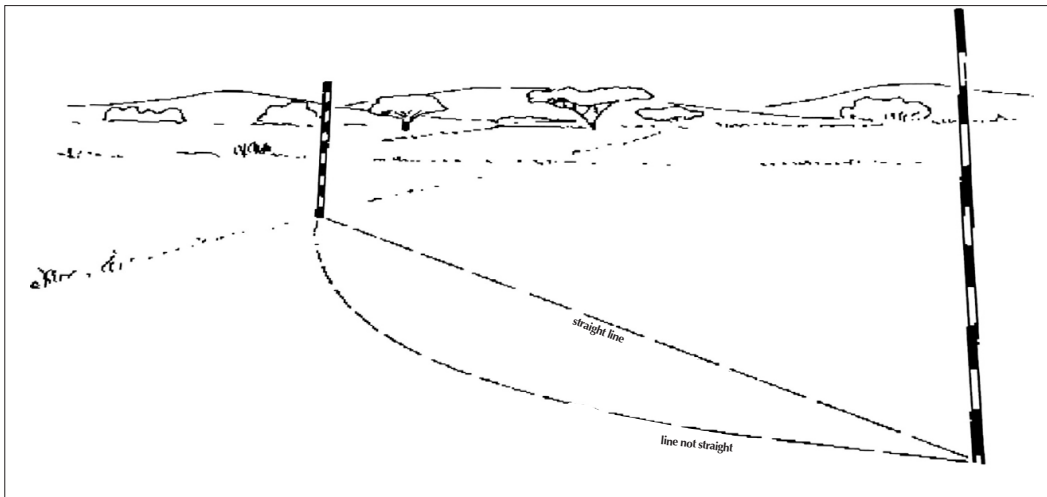


Figure 5.1. A straight line
Source: FAO (1985)

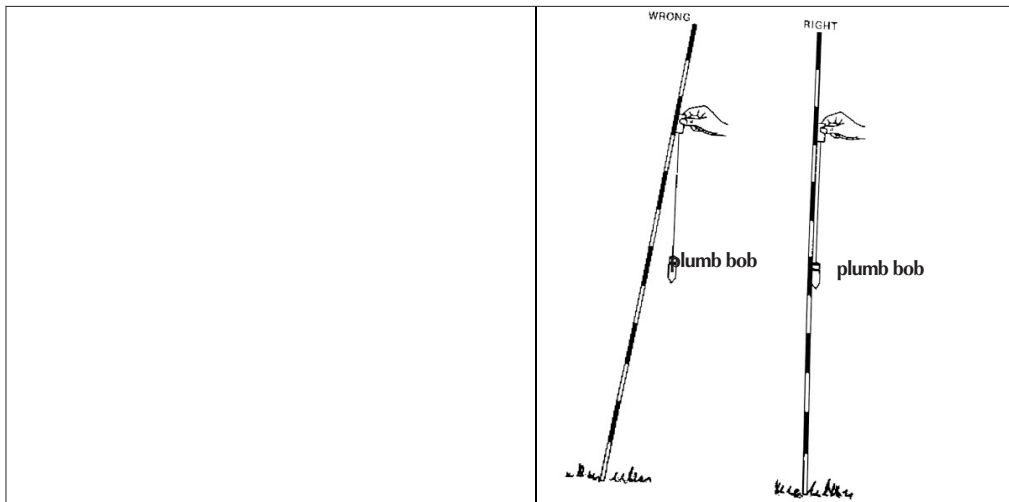


Figure 5.2. Placing of a ranging pole

When erecting ranging pole, make sure it is held in a loose manner, about a few centimetres into the ground (Figure 5.1). The plumb bob or a spirit level is used to ensure that the pole is vertical, and then the pole is firmly inserted in the ground.

Procedures for ranging out are as follows:-

- Step 1: Place the ranging pole at starting point A. Then a second ranging pole at point B should be at a distance which is clearly visible to the observer. Then the observer should stand at 1 to 2 metres behind pole A, in such a way that pole B will completely be obscured by pole A (completely behind pole A);
- Step 2: Then a third pole C should now be placed between A and B. Care should be taken to make sure pole C is hidden behind pole A on the straight line. The observer should remain at the same position as at step 1; and
- Step 3: A fourth pole D will then be placed behind B, on the extension of the straight line connecting pole A and B. The observer remains at the same position where he/she will only be seeing pole A (Pole B, C and D will completely be obscured by A). This will mean that the line is now straight (Figure 5.3).

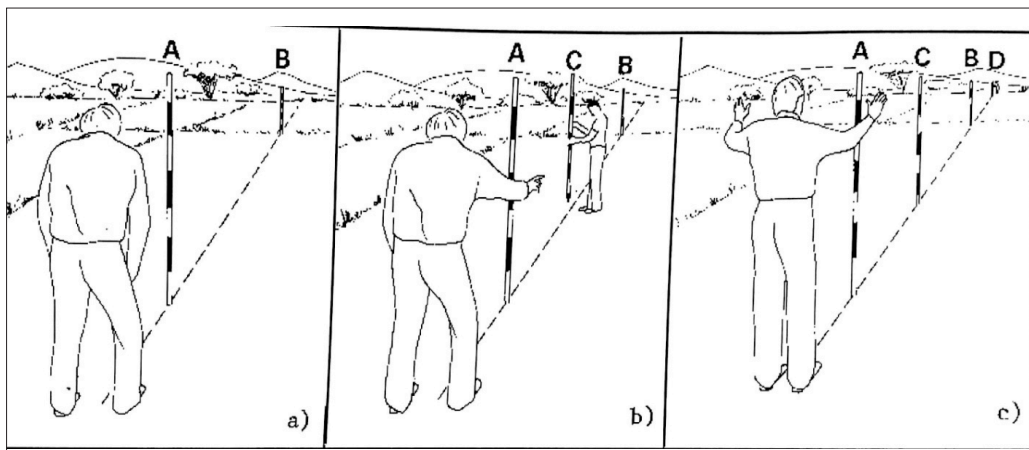


Figure 5.3. Setting out a straight line

If the distance to be measured is long, so the ranging pole at the other end of the line is not clearly visible, fly a small coloured flag (red or orange) on the top of the pole. If it is still not possible to see the other end of the line intermediate ranging poles must be erected following the above procedures. If the distance is very long, and it is difficult or impossible to see the ranging pole at the other end of the line, the surveyor can use a pair of binoculars. If this is still not possible, then ranging out has to be done by help of a theodolite.

Measuring Distance

Having completed ranging out, the survey will proceed into actual measuring of the distances. The process of measuring distances requires chain or measuring tape or surveyor ropes and two persons (leader and follower). The follower should hold the zero end whereas the leader holds the other end. The leader needs to carry at least one bunch of arrows for marking out intermediate points. The steps for measuring distance are:-

- Step 1: The survey crew, places pegs to mark the beginning and the end of the survey line (distance to be measured) point A and B and ranging poles are erected between the two points (Figure 5.4).

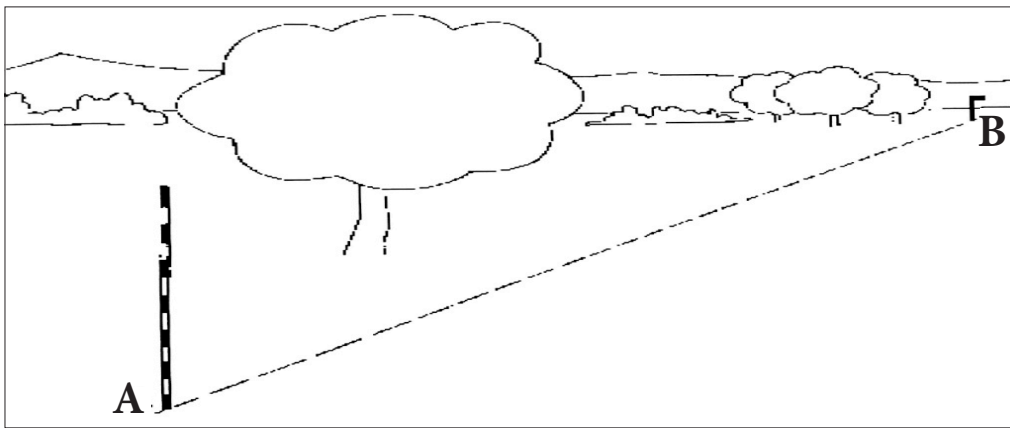


Figure 5.4. Measuring a straight line over a long distance

- Step 2: Using a measuring tape, the follower holds the zero point at the centre of the starting peg at point A, the leader drags and pulls straight the tape towards the second peg at point B. Then the follower directs and aligns the leader with the intermediate ranging pole (Figure 5.5), the leader then inserts an arrow on every intermediate point for marking the end of the tape. The leader should pull out the tape in full length; the follower directs the leader until the tape is pointing towards the ranging pole at the other end of the line or an intermediate pole. The leader pulls the tape tight and inserts an arrow firm and vertical in the ground at the end of the tape.

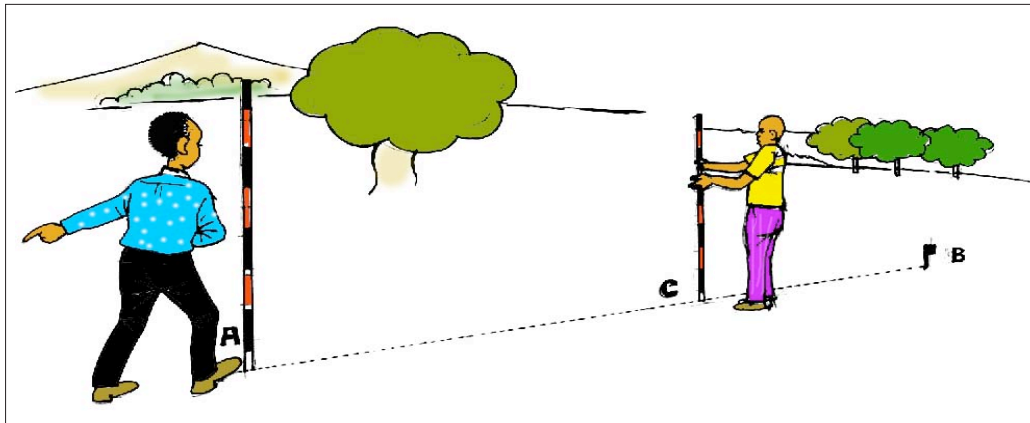


Figure 5.5. Measuring straight line over a long distance

- Step 3: The leader then drags the tape forward until the zero mark is at the arrow. On the signal from the leader, the follower takes up the arrow and the tape is moved further forward and the procedure is repeated until the leader has put in his last arrow, or until the end of line is reached, in this case shorter than ten times the length of the tape. In the first case, a distance of ten times the length of the tape has been measured. This is noted in the note book. The last arrow (the 10th) is now removed and replaced by a wooden peg, on which the distance and the line number is noted (Figure 5.6).

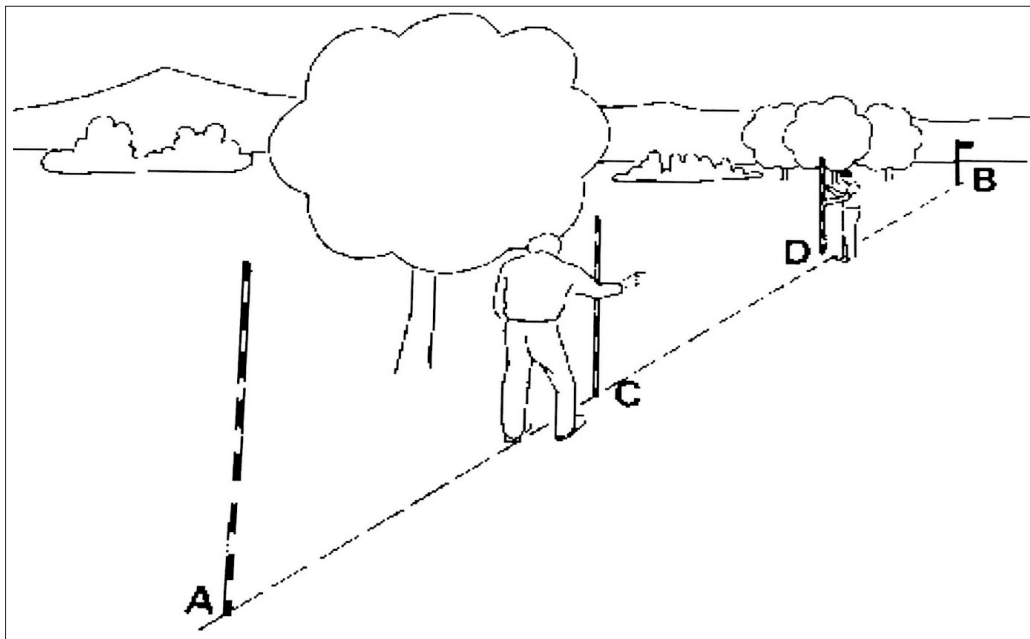


Figure 5.6. Measuring straight line over a long distance

- Step 4: The leader moves forward and the follower holds the zero mark of the tape at the peg. Both the leader and the follower count the number of arrows, which each has, the sum shall be ten. The number of arrows, which the follower has, is noted. The length of the line is the reading on the tape + number of follower's arrows x tape length + number of pegs x ten x tape length.

The total length is computed using the following formula:

$$\text{Total Length} = (\text{Number of Arrows Used} \times \text{length of the tape}) + \text{distance between the last arrow and Peg B (see Figure 5.6)}$$

Measuring distance on steep slopes

The landscape to be measured may have steep slopes and hence must not be assumed as a horizontal ground. Under such circumstances, both horizontal and vertical measurement must be considered and measured separately. Surveying in steep areas involve use of equipment like measuring rod, plumb bob and a spirit level for measuring short horizontal and vertical distances. The following steps are employed in measurement of distances in steep slopes:

- Step 1: Insert two pegs at point A and B such that their tops are the same height above the ground level (Figure 5.7).



Figure 5.7. Measuring of horizontal distance and vertical on steep sloping areas

- Step 2: Place the measuring rod horizontally such that its zero point is placed on top of peg A. Then, the spirit level should be put on the rod (Figure 5.8). The rod is slowly moved up and down until the bubble of the level settles at the middle (between the marks).

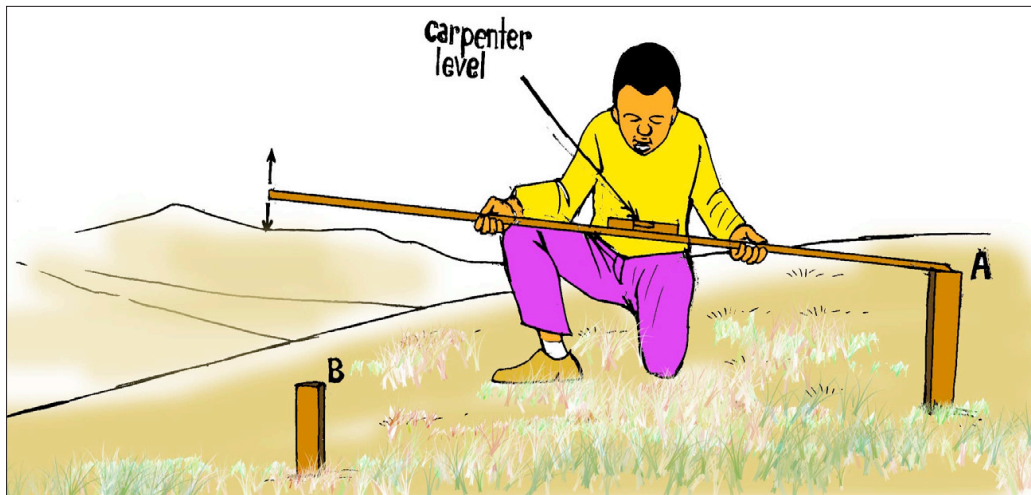


Figure 5.8. Measuring of horizontal and vertical distances

- Step 3: The plumb bob should now be hung just above the centre of peg B. The horizontal distance on the measuring rod will be read at the point where the plumb bob is hanging (Figure 5.9).

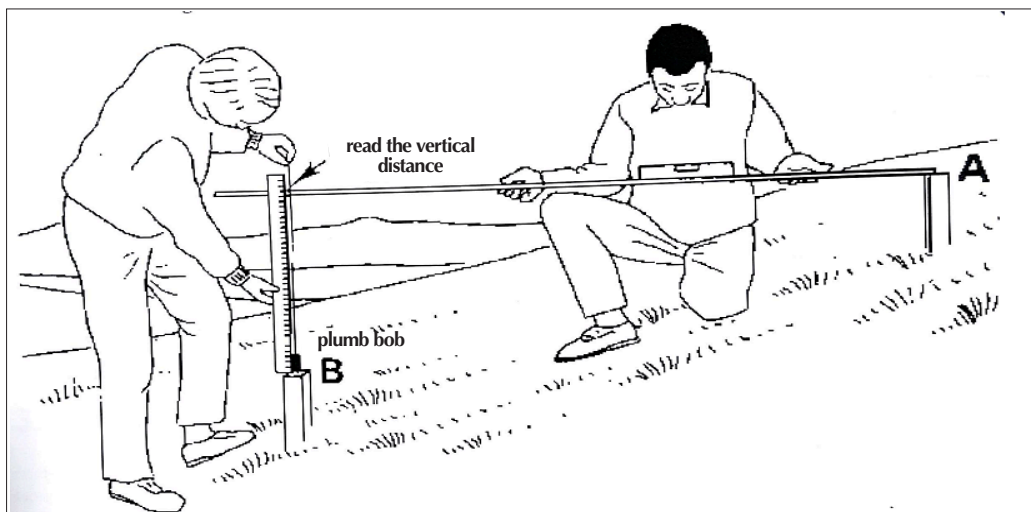


Figure 5.9. Measuring of horizontal and vertical distances

- Step 4: While the measuring rod is still on its horizontal position, the vertical distance between peg A and B should be measured using a ruler or a tape along the plumb bob from the top of peg B (Figure 5.10).

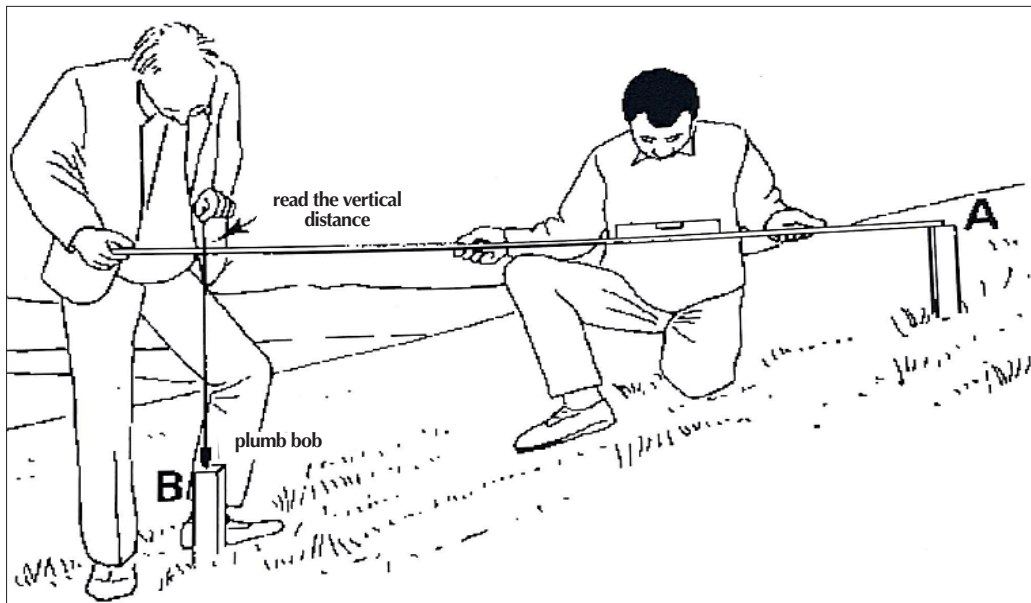


Figure 5.10. Measuring of horizontal and vertical distances

In some cases the distance between the pegs is longer than that of the measuring rod. Should this happen an intermediate peg must be installed between peg A and B at a length not longer than one rod length (Figure 5.11). Then repeat the procedure from step 1 to 4 in all intermediates (Figure 5.12).

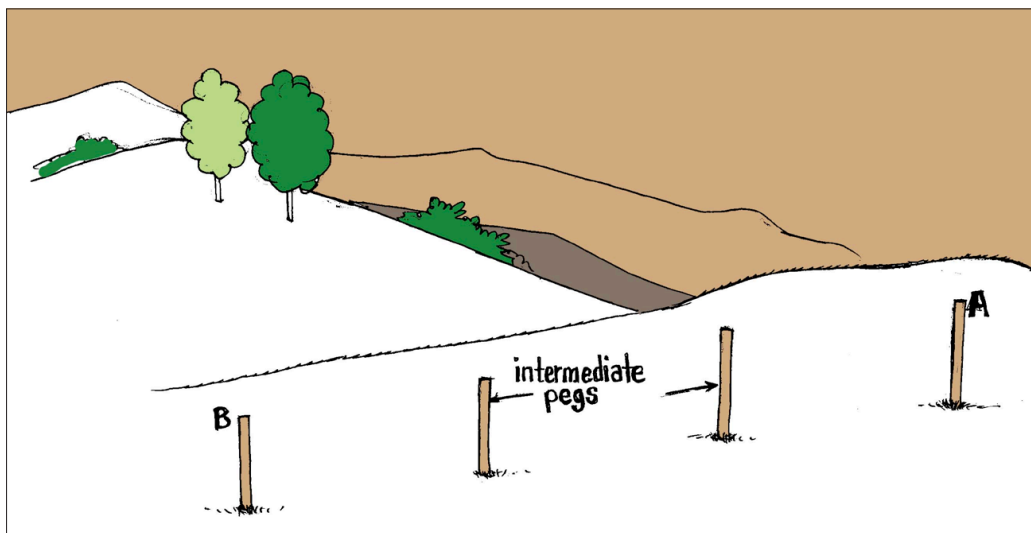


Figure 5.11. Measuring of horizontal and vertical distances when using intermediate pegs

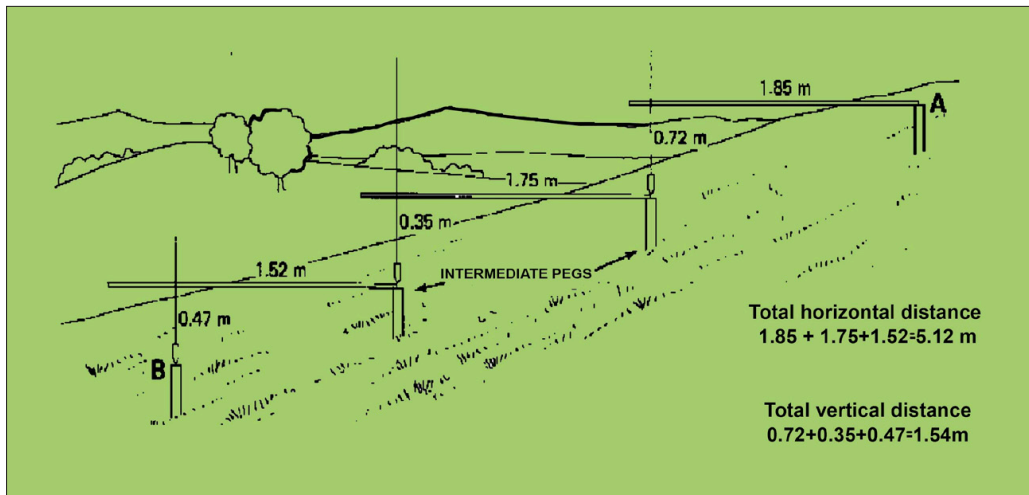


Figure 5.12. Measuring of horizontal and vertical distances when using intermediate pegs

The total horizontal (or vertical) distances between pegs A and B is the sum of the horizontal (or vertical) distances measured between all the intermediate pegs as follows:

$$\text{Total horizontal distances: } 1.85 + 1.75 + 1.52 = 5.12 \text{ m}$$

$$\text{Total vertical distances: } 0.72 + 0.35 + 0.47 = 1.54 \text{ m}$$

From these measurements it is possible to determine the slope and the length of the tangent line/surface distance.

Angles Measurements

There are two systems for measuring angles: the 360° and 400° systems.

In the 360° system a circle is 360° and a right angle is 90° . One degree is divided into 60 minutes, written ' and one minute is 60 seconds, written ". Thus:

$$1^\circ = 60' = 3600'' \text{ and } 360^\circ = 21600' = 1296000'',$$

an angle can then be written: $65^\circ 05' 13''$

In the 400° system a circle is 400° and a right angle is 100° . One degree is $100'$ and one minute is 100 seconds. Thus:

$1^\circ = 100' = 10000''$ and $400^\circ = 40000' = 4000000''$ an angle can then be written: $87^\circ 2635$ and you are then dealing with the decimal system, and for this reason the 400° system is easier to work with than the old 360° system.

In practice, it can happen that the measurements in the field are done in the 360° system, but the plotting equipment (e.g. protractor) is in the 400° system, or opposite. In this case, you will have to convert the measurements from one system to the other. Say you have to convert $65^\circ 05' 13''$ angle from 360° system to the 400° system.

First find the angle expressed in seconds in the 360° system. That is:

$$(65 \times 60 \times 60) + (05 \times 60) + 13'' = 234000 + 300 + 13'' = 234313''$$

Secondly, express the second from 360° to 400° system

There are $1296000''$ in the 360° system which is equal to $4000000''$ in the 400° system, then:

$$234313'' (360^\circ) = 4000000 \times 234313 / (400^\circ) = 72^\circ - 3188 = 72^\circ, 3188$$

If you have to convert the angle from the 400° i.e. $87^\circ 2635$ to the 360° system, first find how many seconds are there in the 360° system.

$$4,000,000'' (400^\circ) = 1,296,000'' (360^\circ)$$

$$87^\circ 2635 = \frac{1,296,000 \times 87,2635}{4,000,000} = 282734''$$

$$282734'' = \frac{282734'}{60} = 4712.23333 = 4712 \text{ and } 0.2333 \times 60 = 14''$$

$$4712' = \frac{4712^\circ}{60} = 78.5333 = 78^\circ \text{ and } 0.5333 \times 60 = 32' \text{ our angle is}$$

therefore $78^\circ 32'$ and $14''$

Basic Concepts of Plans and Maps

Before describing the details of practical surveying, it is important to understand the basic concepts of plans and maps. In surveying, data can be viewed either through a plan or a map. This means that, the key output of surveying is the production of a plan or map. In order to draw a map, a scale should be defined. A scale is the basic requirement for the preparation of plans or maps.

A Plan: A graphical representation to some scale of the features on near or below the surface of the Earth as represented on a horizontal plane. A plan shows all features on the ground correctly to scale.

A Map: A two dimension representation of the Earth surface. If the graphical representation on a horizontal plane is small, the plan is called a map i.e. the scale is too small to allow every feature to be properly represented to scale.

The scale of a map or plan is the ratio of ground length to the map or plan length. It shows the ratio by which the actual length of the object is reduced or increased in the drawing. Scales are basically expressed either as: numerical scales or statement scales and graphical scales. For example a numeric scale can be presented as 1:1000, while statement scale is presented as 1 cm on the paper represents 1000 cm on the ground and graphical scale is a line separated into small intersecting lines like that of a ruler.

The preference on the types of scale for use depends on size of the area to be mapped. The larger the scale the fewer the details and vice versa. Scales can be small, large, site plans and detail plans.

- Small scale map is used for relatively large area e.g. 1:1 000 000, 1:500 000 and 1:250 000
- Large scale map is used for relatively small area e.g. 1:10000,1:5000, 1:2500 and 1:1000
- Site plan scales is used for survey plan maps e.g. 1:500, 1:250, 1:100 and 1:50
- Detail plan scales is used for detailed plan maps like sections of house plans e.g. 1:20, 1:10, 1:5 and 1:1

Practical Surveying

Reconnaissance survey: Prior to any surveying work, a reconnaissance survey has to be done. During reconnaissance the area to be surveyed should be thoroughly examined by the surveyor, to acquaint with the terrain, boundaries, obstacles and whether or not the proposed stations are intervisible, selection of main station and other details of interest for possible arrangement of the framework of survey. The surveyor should then prepare a neat hand sketch of the area (index sketch or key plan). The sketch should show the skeleton of the surveying work by indicating the main survey stations, sub-stations, tie stations, baseline, arrangement for framework of triangles and the relative positions of different objects. The sketch plan is a key document and should be attached on the starting page of the field book to guide the surveyor.

Once reconnaissance survey is completed, a decision of the approach to be used in practical surveying should be made based on equipment available. The most common approaches are chain and compass surveying.

Chain Surveying

Chain surveying is one of the surveying techniques on which only the distances between points are measured in the field using chains or measuring tapes. This technique is best suited for relatively small areas with minimal and simple details as possible, more or less flat (level) grounds, small-scale map is to be prepared and easiness on forming well conditioned triangles.

The principle behind the chain surveying is triangulation, whereby the survey divides the area into small triangles. The triangles should be well conditioned, the sides of the triangle are measured directly on the field by chain or measuring tape, no angular measurements are taken. The accuracy of the entire survey is only controlled by tie lines and check lines.

A well conditioned triangle has angles less than 30° or greater than 120° . An equilateral triangle is considered to be the best-condition or ideal triangle. The preference to these kinds of triangles is based on the fact that their apex points are sharp enough to be located by a single dot. It is

obvious that the degree of accuracy in chain surveying is not very high, it is sufficient to meet the needs of most forest works. This is a common surveying technique used in forestry for collection of data for detailed plans, determination of forest area, consolidation of forest boundaries and compartmentalisation of forests.

Equipment that are used for distance measurements are used for chain surveying

Selection of Survey Stations

When selecting survey stations, the following should be noted:

- The work should proceed from the whole to the part;
- The stations should be intervisible;
- Triangles should be well-conditioned;
- The baseline should be the longest of the main survey lines;
- The survey lines should be taken through reasonably level ground;
- The main survey lines should pass close to the boundary line of the area to be surveyed;
- The survey lines should be taken close to the objects so that they can be located by short offsets; and
- Stations should be so selected that obstacles to chaining are avoided as far as possible.

Chain Surveying Procedures

The illustration presented in Figure 5.13 demonstrates the procedures to be used in chain surveying. Figure 5.13 is a 5-sided polygon in which all sides and diagonals (AC and AD) should be measured.

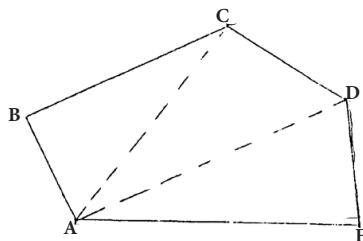


Figure 5.13. A hypothetical field to be chain surveyed

As a control measure, at least one of the remaining diagonals BD, BE or CE should also be included. As many triangles as possible can be formed provided they are all well-conditioned (avoid very acute and very obtuse triangles). All offsets should be taken to fix the position of nearby objects along the survey line. If the area does not form a regular polygon, then form a polygon and from the sides take the necessary offsets to determine the boundaries of the area.

As mentioned earlier, all survey work involves elements of field work and office work. Here below are listed the fieldwork procedures of chain surveying;

- Marking the stations on the ground: after reconnaissance, the stations should be marked on the ground by using wooden pegs. The pegs to be used should have dimension of 2.5 - 3.0 cm square and 15 - 20 cm long, and should be pointed on one end. Pegs should firmly be driven into the ground. The station point be marked with a cross so that it can be traced in case the wooden peg is removed;
- Reference sketches: as a precaution against missing of station pegs, a reference sketch should be prepared for all main stations. This is a hand sketch of the station showing at least two measurements from some of the permanent objects;
- Taking measurements of survey lines and noting them in the field book: starts ranging out and chaining from the baseline, the measurements should be done correctly to avoid errors; and
- Recording (or booking) field notes: during surveying, measurements taken in the field are recorded along with some explanatory sketches in a field note book which should have a single or double line on each page, parallel at the midpoint of the width to represent the chain line (Figure 5.13a and b).

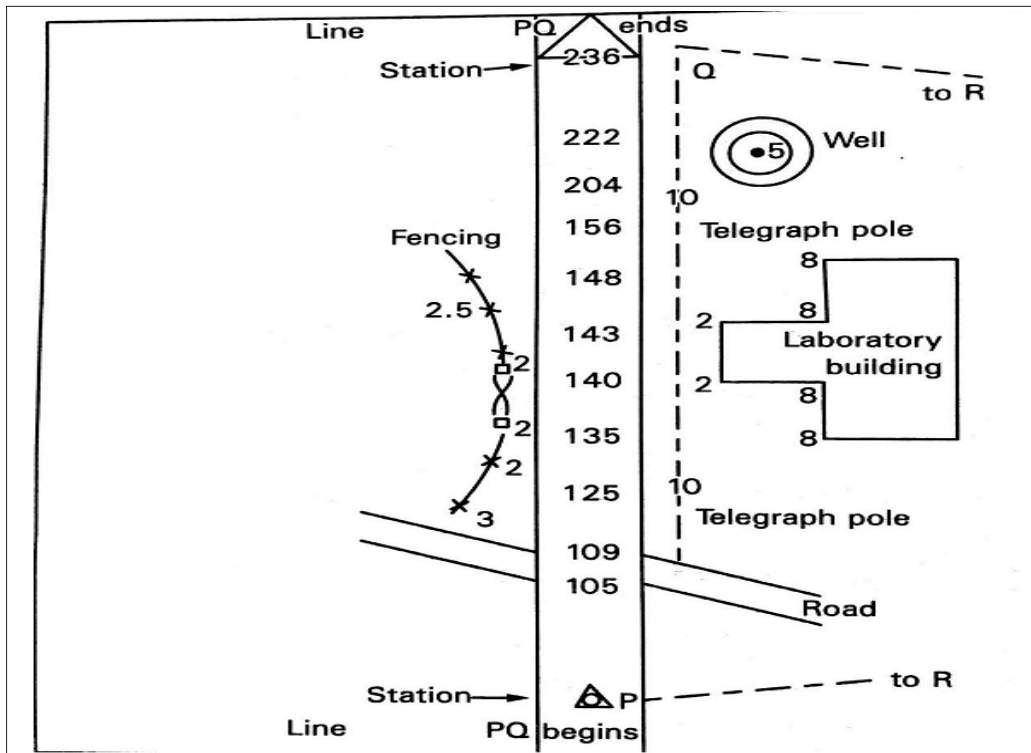


Figure 5.13. Illustration of booking field notes

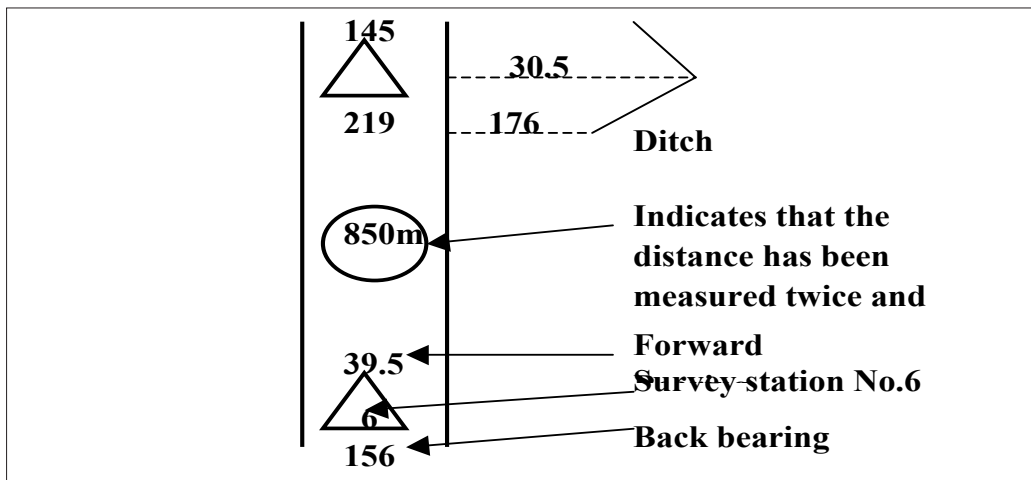


Figure 5.14. Booking steps

Plotting a Chain Surveying Map

After the field work the collected data is used to prepare a map. It is mandatory to decide the scale before you start plotting. Standard symbols should be used to represent various features in a map. When plotting a map appropriate drawing instruments should be used.

A number of equipment are used in plotting a chain survey map, these includes;

- Drawing board (normal size – 1000 mm x 700 mm)
- Tee-square
- Set-square (450 and 600)
- Protractor
- Cardboard scale – set of eight
- Instrument box
- French curve
- Offset scale
- Drawing paper of good quality (normal size – 880 mm x 625 mm)
- Pencils of good quality – 2 H, 3 H or 4 H
- Eraser (rubber) of good quality
- Board clips or pins
- Ink of required shade
- Colour of required shade
- Inking pen (or Hi-tech pen) and brushes
- Handkerchief, knife, paperweight, etc.
- Mini drafter.

Compass Surveying

This is useful for large areas with undulating terrain crowded with many details. In practice, compass surveying applies a method called traversing. In traversing, the length and directions of connected lines is determined. The lengths and directions are measured by tape and compass respectively. Some key terminologies commonly used in compass survey are:

- Forward and back bearing: The bearing of a line AB measured in the direction of the survey line is called the ‘forward bearing’. The bearing of a line measured in the direction opposite to the survey line BA is called the ‘back bearing’ of the line (Figure 5.15).

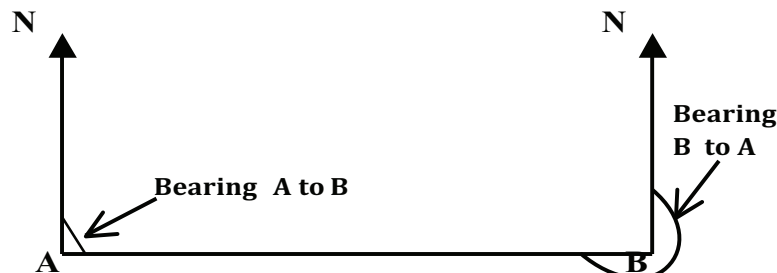


Figure 5.15. Illustration of back and forward bearing

Note: The difference between the forward bearing and back bearing is always exactly equal to 180°

$$\text{Back bearing} = \text{Forward bearing} \pm 180^{\circ}$$

A positive sign is used when forward bearing is less than 180° , and the negative sign when it is more than 180° .

- Local attraction: Refers to disturbing influence of magnetic substances such as iron ore, steel structures and electric cables that deflects the magnetic needle from its true direction and indicates false north direction. Compass surveying is limited to areas with no or little local attraction suspected due to the presence of magnetic substances like steel structures, iron ore deposits and electric cables conveying current to mention a few.

To detect the presence of local attraction, the forward and back bearings of a line should be taken. If the difference of the forward and back bearings of the line is exactly equal to 180° , then there is no local attraction. If the difference of forward bearing and back bearing of a line is not equal to 180° , then the needle is said to be affected by local attraction, if there is no instrumental error.

Principle of Compass Surveying

The principle of compass surveying is traversing; consisting of a series of consecutive lines. Traversing is one of the most basic and widely used means of locating points. Interior details are located by taking offsets from the main survey lines.

There are basically two types of traverses i.e. closed and open traverse (Figure 5.15). In the closed traverse, the finishing point coincides with the starting point of a survey which means the work returns to the starting point, forming a polygon that is closed. Closed traverses are suitable for the survey of boundaries of forests area, agricultural field and water bodies.

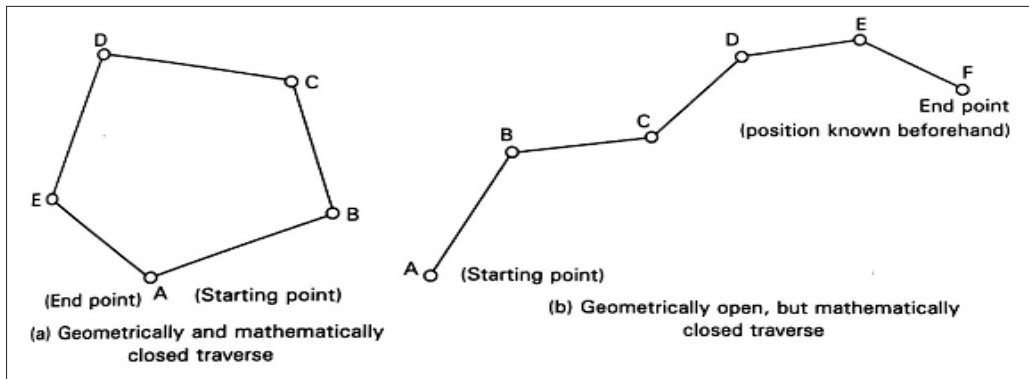


Figure 5.16. Examples of closed and open traverse

In the open traverse, a sequence of connected lines extending along a general direction and does not return to the starting point. This means that the series of connected lines do not close. Open traverse are commonly used on route survey (roads, rivers and coast line). In this kind of traverse measurements must be repeated to reduce mistakes, since there are no error checks.

There are several ways of traversing, including chain, compass, theodolite and plane table.

- Chain traversing (by chain angle): In this method, the angles between adjacent sides are fixed by chain or measuring tape angles. The whole survey is conducted by using measuring tape or chain only, no angular measurements are taken. Chain traversing is used when it is not possible to form triangles, for example, in a pond/water body's survey.
- Compass traversing (by free needle): In this method, the forward and back bearings of the traverse legs are measured by using a compass and sides by tape. Verification of the observed bearings is then done. The closing error may occur when the traverse is plotted. The closing error must therefore be corrected.

Field Work in Compass Traversing

The field works involve measurement of the bearings and length of all lines by surveyor's rope or tape. Sometimes, a compass is fixed on a tripod stand. Forward and back bearings of all lines should be taken. Measurement of interior details should be done as appropriate. Traverse

stations must carefully be selected to satisfy the survey's needs. During field work, the following should be observed:

- Check on angular measurements: the following needs to be done:
 - ensure that, the sum of the measured interior angles should be equal to $(2N - 4) \times 90^\circ$ where N is the number of sides of the traverse.
 - ensure that, the sum of the measured exterior angles should also be equal to $(2N + 4) \times 90^\circ$.
- Check on linear measurement: the following should be performed:
 - The lines should be measured at least twice (*along opposite directions*). Both measurements should tally.

Computation and Plotting of a Compass Traverse

This depends on the method for plotting. In practice, compass traverse may be plotted from observed bearings and lengths of sides. There are several approaches for plotting a compass traverse such as use of parallel meridians, paper protractor, tangents, chords, rectangular coordinates and included and deflection angles.

In plotting, the traverse commences from a suitable location of the first point, say A and oriented by drawing the first line to the direction of its bearing with respect to the meridian at point A. Point B is obtained by measuring the distance AB in this direction to a chosen scale corresponding to the field measured distance. With the aid of the protractor a line BC at point C, is drawn with their corresponding distance. This procedure is repeated at all other stations to complete the traverse. In most cases, the traverse do not close, the gap is called closing error which should be adjusted.

Graphical Adjustment of a Compass Traverse (closing error)

Normally, the closed traverse when plotted should end up at the starting point. But due to small errors, it will probably end up at A_1 , a small distance from the starting point A as indicated in the Figure 5.17.

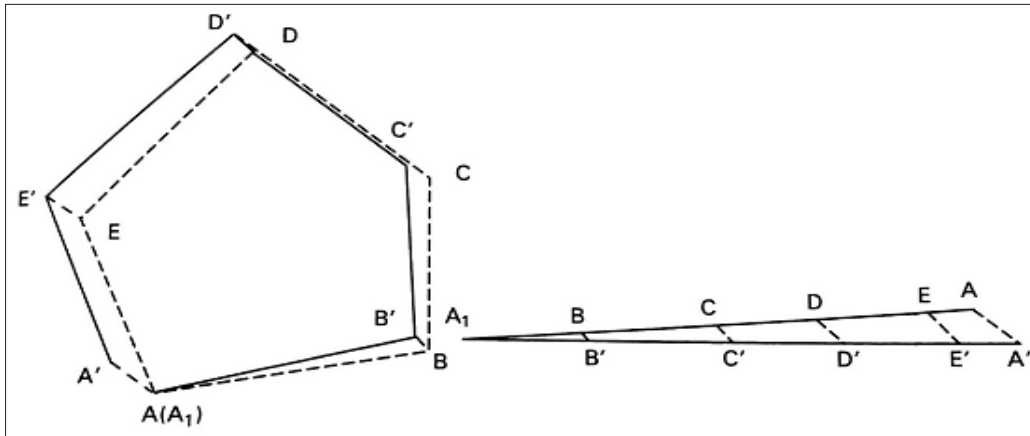


Figure 5.17. Graphical adjustment of a compass traverse

It is necessary to adjust all the lines in proportion, so that A_1 and A will converge and the error will be proportionally distributed. Through B , C , D and E lines parallel to A_1A , are drawn as shown on Figure 5.18. Then, a straight line AA_1 is drawn to a smaller scale than the plotted traverse, e.g. $1/5$ or $1/10$ of the scale of the plotted traverse.

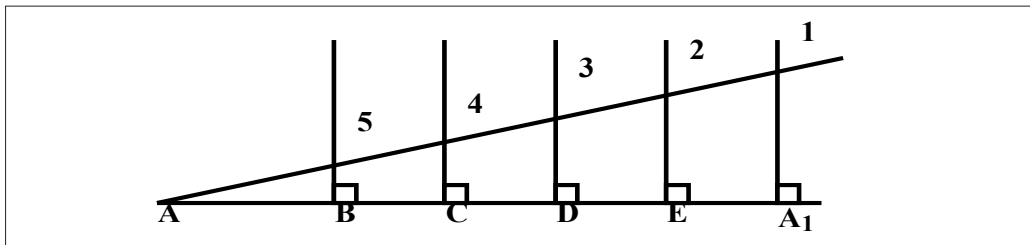


Figure 5.18. Illustration of closing error adjustment

Mark off in this scale along this line the various lengths of the traverse sides AB , BC , CD , DE and EA_1 (or EA) as shown in Figure 5.18. At A_1 erect a perpendicular and on this set off A_{11} in the same scale as the plotted traverse to represent the closing error. Parallel to A_{11} draw the lines $E2$, $D3$, $C4$ and $B5$ cutting the line A_1A . Then these distances $E2$, $D3$ etc. are those by which the points E , D , C and B have to be moved parallel to the closing error as shown by the broken perimeter. The dotted line $ABCDEA$ is then the corrected traverse. The closing error is usually expressed as a percentage.

Closing error percentage depends on the conditions of survey, size of

polygon and instruments used, but should not exceed 2%. If it shows up that the closing error is too big, check first, if the error is in the plotting. If not, the field data must be checked again or field measurement be repeated.

$$\frac{\text{Closing error}}{\text{Perimeter of polygon}} \times 100$$

Forest Inventory

Tree and forest parameters are essential since they provide information on the state and dynamics of forests for strategic and management planning. This may include but not limited to the volume of timber available, extent of forest regeneration, available non-timber forest product, and disturbance level. Whether through remote sensing or ground measurement the aim is to get data on tree/stand parameters and forest cover change.

Ground assessments are common and have been used in various areas in Tanzania (e.g. Luoga *et al.*, 2002 in Kitulang’halo; Zahabu, 2008 Duru-haitemba, Kitulang’halo and Tanga; Mugasha *et al.*, 2016). A large scale forest inventory named National Forest Resource Monitoring and Assessment (NAFORMA) was carried out in Tanzania between 2009 and 2014 (MNRT, 2015).

Single Tree Parameter

Single Tree parameters refer to measurable tree dimensions, such as diameter at breast height (dbh), total tree height, and crown diameter. Tree dbh is stem diameter at the height of 1.3 m above ground, usually measured from the uphill side of the stem. The dbh is normally measured by calliper or diameter tape. Often a single calliper measurement is adequate, but for an elliptical cross section of a stem, two calliper readings at right angles should be made and the average recorded. Often dbh measurements with the tape are more consistent than using calliper provided that the tape is level and pulled tightly at the time of measurement. Callipers are convenient for measuring trees up to 60 cm dbh. For larger trees, diameter tapes are preferred because corresponding large callipers are bulky and inconvenient to handle. It should be noted that measuring elliptical stems with the tape tends to overestimate diameter in which case a calliper is preferable.

Total tree height is the length from the base to the tip of the tree. It is normally expressed in metre (m). Total tree height is measured by Suunto hypsometer (Figure 5.19), Vertex hypsometer or graduated pole.



Figure 5.19. Example of Suunto hypsometer

Common hypsometers apply trigonometric principle. The following are the steps to be followed when measuring total tree height by Suunto hypsometer

1. The user stands at 15 or 20 m from the tree to be measured:
2. Then sights the bottom of the tree and record the readings:
3. Then sights the top of the tree and record the readings: and
4. The sum of the two readings is the total height of the tree.

It is important to stand at the correct distance from the tree. This depends on the scale you are using i.e. 15 or 20 m scale in the hypsometer. You should also correctly identify the tip of the tree and avoid measuring the height of abnormal trees e.g. broken trees.

The importance of both tree dbh and height is that they are highly correlated with total tree volume, merchantable volume and biomass (both below- and aboveground). Therefore, these parameters are used to estimate tree/stand volume and biomass using volume or biomass allometric equations (regression equations). In addition, basal area per ha, a forest parameter and potential indicator of forest health is computed from dbh.

Forest Stand Parameters

Forest Stand Parameter are collective characteristics of a given forest normally, computed from individual trees and converted to per unit area. It includes number of trees (N), basal area (G), volume (V), belowground biomass (BGB), aboveground biomass (AGB) and crown cover per hectare. Forest parameters may also include tree species diversity which is the function of the number of tree species encountered during forest assessment.

Importance of Forest Inventory

Precise and up to date information on the quality, quantity and distribution of the growing stock (the trees) in a forest is a basis for determining their production potential. Information from forest inventory, among others, may be used for the following:

- Planning for sustainable forest resource use through development of management plans detailing prescriptions/interventions;
- National policy formulation, analysis and monitoring for forest sector e.g. determination of contribution of forest resources to GDP, social, environmental and forest resource management and development of policies; and
- International policy development and negotiation for management of national forestry resources.

Forest Inventory Planning

Collecting forest inventory data efficiently and presenting it in a meaningful and useful format is complex. Therefore planning in all stages involved forest inventory activities up to the point of reporting is necessary. This will however, depend on the nature and detail of forest information required. Among others, planning will require the following:

- Collection of forest secondary data i.e. reports, maps, photographs, interviews or direct visit (reconnaissance survey) which are useful in preliminary learning the forest types, terrain etc.;
- Decide what information the inventory will provide. It is emphasized that, at this stage of planning, decisions should be made as to exactly what kind of information will appear in the final results of the inventory. It is important to include descriptions of the stand

parameters, units, and the desired limits of accuracy for the estimate. One need not blindly follow some conventionally accepted error or probability;

- Time and funds available. This has to be arranged well in advance to permit the inventory to proceed smoothly;
- Intended output of the inventory, detailed design can be done to include sampling techniques (e.g. random or systematic) and the possibility of utilizing aerial photography for stratification;
- Detailed instructions must be prepared, describing the size and number of crews, their distribution in the inventory area, and their work schedules. Instructions should be prepared for each crew member so that all work is uniform;
- Procedures to be followed for field location of sample plots, establishment of the plot, and measurements to be taken when on the plots should be in place.
- Transportation must be arranged and suitable communication facilities provided;
- Field recording forms should be designed to permit easy and accurate recording of the measurements. Forms should be as simple as possible to fill in as well as to ease computation or transfer of data during office work; and
- Design of the compilation and calculation procedures. This should include description of the data processing techniques.

Forest Sampling Design and Number of Plots

A sampling design is determined by the kind of sampling units used, the number of sampling units employed, and the manner of selecting and distribution of the sample units over the forest area, as well as the procedures for inventory and analyzing the results. Some of the sampling designs used in forest inventory include: Simple random sampling is the fundamental selection method. In systematic sampling, sampling units are spaced at fixed intervals throughout the population. Selective or opportunistic sampling is an example of nonrandom sampling used in forest inventory work. Clusters are frequently used in forest inventories of large areas, such as regional or national inventories, especially in remote areas with difficult access and long distances.

Number of plots: The actual number of sample plots is frequently determined after a reconnaissance survey to understand forest stocking variation. To determine the spatial variation of forest standing stock and the number of plots required to sufficiently represent the forest variation, as a rule of thumb, a total of 20 plots are laid out randomly where Relascope is used to estimate Basal Area (BA , $m^2 ha^{-1}$) for each plot. Number of plots is computed using the following formula:

$$N = \frac{CV^2 t^2}{E^2}$$

Where N is the number of plots, CV is the coefficient of variation between plots (standard deviation/mean) expressed in percentage, t is Student's t -value obtained from $n-1$ degrees of freedom at probability level of 0.05 from t -Table and E is allowable sampling error.

Sampling error results from the fact that the sample is only a portion of a whole population and may not produce estimates equal to the population parameters. Decision on the level of sampling error depends on purpose of the forest inventory and available financial resources. Often sampling error of between 5 and 10% is acceptable in forestry. For example, volume determination of selected tree species may require low allowable error and therefore large number of plots compared to when estimating crude volume of timber in a forest.

Plot layout and measurements

Plot layout depends on sampling design and intention of the inventory. In most cases systematic sampling is used to layout plots. For precision, the area of forests needs to be known, and used to determine the area each plot represents. The forest area " a " represented by plot is computed as follows:

$$a = \frac{\text{area of the forest compartment}}{\text{number of plots}}$$

The square root of the area (" a ") presents the distance between transects and between plots. Alternatively a convenient number of transects may be established in to cover the forest. Then, the transect lengths are measured and summed. The first transect is randomly placed in the forest by using

random number (by using calculator or computer). In this case the inter-plot distance is computed as follows:

$$\textit{The distance between plots} = \frac{\textit{Total transect length}}{\textit{number of plots}}$$

The first plot is established at half the standard distance. The plot locations must be shown on a sketch map of the forest.

- Plot lay out in a transect: conventionally, plots are laid out systematically in delineated transects as illustrated in Figure 5.20.

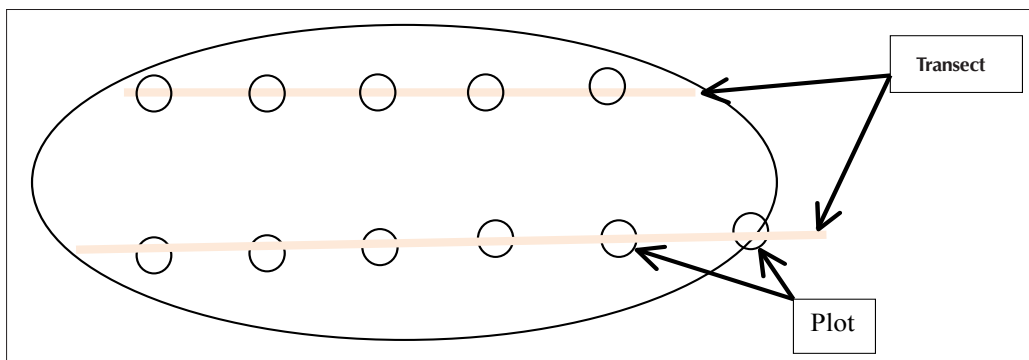


Figure 5.20. Transects and plots layout

- Plot shape, sizes and measurements: when dealing with natural forests inventory circular plots are usually preferred because is easier to establish. This type of plots (circular nested plot) was also used by NAFORMA (Figure 5.21). This is because tropical natural forests are characterized with high variation in terms of tree ages, sizes and species (MNRT, 2015). In addition, the distribution of stem numbers by diameter classes assumes a negative exponential or reversed J-shape such that there are many small trees, but decreasing with increasing tree dbh. In order to measure approximately the same number of trees for each size class, circular concentric plots of 2, 5, 10 and 15 m are recommended (MNRT, 2015). In each circular plot (2, 5, 10 and 15 m) all trees with dbh of ≥ 1 cm, ≥ 5 cm, ≥ 10 cm and ≥ 20 cm are measured respectively and their species identified and recorded.

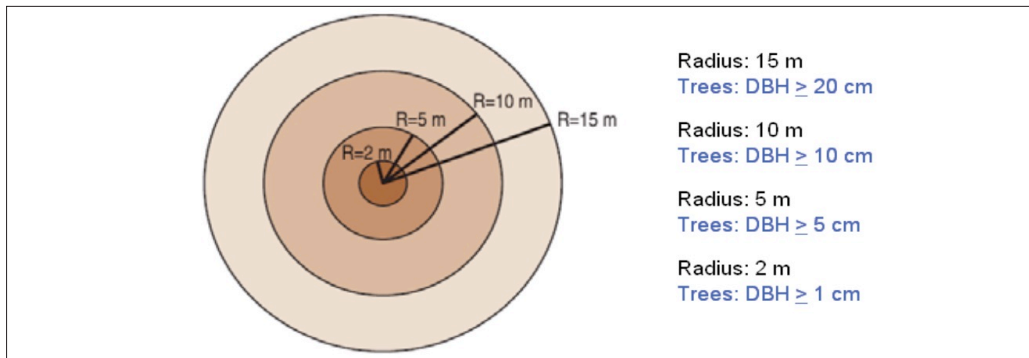


Figure 5.21. Nested plot design and tree sizes measured
Source: MNRT (2015).

- Other parameters to be measured at the plot include slopes, stumps height and diameter, percentage of crown cover and soil characteristics. Form for recording forest inventory information is shown in Box 5.1. Additional measurements in a plot can be taken according to the purpose of the inventory.

Name of the forest: Ownership:

Area: (ha) Date: Starting time End time

Name of the Recorder:

Transect No: Plot No.

GPS Coordinates: N E..... Altitude:

Terrain/Slope: Vegetation Type:

Spp Code	Local Name	Botanical name	Dbh (cm)	Height (m)

Other information	Terrain features.....
	Hydrological.....
	Wildlife.....
	Accessibility.....
Disturbances (e.g. Fire Grazing, Stumps, Encroachment)	

Box 5.1. Sample form for recording forest inventory data

Analysis of the Forest Inventory Data

Data analysis will be carried out based on the sampling design. Descriptive and inferential statistics are used to summarise data. However, this section

focuses on descriptive statistics which summarises data in terms of mean (\bar{x}), standard deviation (S), standard error (SE), standard error of mean and confidence interval.

Mean: Is a statistic property used to describe or measure the central tendency of data set. There are three types of mean i.e. Arithmetic mean, Geometric mean, and Harmonic mean. Arithmetic mean is the most used and computed as follows:

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

Where; n is the number of samples and x is the magnitude of observation i .

Consider the following example of data sets.

Data set 1: (n = 10)

Plot	X	X ²
Plot_1	9	81
Plot_2	9	81
Plot_3	11	121
Plot_4	9	81
Plot_5	7	49
Plot_6	7	49
Plot_7	10	100
Plot_8	8	64
Plot_9	9	81
Plot_10	11	121
Sum	ΣX =90	ΣX² = 828

Data set 2: (n = 8)

Tree	X	X ²
1	300	90000
2	280	78400
3	300	90000
4	280	78400
5	200	40000
6	320	102400
7	310	96100
8	300	90000
Sum	ΣX = 2 290	ΣX² = 665 300

Mean for data set 1 and data set 2 is 9 (= 90/10) and 286.25 (= 2290/8), respectively.

Standard deviation: Standard deviation (S) characterizes dispersion of individuals about the mean. It gives us an idea whether most of individuals in a population are close to the mean or spread out. The standard deviation

of individuals in a population is often symbolized by σ (sigma). We will seldom know or be able to determine σ exactly. However, given a sample of individual values from the population we can often make an estimate of σ , which is commonly symbolized by s .

S is computed as follows:

$$S = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

Or

$$S = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n - 1}}$$

For data set 1, S will be equal to $\sqrt{\frac{\sum 828 - \frac{90^2}{10}}{10 - 1}}$,

$$S = 1.414$$

Standard error (SE): is a statistical term that measures the accuracy with which a sample represents a population. In statistics, a sample means deviates from the actual mean of a population; this deviation is the standard error. It is denoted by SE and its computation uses the following formulae:

$$SE = \frac{S}{\sqrt{n}}$$

Where S is standard deviation and n is the number of samples.

Standard error of mean: There is usually variation among the individual units of a population. The standard deviation is a measure of this variation as we have seen previously. Since the individual units vary, variation may also exist among the means computed from samples of these units.

Take, for example, a population with a true mean of 10. If we were to select four units at random, there might have a sample mean 8, another of 11, another of 10.5, and so forth. Clearly, it would be desirable to know the

variation likely to be encountered among the means of samples from this population. A measure of variation among sample means is the standard error of the mean.

The computation of the standard error of the mean depends on the manner the sample was selected. For simple random sampling without replacement (i.e., a given unit cannot appear in the sample more than once) from a population having a total of N units the formula for the estimated standard error of the mean is:

$$SE_{\bar{x}} = \sqrt{\frac{s^2}{n} \left(1 - \frac{n}{N}\right)}$$

Coefficient of variation: In nature population with large means often show more variation (large S) than population with small means. The coefficient of variation (CV) facilitates comparison of variability about different sized means. It is the ratio of the standard deviation to the mean. It is normally expressed in %.

Take, for example data set 1 and data set 2. Data set 1 has standard deviation of 1.414 and that of 2 has standard deviation of 37.4 suggesting that “data set 2 has more variability than data set 1”. Data set 1 and data set 2 has a CV of 16% and 13%, respectively. It is clear that although the magnitude of S in data 1 is small but the variation among the individuals are larger compared to the data set 2 as specified by CV.

Confidence interval: Sample estimates are subject to variation. How much they vary depends primarily on the inherent variability of the population variance (σ^2), and on the size of the sample (n) and of the population (N). The statistical way of indicating the reliability of an estimate is to establish confidence limit (CI). For estimates made from normally distributed populations, the confidence limit is given by:

$$CI = \text{estimates} \pm t \times SE$$

Where t is the t-value read in t -distribution table. When performing a t -test, is about trying to find evidence of a significant difference between populations means (2-sample t) or between the populations mean and a hypothesized value (1-sample t). The t -value measures the size of the difference relative to the variation in the sample data.

Remote Sensing and GIS for Forest Resources Assessment

Fundamentals of Remote Sensing

Remote sensing is the science (and art) of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area or phenomenon under investigation. Remote sensing is carried out by using satellite or aircraft based sensor technologies. Remote sensing is a recent technology which extends the ability of the eye to see natural objects which are invisible under normal vision because of either being far away or they radiate energy which is beyond the visible spectrum or they are simply obscured.

Energy sources and radiation principles: The only form of energy transfer that can take place through a vacuum like outer space is the Electromagnetic Radiation (EMR). Electromagnetic energy can be detected easily by remote sensing sensors on board satellites. Every object emits, absorbs, diffuses, transmits and reflects this type of natural and measurable radiation in a specific way. Therefore it is possible to gather information about objects by studying their spectral characteristics. The electromagnetic radiation from the sun is the main source of energy used in remote sensing. The EMR has been classified on the basis of wavelength into different regions or wavelength bands called electromagnetic spectrum (Figure 5.22). The wavelength range of the electromagnetic spectrum varies from infinitely very short cosmic rays to the long waves of radio and beyond.

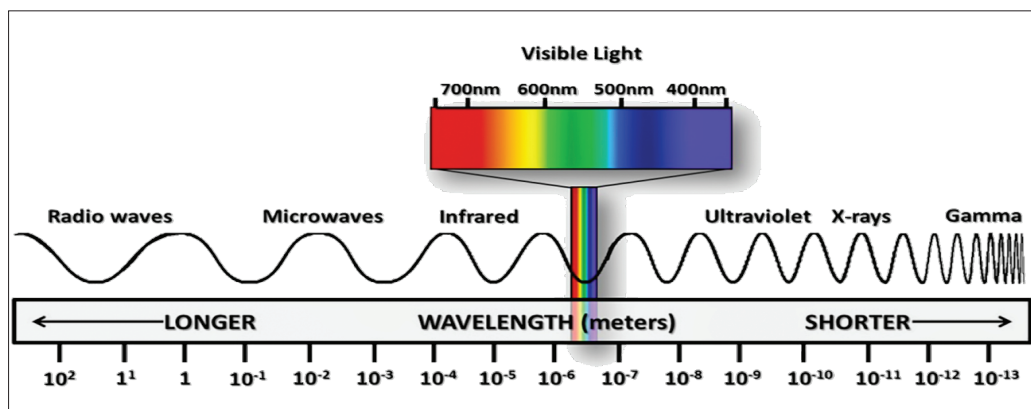


Figure 5.22. Illustration of electromagnetic spectrum

Energy interactions in the atmosphere: all radiations detected by remote sensors pass through a path length of the atmosphere. Path length is the total distance a radiation travels and varies widely. Because of this variation, the atmosphere can have a profound effect on the intensity and spectral composition of radiation available to any sensing system. These effects are caused by mechanism of atmospheric scattering and absorption as explained below:

- **Scattering:** occurs when particles or large gas molecules present in the atmosphere interact with and cause the atmospheric radiation to be redirected from its original path (Figure 5.23). Scattering depends on several factors including the wavelength of the radiation, abundance of particles or gases and distance travelled by radiation through the atmosphere. Upon reaching the atmosphere, Electromagnetic radiations (EMR) encounters large molecules or particles that cause scattering. Water vapour and dust particles are examples of substances that contribute to scattering. Shorter wavelengths scatter more often than longer wavelengths. Since blue wavelengths are shorter than green or red wavelengths, they are scattered more easily causing the sky to appear blue.

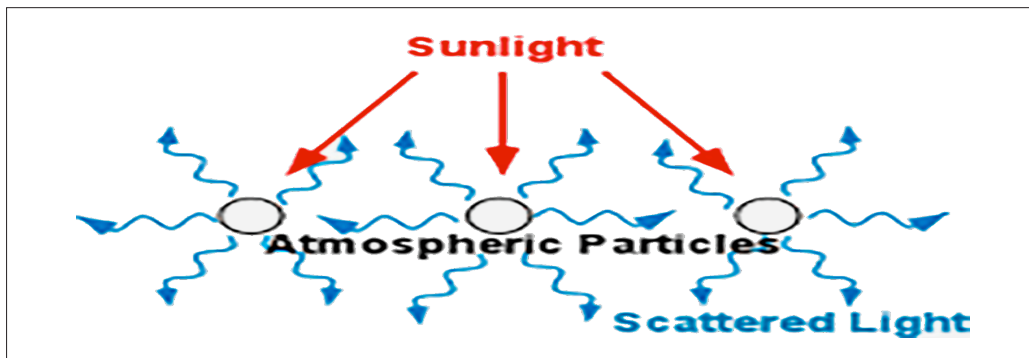


Figure 5.23. Illustration of scattering of electromagnetic radiations

- **Absorption:** this causes molecules in the atmosphere to absorb energy at various wavelengths (Figure 5.24). Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation. Scattering is the main cause of energy reduction in the visible and near visible regions, while absorption is the chief cause of radiation disturbances in the infrared region.

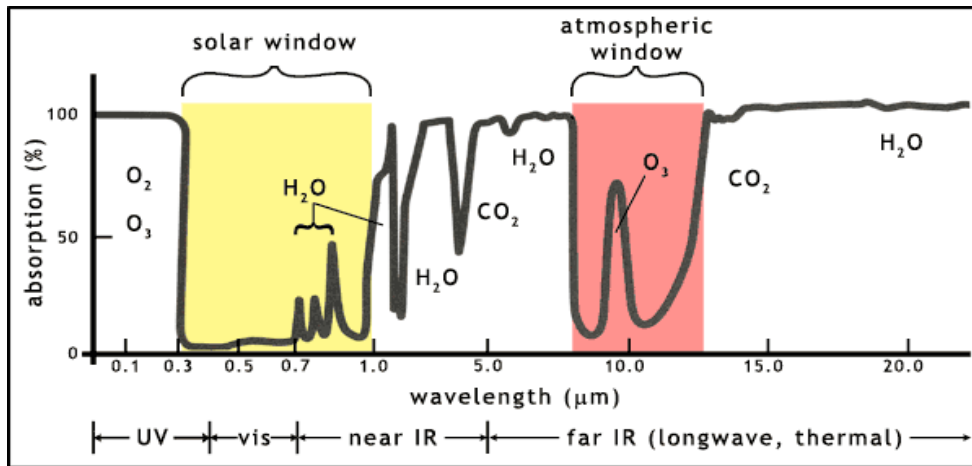


Figure 5.24. Illustration of atmospheric absorption

Energy Interactions with the Earth Surface

When radiation from the sun reaches the surface of the Earth, some of the energy at specific wavelengths is absorbed and the rest of the energy is reflected by the surface material. The only two exceptions to this situation are, if the surface of a body is a perfect reflector or a true black body. The occurrence of these surfaces in the natural world is very rare. In the visible region of the electromagnetic (EM) spectrum, the feature described as the colour of the object is the visible light that is not absorbed by that object. In the case of a green leaf, for example, the blue and red wavelengths are absorbed by the leaf, while the green wavelength is reflected and detected by human eyes. In remote sensing, a detector measures the EM radiation that is reflected back from the Earth's surface materials. These measurements can help to distinguish the type of land covers. Soil, water and vegetation have clearly different patterns of reflectance and absorption over different wavelengths (Figure 5.25).

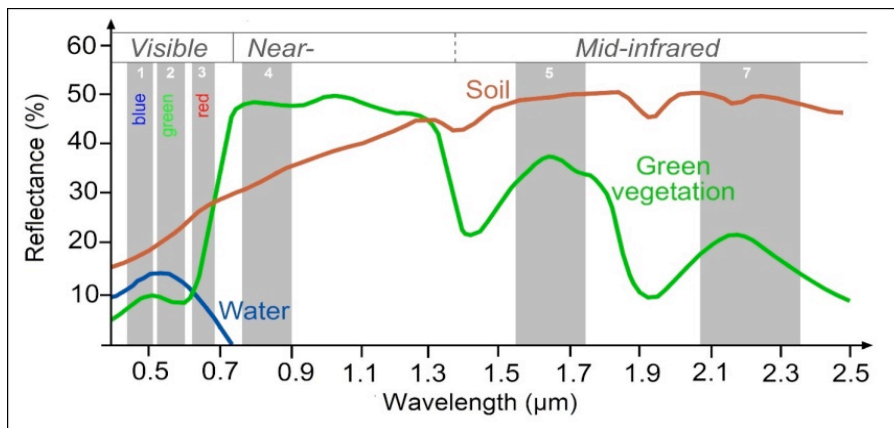


Figure 5.25. Illustration of spectral reflectance of land covers

Satellite Remote Sensing Process

Aircraft and satellites are the common platforms for remote sensing of the Earth and its natural resources. Aerial photography in the visible portion of the electromagnetic wavelength was the original form of remote sensing but technological developments has enabled the acquisition of information at other wavelengths including near infrared, thermal infrared and microwave. Collection of information over a large numbers of wavelength bands is referred to as multispectral or hyper-spectral data. The development and deployment of manned and unmanned satellites has enhanced the collection of remotely sensed data and offers an inexpensive way to obtain information over large areas. The capacity of remote sensing to identify and monitor land surfaces and environmental conditions has expanded greatly over the last few years and remotely sensed data are an essential tool in natural resource management.

A sensor is a device that measures and records electromagnetic energy. Sensors can be divided into two groups (Figure 5.26) namely passive and active. Passive sensors depend on an external source of energy, usually the sun. The most common passive sensor is the photographic camera. Active sensors have their own source of energy; an example would be a radar gun. These sensors send out a signal and measure the amount reflected back. Active sensors are more controlled because they do not depend upon varying illumination conditions. In remote sensing, the sensor is mounted in a platform. In general remote sensing sensors are attached to moving platforms such as aircraft and satellites. Airborne observations are carried out using aircraft with specific modifications to carry sensors. For space-borne, satellites are used. Satellites are launched into spaces with rockets. Satellites for Earth observation are positioned in orbits at a distance between 150 and 3600km above sea level. The specific orbit depends on the objectives of the mission such as continuous observation of large areas or detailed observation of smaller area. Remote sensing instruments used to create base map imagery and elevation data, include film cameras, digital multispectral and hyper-spectral sensors, lidar and radar.

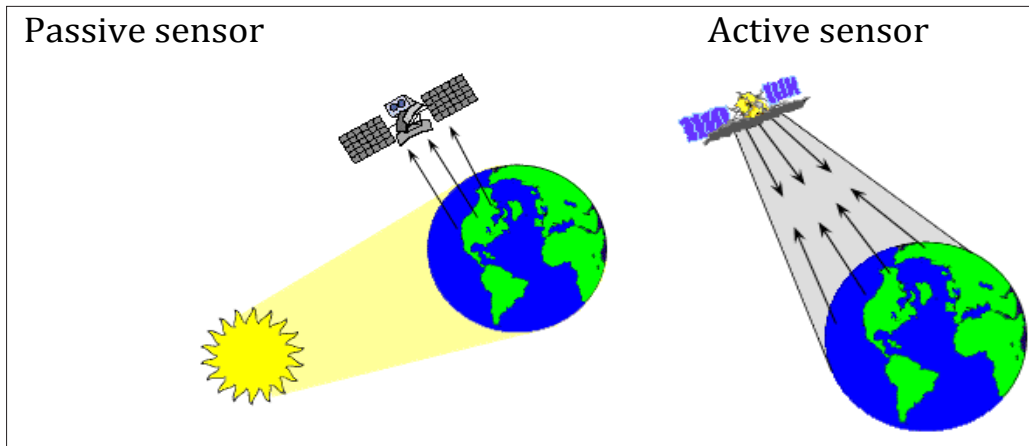


Figure 5.26. Illustration of passive and active sensors

Remote Sensing Data Acquisition and Storage

The source data (raw data array), registered by the ground receiving center, is downlinked as a signal from the satellite as a bit chain, containing both the Earth imaging results, service information about the trajectory, attitude of the spacecraft, and imaging equipment operation modes to mention a few. The data signal passes several processing stages (demodulation, synchronization, decoding), part of which is performed by the hardware, and the other part using software tools straight after the loss of signal with the satellite. Remotely sensed data whether directly downloaded from the Internet site of a data vendor or scanned from analogy materials, must be stored digitally in a certain format before is imported to an image analysis system for processing. Besides, the analysed results must be saved in a certain format appropriate to be integrated with data from another source for further analysis.

Image processing and analysis: many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. The choices of specific techniques or algorithms to use depend on the goals of each individual project. In this section, only procedures commonly used in analysing/interpreting remote sensing images are described.

- Pre-processing: prior to data analysis, initial processing of the raw data is usually carried out to correct for any distortion due to

the characteristics of the imaging system and imaging conditions. Depending on the user's requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include radiometric correction to correct for uneven sensor response over the whole image and geometric correction distortion due to Earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if accurate geographical location of an area on the image needs to be known, ground control points (GCP's) are used to register the image to a precise map (geo-referencing). In order to aid visual interpretation, visual appearance of the objects in the image can be improved by image enhancement techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges.

- **Image Classification:** different land cover types in an image can be discriminated using some image classification algorithms spectral features, i.e. the brightness and colour information contained in each pixel. The classification procedures can be supervised or unsupervised. In supervised classification, the spectral features of some areas of known land cover types are extracted from the image. These areas are known as the training areas. Every pixel in the whole image is then classified as belonging to one of the classes depending on how close its spectral features are to the spectral features of the training areas. In unsupervised classification, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a land cover type by the analyst. Each class of land cover is referred to as a theme and the product of classification is known as a thematic map. The accuracy of the thematic map derived from remote sensing images should be verified by field observation.

Remote Sensing Software

In the mid-1980s when digital image processing was still in its infancy, satellite data were analyzed in microcomputer-based image analysis systems comprising a few separate but linked components. A monitor

was reserved for user interface with the system and another monitor for displaying images. These command-driven systems running in the VAX and later the UNIX environment were user-unfriendly and cumbersome and inefficient to operate. Since then digital image processing systems have greatly improved to graphical user interface. Table 5.1 shows a list of open source and commercial remote sensing software.

Open source (Free) remote sensing software	Commercial remote sensing software
SAGA GIS: System for Automated Geo-scientific Analyses	ERDAS imagine
GRASS: Geographic Resources Analysis Support System	ArcGIS
ORFEO: Optical and Radar Federated Earth Observation	
OSSIM: Open Source Software Image Map	
ILWIS: Integrated Land and Water Information System	
IDRISI	
Opticks	
PolSARPro	
InterImage	
E-foto	
gvSIG	

Table 5.1. Open source and commercial remote sensing software

Geographical Information Systems

Geographical Information Systems (GIS) is a system that handles geographical information or geographical data. As such, it is a tool that helps bridging the gap between different disciplines, e.g. scientific understanding of the environment and sound resource management. It also provides the tools for using different types of information together to solve different problems. But the most important feature of the GIS is that

it handles information in a digital format. In the past, such information was mainly maps in paper format but now computers are used. From the computerised databases, information can be retrieved quickly and easily, as both maps and/or tables. Another important feature with GIS is that it provides tools to bridge between technology and natural sciences, social sciences or human sciences, since it can be used to combine quantitative and qualitative data types. A synthesised definition, GIS is a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially-referenced data for solving complex tasks including planning and management.

The components (Figure 5.27) needed to perform GIS tasks include:

- People (personnel): this is the most important component in a GIS. Experts must develop the procedures and define the tasks of the GIS. They can often overcome shortcomings in other components of the GIS, but the best software and computers in the world cannot compensate for their incompetence;
- Data: the availability and accuracy of data will affect the results of any query or analysis in GIS;
- Hardware: the capabilities affect processing speed, ease of use, and the type of output available;
- Software: this includes not only actual GIS software but also various databases, drawing, statistical, imaging, or other software; and
- Analysis: requires well-defined, consistent methods to produce accurate, reproducible results.

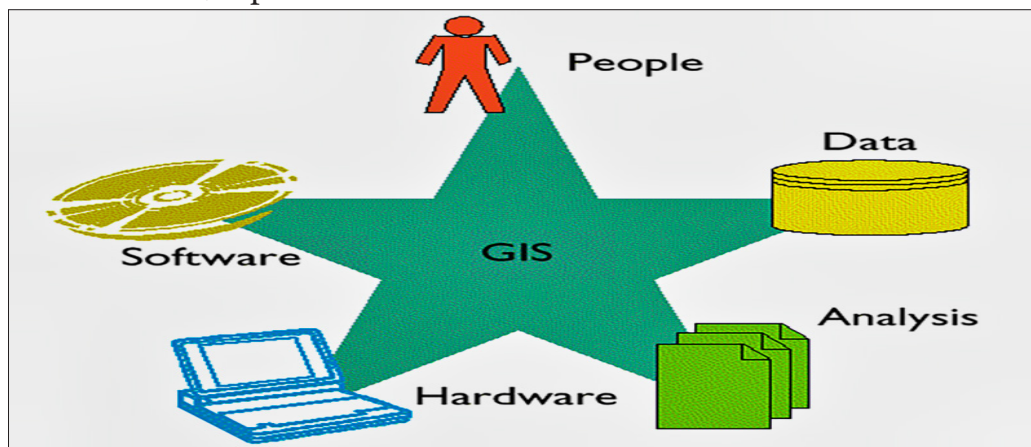


Figure 5.27. Components needed to perform GIS tasks

During the seventies and eighties developments in spatial awareness and how to handle spatial data were being made in key academic centres such as Harvard and ESRI. In the 1990s, one of the largest GIS suppliers released ArcView in 1982 which was a desktop solution for producing mapping systems via a Windows based interface and later ArcGIS Desktop was released in 1999. In 2010, ArcGIS online that can handle imagery processing was released, but both are commercial software sold at high prices. Recently there is a huge development of open source software such as QGIS that are free of costs as shown in Table 5.2.

Open source GIS software	Commercial GIS software
QGIS – Formerly Quantum GIS	ArcGIS
Whitebox GAT	ArcView
SAGA GIS	ArcMap
GRASS GIS	Arcinfo
gVSI	AGISMap
MapWindow	Cartographica
ILWIS	Manifold
GeoDa	MapInfo
uDig	Maptitude
OpenJump	Map Maker
Diva GIS	MyWorld
FalconView	SuperGIS Desktop
OrbisGIS	

Table 5.2. Some GIS softwares

GIS System

Figure 5.28 shows that a geographic information system is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse and

display all forms of geographically referenced information to support decision making. GIS cannot run without data, so data is the food for the GIS. In addition, GIS exists within an institutional context with specific skill requirements e.g. database manager to manage the data, operators to input and process data, and scientists to analyze and interpret the results. A complete GIS system should be able to:

- Handle input and output of geometrical data and attribute data. This involves converting between analogue (paper map or paper table) data and digital format and between different digital formats;
- Store the information in compatible formats usable in GIS applications;
- Structure the information to ensure data access at maximum performance, and maximum security for the data holdings;
- Edit and update the information to reflect changes in the real world;
- Provide tools for analysing the stored data; and
- Display tools for visualizing the information in the database.

GIS Cycle

Data is collected, digitised and structured in a computer database. Data from different sources may be combined and analysed together to yield results that are used for decision-making. The effects of decisions made will eventually necessitate new data collection to update the database. Thus, the GIS-“cycle” will never end as long as there are changes in the real world (Figure 5.28).

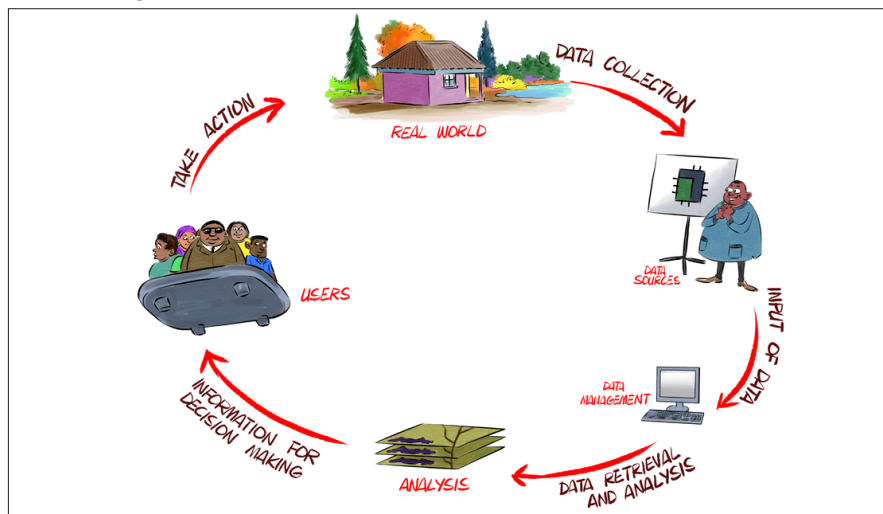


Figure 5.28. GIS cycle
Source: Lund University

GIS Functions

Any GIS should be capable of the following fundamental operations in order to be useful for finding solutions to real-world problems as follows:

- Capturing data: A GIS must provide methods for inputting geographic (coordinate) and tabular (attribute) data. The more input methods available, the more versatile the GIS;
- Storing data: There are two basic data models for geographic data storage: vector and raster. A GIS should be able to store geographic data in both models;
- Analysing data: A GIS must be able to answer questions regarding the interaction of spatial relationships between multiple datasets;
- Displaying data: A GIS must have tools for visualizing geographic features using a variety of symbology;
- Output: A GIS must be able to display results in a variety of formats, such as maps, reports, and graphs; and
- Querying data: A GIS must provide utilities for finding specific features based on location or attribute value.

Geographical Data

These are location data, most often described by geographical co-ordinates. This means that anything that can be put on a map is geographical data. Almost all objects in our surroundings can be connected to a specific location and can be handled in a GIS. Even dynamic objects, e.g. objects that are moving, are possible to include in a GIS. GIS is also very efficient for handling information about change and development by comparing maps from different time periods. Geographical positions are described by an x co-ordinate and a y co-ordinate that indicate the position in a two-dimensional co-ordinate system. Many maps use co-ordinates given in longitude and latitude to describe geographical position.

In the case of GIS, the map data is stored in digital format. Geographical data is partly map data, often referred to as geometrical data, that is, objects with a spatial structure. Examples of geometrical data are vegetation, buildings, topography, roads, wells, cultivated areas, rainfall, etc.

Geometrical objects: Almost every object in our surroundings can be represented on a map using one of three different basic geometrical object types. The simplest type is the point, which is indefinitely small since it has no spatial extension. Points can be used to represent objects like a well, a tree, a soil sample pit, etc. The second object type is the line. Linear objects could be, for example, a road, a river or a power line. The third type of object is the polygon or surface, which covers an area.

In map-making the selection of geometrical object type used for representing different features is very important. Depending on the scale, the object types can also be dynamic. For example, on the map of Tanzania, the FTI-Olmotonyi would be represented as a point while Arusha District would be presented as a polygon. Points, lines and polygons can be used to represent most objects in our environment, which have a discrete and defined spatial delimitation. However, some geographical data have no defined spatial delimitation, and represent instead events that vary continuously over space, e.g. topography, temperature, precipitation and distance. These continuous surfaces must be represented differently on a map.

Attribute data: Geographical data is not only geometrical data but is also composed of what is called attribute data. Attribute data provides information about the geometrical objects. A line object representing a road could have attributes describing the speed limit of that road, whether it is paved or not as well as the number of vehicles passing per day. The owner of a property, the age of a forest, the size of a house, are all attribute data about different geometric objects. The attributes describe the characteristics of the map objects and are linked to these objects in the GIS. The complete geographical database is composed of both geometrical data (map objects) and attribute data. Traditionally, only tables have been considered as attribute data, but with computer technology, any type of digital information can be considered as attribute data. Tables, text, images, audio, video are all examples of attribute data that can be linked to the geometrical objects.

Link between geometrical and attribute data: To be able to connect geometrical data (e.g. map) and the attribute data (e.g. tables), a link indicating which objects belong to each other is needed. The link is used by the computer to recognise what attribute data is connected to what map object. This link is the very essence of GIS since without it the system will not operate properly. Geometrical data containing a number of map objects and a table containing attribute data describes the map objects. Without a link between them, it is impossible to know which row in the table describes which object on the map. A link that unites them is necessary. The link between map and attribute data is established using unique id-numbers. All objects on the map have been assigned unique id-numbers and the corresponding row in the table has been given corresponding unique id-numbers. If the Id-numbers are not unique, the system will not be able to distinguish between two rows in the table or between two objects on the map.

GIS Data Models

There are two conceptually different data models available for storing GIS-databases; the vector model and the raster model. Most advanced GIS software can handle both models and even convert data between the two. The reality can be described using two conceptually different models as discrete objects, possible to represent as points, lines or polygons and continuous surface with no discrete or distinct borders, like temperature, precipitation and topography. To map houses and roads in an area, discrete objects are more suitable to use since these have a defined spatial extent, but to make a topographic map, a continuous surface should be used since topography has a continuous spatial variation. Figure 5.29a presents an example of a vector model representation of the reality, picturing a lake, some roads, villages and some smaller properties, all separated from each other by defined borderlines while Figure 5. 29b presents an example of a raster model representation of the real picturing gradual changes in topography (a continuous surface) with no distinct border lines.

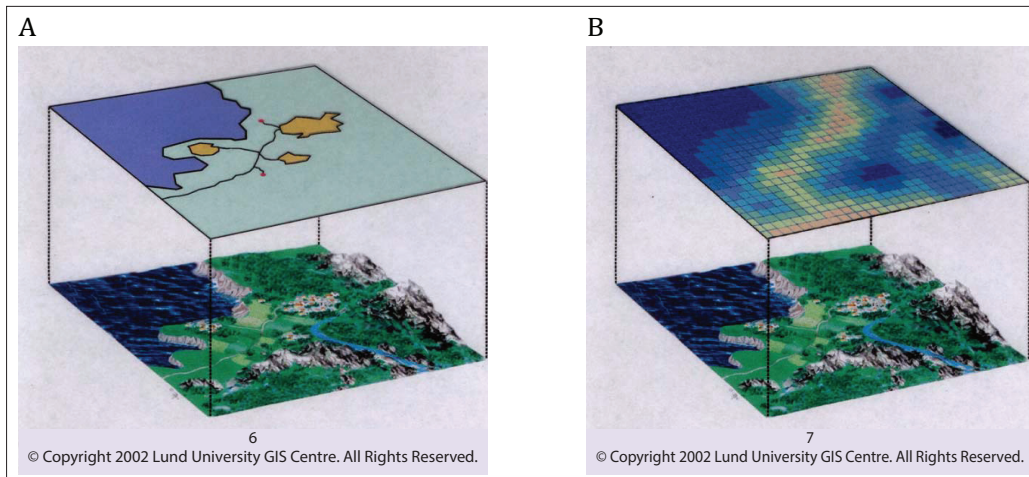


Figure 5.29. Vector and raster models

Geographical and Projected Coordinate Systems

Coordinate systems enable geographic datasets to use common locations for integration. A coordinate system is a reference system used to represent the locations of geographic features, imagery, and observations, such as Global Positioning System (GPS) locations, within a common geographic framework.

Types of coordinate systems: There are two common types of coordinate systems used in a geographic information system (GIS): 1) A global or spherical coordinate system such as latitude-longitude. These are often referred to as geographic coordinate systems; 2) A projected coordinate system such as Universal Transverse Mercator (UTM), Albers Equal Area, all of which (along with numerous other map projection models) provide various mechanisms to project maps of the Earth's spherical surface onto a two-dimensional Cartesian coordinate plane. Projected coordinate systems are referred to as map projections. Coordinate systems (both geographic and projected) provide a framework for defining real locations.

- Geographic coordinate systems: A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the Earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid). The spheroid defines the size and shape of the Earth model, while

the datum connects the spheroid to the Earth's surface. A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the Earth's center to a point on the Earth's surface. The angles often are measured in degrees (or in grads).

- Projected coordinate systems: A projected coordinate system (PCS) is defined on a flat, two-dimensional surface. Unlike a GCS, a PCS has constant lengths, angles, and areas across the two dimensions. A PCS is always based on a GCS that is based on a sphere or spheroid. In addition to the GCS, a PCS includes a map projection, a set of projection parameters that customize the map projection for a particular location, and a linear unit of measure.

Importance of GIS

There are several reasons for using GIS instead of manual techniques traditionally used. The GIS simplifies the geographical analysis and presentation. When working with paper maps, results from analysis often had to be redrawn on new maps, a step that is now omitted in the analysis. Data from different sources can easily be combined in a GIS provided that it is stored in a compatible format and a corresponding geographical reference system. By combining information, it is possible to create new knowledge about the field of study or area of interest. GIS makes storing and handling of data more efficient, data can be accessed from any computer connected to the common database. This means that data is stored only at one place (thus conserving computer space) and handled more efficiently since it is shared online, a user in one country can connect to a database in another country and manipulate the data if permission is granted.

GIS speeds up handling of data and maps since everything can be accessed from the user's computer, reducing time for search and retrieval of information. Advanced GIS analysis, such as simulation, modelling and creation of scenarios, used to be very complicated when working with paper maps describing different spatially related problems. In a computerised environment, modelling of even very complex situations is possible due to the fact that data is stored in compatible databases, which can be

handled and combined in different ways. At the same time, editing and updating is done more efficiently since there is no need for reprinting or redistributing material, as everybody can access the updated data directly in a computer network.

GIS also provides powerful tools for visualising data. GIS software contain tools for professional map-making that makes the communication with decision-makers and other “end users” more efficient. The GIS concept contains a strong component for data sharing, most often in the form of common databases shared by many users online. Independent of the physical location, it is possible for all concerned parties to access and work with the same database at the same time.

Application of Remote Sensing and GIS in Forest Resource Assessment

Spatial Information helps to understand the spatial as well as temporal distribution of the resources for sustainable management as they help to assess status of resources at different geography. Based on the resource base situation, certain management prescriptions can be recommended. Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) are reliable, precise and efficient than any other available resources assessment technologies. These technologies give a visual impression of the landscape that helps to make quick decision in resource management.

Moreover, most aspects of natural resources management require information on the current extent of features and the ways in which their distribution has changed over period of time. Such information can be collected through ground survey and/or the use of aerial survey

and satellite imagery. By capturing these spatial data on computer-based geographical information system and overlaying different data sets, land resource planners and managers have the capability to analyse changes of distribution of features over years. This is important for assessing the impact of previous planning decisions and for carrying out analysis of existing procedures. Major applications of GIS in NRM are resource assessment, change detection, suitability analysis, scenario analysis and impact assessment.

As an example, REDD+ projects in Tanzania applied geospatial technology in the form of geographical information systems to collate, map and report forest carbon emission information. The Monitoring, Reporting and Verification (MRV) system for REDD+ requires the GIS and Remote Sensing techniques to enable the monitoring of larger size areas regularly and with high reliability. Satellite imaging has the advantages of being able to conduct periodic monitoring for large scale landscapes. It is widely used in studies of land utilization and cover classification. GIS and RS technologies have the advantage of offering the easy ascertainment of deforestation regions.

Summary

Forest resource assessment is fundamental in decision making to provide essential data and information for forest managers and decision makers to ensure sustainable forest management. This chapter has described objectives and importance of forest resource assessment, forest inventory planning and methods/designs and important descriptive statistics which should be applied when describing forest parameters of interest. Other essential aspects which also guide and compliment forest resource assessment, i.e. survey and mapping; and remote sensing are described. Application of remote sensing and GIS in forestry has also been covered.

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