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ENSE - 656

RS, GIS and GPS: Basics and Applications

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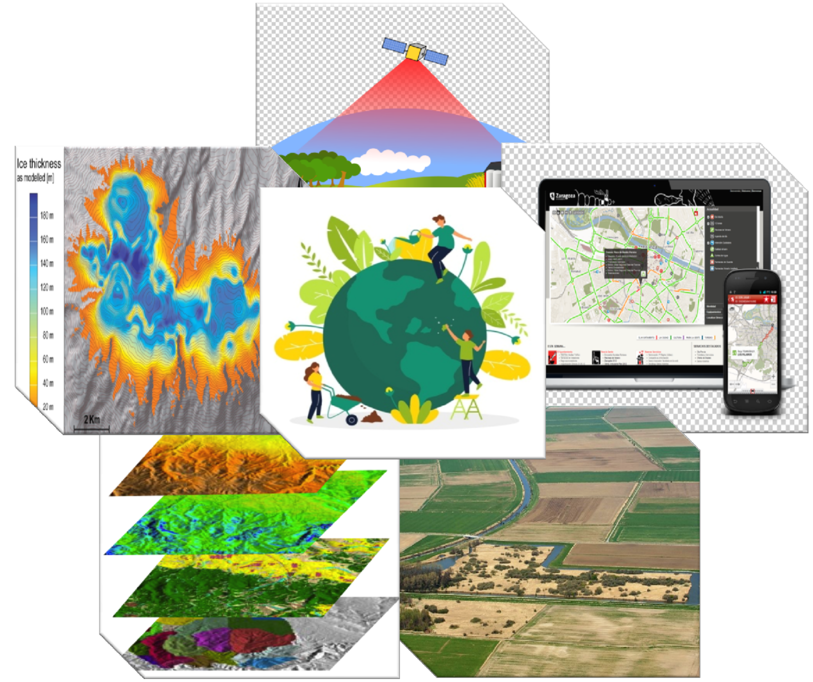
# RS, GIS and GPS: Basics and Applications



Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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# Unit 1: Photogrammetry

**Unit Structure**



## 1.0. Learning objectives

After studying this unit you will be able to explain:

- About digital photogrammetry.
- Learners will acquire skill to work upon DEM, DTM and ortho photos.
- Learners will be equipped with knowledge to study further digital photogrammetry needs, applications and advancement in remote sensing field.

## 1.1. Introduction to Digital Photogrammetry

- Photogrammetry as a science is among the earliest techniques of remote sensing.
- The word photogrammetry is the combination of three distinct Greek words: ‘Photos’ -light; ‘Gramma’ -to draw; and ‘Metron’ –to measure. The root words originally signify "measuring graphically by means of light."
- The fundamental goal of photogrammetry is to rigorously establish the geometric relationship between an object and an image and derive information about the object from the image.
- For the laymen, photogrammetry is the technological ability of determining the measurement of any object by means of photography.

## 1.2. Why Digital Photogrammetry?

- With the advent of computing and imaging technology, photogrammetry has evolved from analogue to analytical to digital (softcopy) photogrammetry.
- The main difference between digital photogrammetry and its predecessors (analogue and analytical) is that it deals with digital imagery directly rather than (analogue) photographs.
- Digital photogrammetry invovles processing of imagery of all types, including passive (e.g., optical sensing) or active (e.g., radar imaging), and taken from any platform (e.g., airborne, satellite, close range, etc.).
- The unique advantages of Digital Photogrammetry in terms of precision and accuracy offers opportunities for automation of DEM/DTM and integration of images acquired on a multi-platform and multi-sensor basis.

## 1.3. Techniques of photogrammetry

1. Depending on the lenses setting:
   A. Far range photogrammetry (with camera distance setting to indefinite).
   B. Close range photogrammetry (with camera distance settings to finite values).
2. on the basis of type of surveying:
   A. Terrestrial or ground photogrammetry.
   B. Aerial photogrammetry.

**A. Terrestrial or Ground Photogrammetry:**

In terrestrial photogrammetry maps are prepared from terrestrial (or ground) photographs or terrestrial photogrammetry employees take photographs from different points on the earth surface for measurement purposes.

The terrestrial photographic surveying considered as the further development of plane table surveying.

**B. Aerial Photogrammetry:**

In aerial photogrammetry maps are produced from air photographs (photographs taken from the air).

Fig 1: Aerial Photography

Aerial Photogrammetry encompasses two major areas of specialization:

- Metrical
- Interpretive

The first area is of principal interest to surveyors since it is applied to determine distances, elevations, areas, volumes, cross-sections and to compile topographic maps from measurement made on photographs.

Interpretive photogrammetry involves objects from there photographic images and judging their significances. Critical factors considered in identifying objects of shape, sizes, patterns,

**Outputs**

1. **Determining the scale of a vertical photograph and estimating horizontal ground distances from measurements made on a vertical photograph.**

**Scale:** The ratio of the distance between two points on a photo to the actual distance between the same two points on the ground (i.e. 1 unit on the photo equals "x" units on the ground).

If a 1 km stretch of highway covers 4 cm on an air photo, the scale is calculated as follows:

$$\frac{\text{PHOTO DISTANCE}}{\text{GROUND DISTANCE}} = \frac{4\text{ cm}}{1\text{ km}} = \frac{4\text{ cm}}{100\,000\text{ cm}} = \frac{1}{25\,000} \quad \text{SCALE: 1/25 000}$$

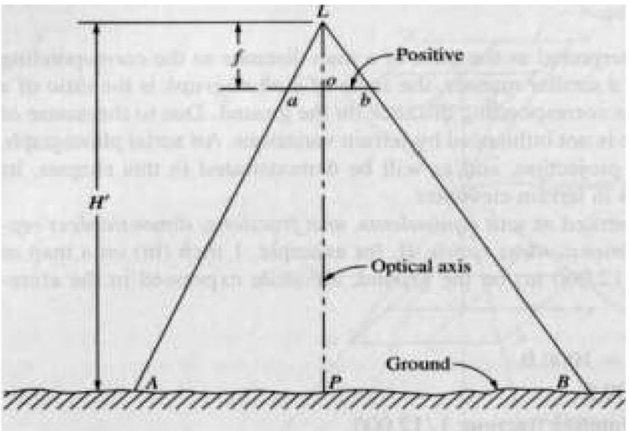



Fig 2: Scale of aerial photograph.

**2. To determine the equivalent areas in a ground coordinate system using area measurements made on a vertical photograph.**

The only difference is that whereas ground distances and photo distances vary linearly, ground areas and photo areas vary as the square of the scale (S).

**Ground area=Photo area * 1/(S*S)**

3. Determination of object heights from relief displacement measurement.

**Relief displacement:** The images of the tops of objects appearing in a photograph are displaced from the images of their bases this is known as relief displacement. The

**Flying height:** When the flying height increased, the relief displacement will be increased.

**The distance from the object from the nadir point:** W hen the distance of object is more from nadir point, the relief displacement will be more.

**The height of the feature:** When the distance of objects from the nadir point is remain same. But the object height increased or decreased. Higher object is more displaced.

**Focal Length:** When the focal length of camera lens is increased, the relief displacement will be more.

Relief displacement is expressed mathematically as:

$$d = hr/H \quad (1)$$

Where, d = Relief Displacement h = Height of the object r = Radial distance from nadir point H = Total altitude of the camera or flying height from equation (1)

Height of the object (h) = dH/r

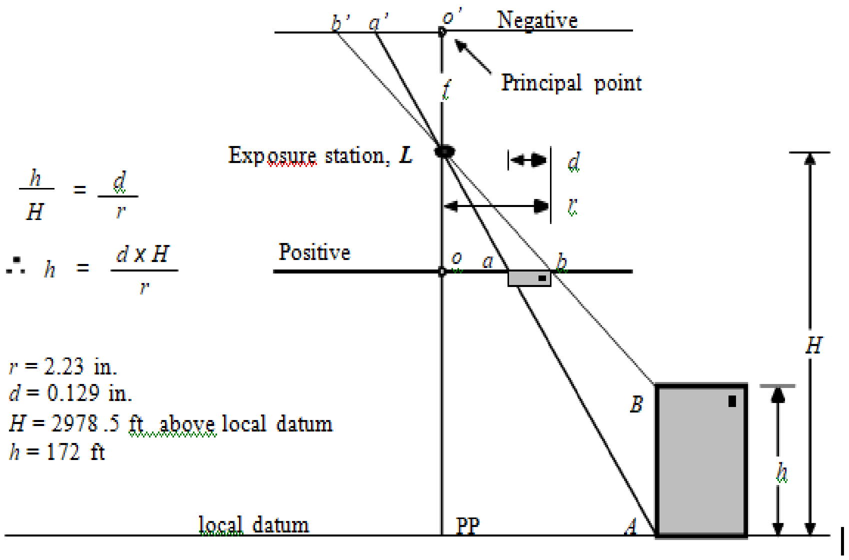



Fig 3: Measurement of height of the object from relief displacement

## 4. Determination of object heights and terrain elevations by measurement of image parallax.

**Image parallax:** The term parallax refers to the apparent change in relative position of stationary objects caused by a change in viewing position.

The absolute stereoscopic parallax is the algebraic difference, in the direction of the flight, of the distance of the two images of the object from their respective principal points. The parallax difference can be used to determine the height of the objects and the dip and slope from the stereo pairs.

To measure the height of an object above or below a reference point from stereo-pair of aerial photograph following data is required: -

i) Flying height above the reference point.

ii) Photo base – Which can be measured from the stereo-pair

iii) Parallax difference – It is measured by the use of a set of measuring marks (sometimes called locating marks.

Now by using following (parallax) formula the height of the objects can be measured.

$h = (Z^*\Delta P) / (b + \Delta P)$

For smaller heights e.g. trees, embankments, buildings the formula is further simplified to:

$h = (Z^*\Delta P) / b$

Where h = height of object , Z = flying height above the reference point, b = photo base, $\Delta P$ = Parallax difference.

This formula gives correct result when the photographs are truly vertical.

## 5. Generation of maps in stereoplotters.

Stereoplotter: Two pictures of a particular area are simultaneously taken, but from slightly different angles. The overlapping area of the two resulting photos is called a stereo pair. A Stereo plotter is an instrument designed for the production of topographic maps from stereo pairs. With this topographic contours can be plotted on the map and the height of vertical features appearing in the model can be determined.

With the advent of technologies Stereo plotters have changed. Starting from projection stereoplotters to Kelsh Plotter to analog stereoplotters to analytical stereoplotter.

Analytical stereoplotter is now being used for different analysis. It incorporates a computer which does the work of mathematically aligning the images so that they line up properly. The analytic stereoplotter also allows for storing the data and redrawing at any desired scale.

Examples of Analytical Stereoplotters Galileo Digicart

Intergraph Intermap

Kern (now Leica) DSR series

Wild (now Leica) AC and BC series, Zeiss Planicomp P series

Matra Traster series

Leica Photogrammetric suite (LPS).

Fig A: Kelsh stereoplotter Fig B: Alpha 2000 stereoplotter

## 6. Generation of Digital Elevation Models and Orthophotographs.

Digital Elevation Model: A digital elevation model (DEM) is a digital model or 3D representation of a terrain's surface. Three different terms are frequently being used

i.e. digital elevation model (DEM), digital terrain model (DTM) and digital surface model (DSM) in scientific literature. In most cases the term digital surface model represents the earth's surface and includes all objects on it. In contrast to a DSM, the digital terrain model (DTM) represents the bare ground surface without any objects like plants and buildings.

DEM is often used as a generic term for DSMs and DTMs, only representing

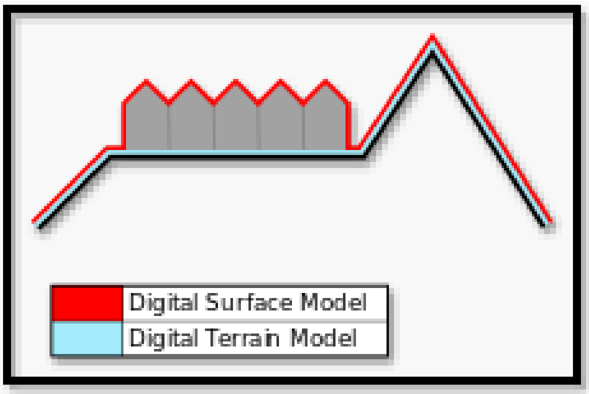



Fig 4: Surfaces represented by a Digital Surface Model include buildings and other objects. Digital Terrain Models represent the bare ground.

height informationwithout any further definition about the surface.

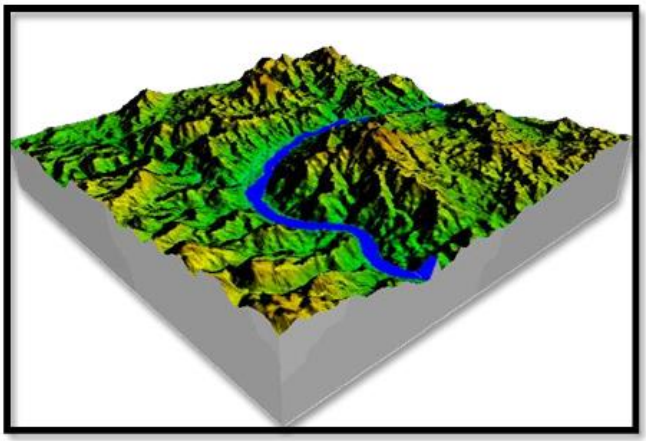


Fig 5: Digital elevation model of Orange River.

## 1.4. Orthophotos and Digital Orthophotography

An orthophoto is an aerial photograph that has been geometrically corrected or 'ortho-rectified' such that the scale of the photograph is uniform.

• Orthophotos are photographs that have been corrected for distortions due to tilting of the camera during the photographic survey, distortions from the camera lens, and relief distortions.

• Orthophotos display all the valuable information of a photograph, but unlike a photograph, true distances, angles and areas can be measured directly (Rossi,2004).

• An orthophoto is an accurate representation of the Earth' s surface. Orthophotos have the benefits of high detail, timely coverage combined with the benefits of a map including uniform scale and true geometry.

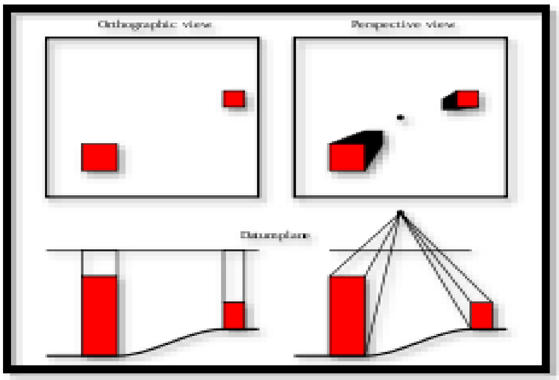


Fig 6: Orthographic views project at a right angle to the data plane. Perspective views project from the surface onto the datum plane from a fixed location.

### 1.4.1. Digital Orthophotograph

A digital ortho-photo is a digital image of an aerial photograph with displacements caused by the camera angle and the terrain removed. It, thus, combines the image characteristics of a photograph with the geometric qualities of a map.

**Requirements:**

Photogrammetry is the technique of determining the geometric properties of objects from photographic images where the 3D coordinates of points, features or objects can be determined by measurements made in stereo pair using the principles of triangulation. The following are essential elements required to produce a digital orthophoto:

1) Photo identifiable ground control points.

2) Camera calibration and orientation parameters.

3) A digital elevation model (DEM).

4) A digital image produced by scanning an aerial photograph with a precision high- resolution scanner.

5) Softcopy Photogrammetric Workstations: Processing the imagery to derive image and vector products using Digital Photogrammetric Workstation (DPW).

A DPW combines computer hardware and software i.e., a graphics workstation with, in most but not all cases, a stereo viewing device and a 3-D mouse. Software configuration includes Erdas Imagine with Leica Photogrammetric Suite (LPS).

For modern DPWs, there's no specific requirement for the host computer. Often a DPW can be built on a high-end desktop PC with at least 256RAM, one or two 19- or 21-inch monitors and a high-performance graphics card.

**Ortho Image generation using Analytical Stereo plotter i.e. Leica Photogrammetric suite:**

**Leica Photogrammetric suite (LPS):** IMAGINE Photogrammetry (formerly LPS and Leica Photogrammetry Suite) is a software application for performing photogrammetric operations on imagery and extracting information from imagery. IMAGINE Photogrammetry is significant because it is a leading commercial photogrammetry application that is used by numerous national mapping agencies, regional mapping authorities, various DOTs, as well as commercial mapping firms. Aside from commercial and government applications, IMAGINE Photogrammetry is widely used in academic research. Research areas include landslide monitoring, cultural heritage studies, and more.

Ortho Image generation involves the following steps to be followed:

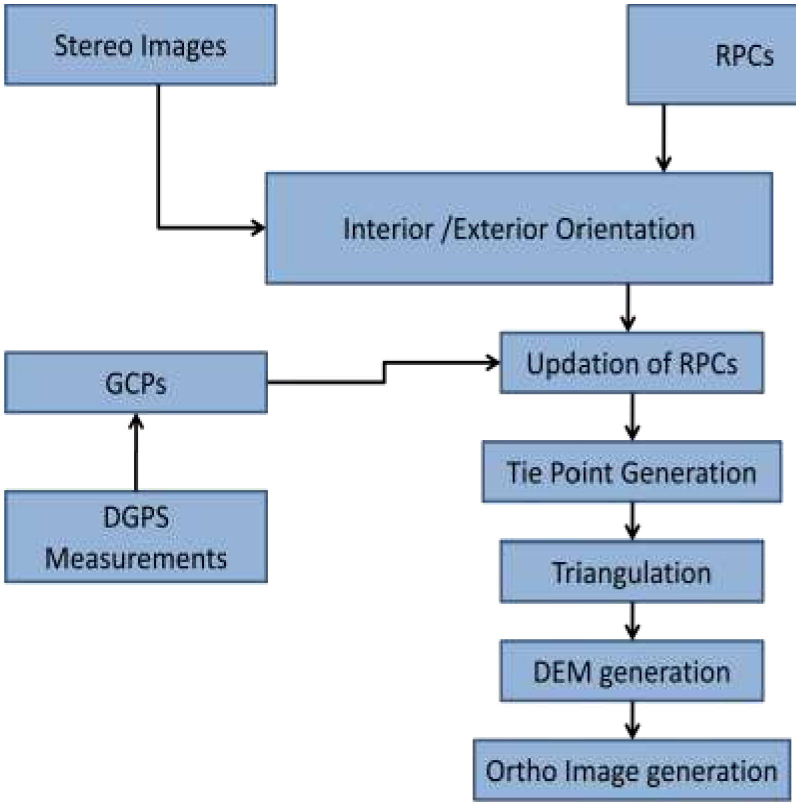


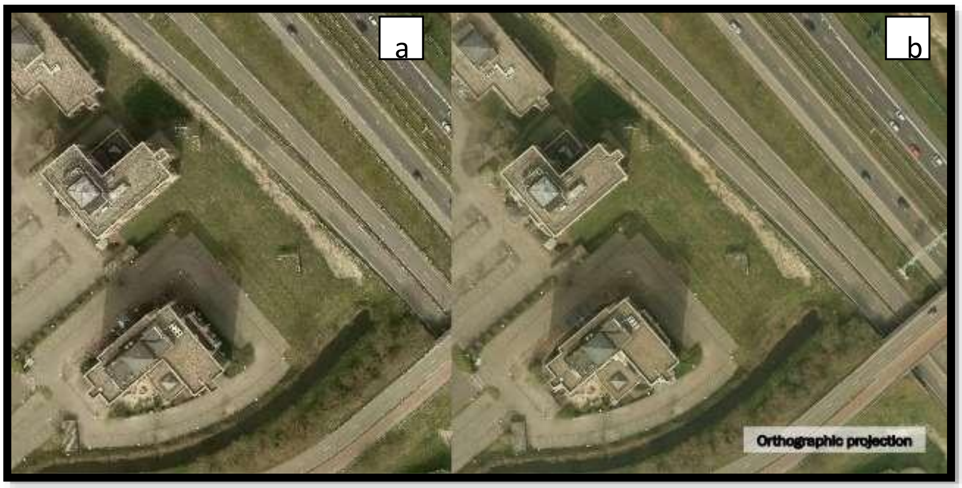

Fig 7: Flowchart for orthoimage generation

In the course of a photogrammetrical project we can provide:

- GPS Control
- Aerial Photography
- Airborne GPS and Triangulation
- Triangulation & Adjustments
- Precise Photogrammetric Observations
- Contour and Feature Mapping

Using a computer called a stereo plotter; the stereo pair can be viewed as a single image with the appearance of depth or relief. Ground control points are established based on ground surveys or aerial triangulation and are viewed in the stereo plotter in conjunction with the stereo pair. In this setting, the image coordinates of any (x,y,z) point in the stereo pair can be determined and randomly selected and digitized. These points, in conjunction with the control points, comprise the data points for the DTM. The accuracy of the final digital orthophoto will depend in large part on the point density of the DTM.

Fig 8: image before (a) and after(b) Orthorectification.




## 1.5. Advantages of Photogrammetry

- Cover areas quickly.
- Low costs.
- Easy to obtain/access information from air.
- Illustrates great detail.
- 3D Visualization.

## 1.6. Applications of Photogrammetry

Photomapping Services provides solutions to the highly specialised needs of today's world to compile datasets from photogrammetry such as the following:

- **Land Surveying:** Surveying or land surveying is the technique, profession, and science of determining the terrestrial or three-dimensional position of points and the distances and angles between them. it involves land use land cover planning urban planning wasteland mapping, etc.

Fig 9: Area demarcation for land surveying

- **Topographic mapping:** One of the most widespread use of Photogrammetry is topographical mapping, which is considered the primary approach to GIS base data collection and updating. it provides topographical information of the area.


Fig 10: Contours draped over the topography of the area

- **Terrain Models:** Digital Elevation Models (DEMs) / Digital Terrain Models (DTMs), Spot Heights, Contours, and Breaklines, which in turn useful to:

- Superimposed over an ortho-photo.
- useful to determine irrigation requirements
- useful to determine drainage requirements

- ideal for rural property mapping

Fig 11: Contour superimposed on ortho-photos.

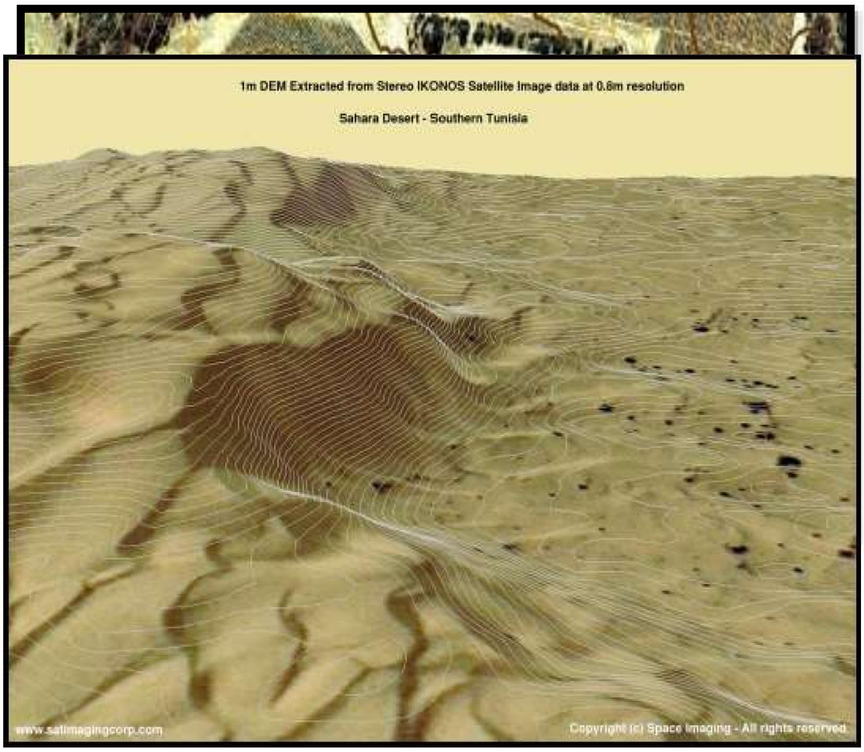



Fig 12: 1m. DEM extracted from Stereo IKONOS satellite image data.

- **Engineering design:**

- 3D model of a busy intersection and railway junction.
- useful for urban infrastructure planning.
- useful for infrastructure design and modelling.

Fig 13: Engineering design planning

- **Natural resource and environmental inventory:** Photogrammetric products are being used to monitor natural and cultural ecosystems.
- **Hydrographic survey:**
  - Detailed Drainage Studies

- 3D model of extensive drainage network
- useful to optimize drainage systems
- ideal for high density urban mapping

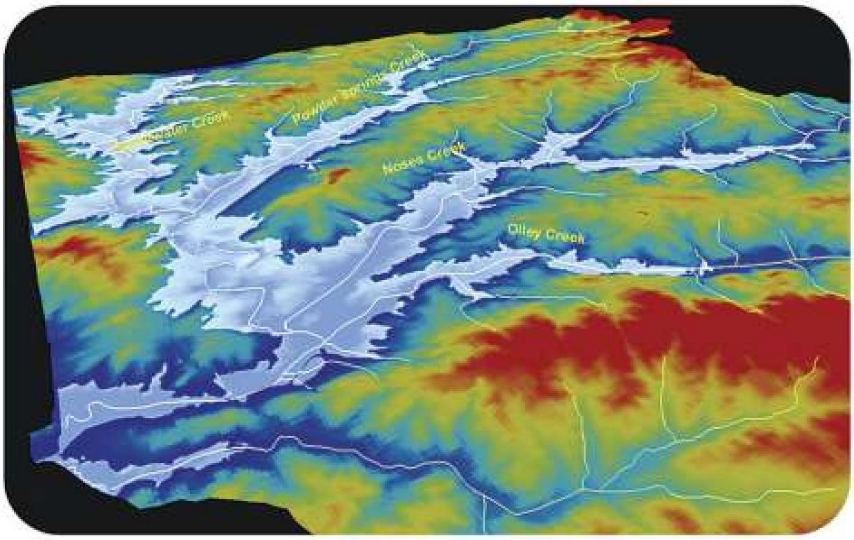



Fig 14: A three-dimensional view of the flooded area showing stream centerlines and elevation

- **Geological Mapping:** This technique allows obtaining a highly accurate 3D picture of the visible outcrop. The spatial pattern of joints in nature can be investigated using the software. This might help to understand how physical rock properties influence the spatial complexity of fracture systems and develop constitutive scaling relationships for certain rock types.

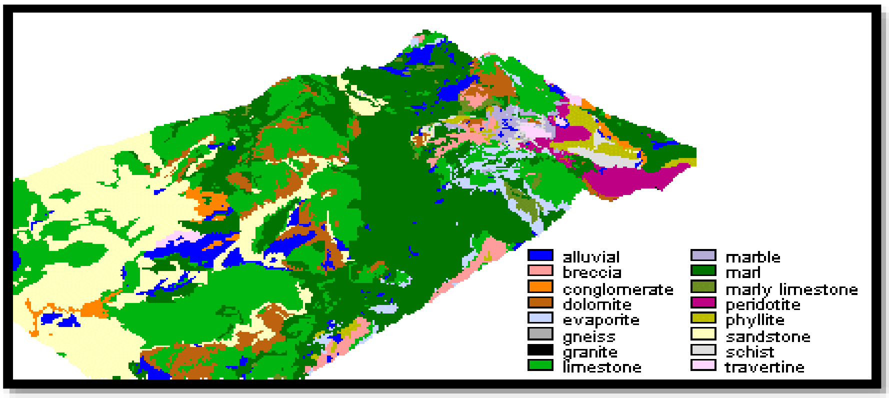



Fig 15: Lithological map draped over the topography

- **Medical Photogrammetry:** Photogrammetric measurement for the diagnosis and treatment of human conditions and for bio-medical research is a form of close-range photogrammetry with its own distinctive challenges and constraints. Reports of fully have been used for a broad variety of medical applications. Amongst them, craniofacial mapping, human trunk and extremity mapping, wound and sore mapping, as well as dental mapping are the most common. Nowadays, laser scanning and 3D probing devices have superseded photogrammetry for many of these applications, whilst photogrammetry has advanced to on-line measuring and real-time navigating applications in the medical field.

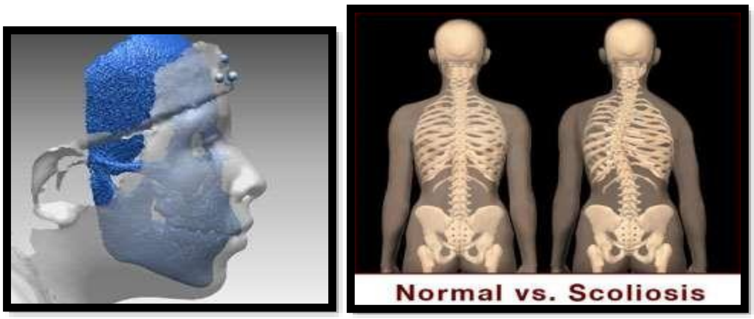



Fig 16:Bone structure and 3D representation of skin

- **Police investigation:** There's an easier way to get all the information at an accident scene than walking around taking painstaking measurements – by using photogrammetry to map the scene instead. Your camera can help you gather all of the important information quickly and accurately, so that you can clear out faster and get traffic back to normal.

Fig 17 collision analysis and accident reconstruction

- **Architectural photogrammetry:** Photogrammetric techniques are being used for the representation of the facades or elevations of historic buildings and structures. The most common product is the line drawing which delineates architectural form. Such surveys are needed by the various disciplines involved in building repair and conservation.

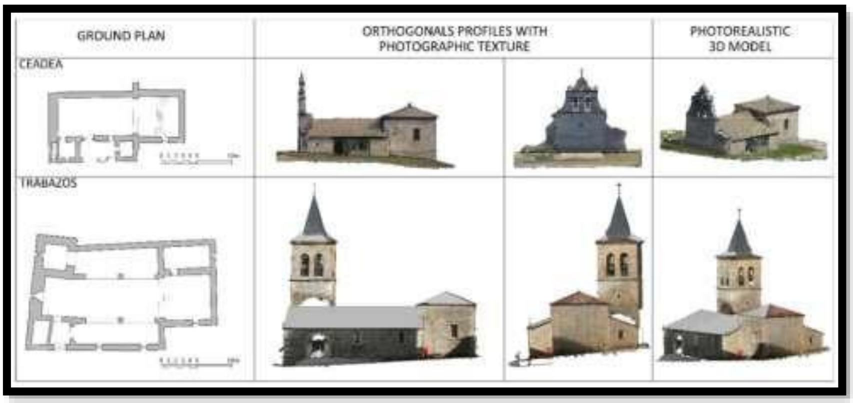



Fig 18: Final graphic documentation of the churches of Ceadea (top) and Trabazos (bottom): ground plan, orthogonal profiles with photographic texture and photorealistic 3D model.

- **Archaeological mapping:** Using Terrestrial photogrammetry archaeologists can produce photographic plans of sites and their stratigraphy, take accurate measurements directly from the photo, and import photographic data into other computerized technologies for mapping and visualizing archaeological features. The production of a photogrammetric image involves the combination of a number of technologies:

- Total station surveying.
- Traditional archaeological photography.
- Geospatial rectification.

By combining these technologies, we are able to produce a hybridized documentation technique that can serve many purposes.

Fig 19: 3D model of archaeological site

- **Industrial machinery:** Photogrammetry has been increasingly applied as a precise 3D measuring tool in industrial and engineering works. Analytical photogrammetry is now routinely employed in tasks of measurement:

o Machine tool inspection.
o Fixture checking.
o Structural deformation monitoring.
o Provision of control databases to guide
o Industrial robots
o Measurement of structures in earth orbit.

Photogrammetric method has advantages of a non-contacting 3D object reconstruction by means of spatial rays. It provides, a short recording time on-site nearly independent from the amount of object points to be measured, and the possibility to choose the recording stations in a very flexible way, If a dynamic or kinematic process has to be recorded, photogrammetry seems to be the only way to measure a whole object simultaneously.

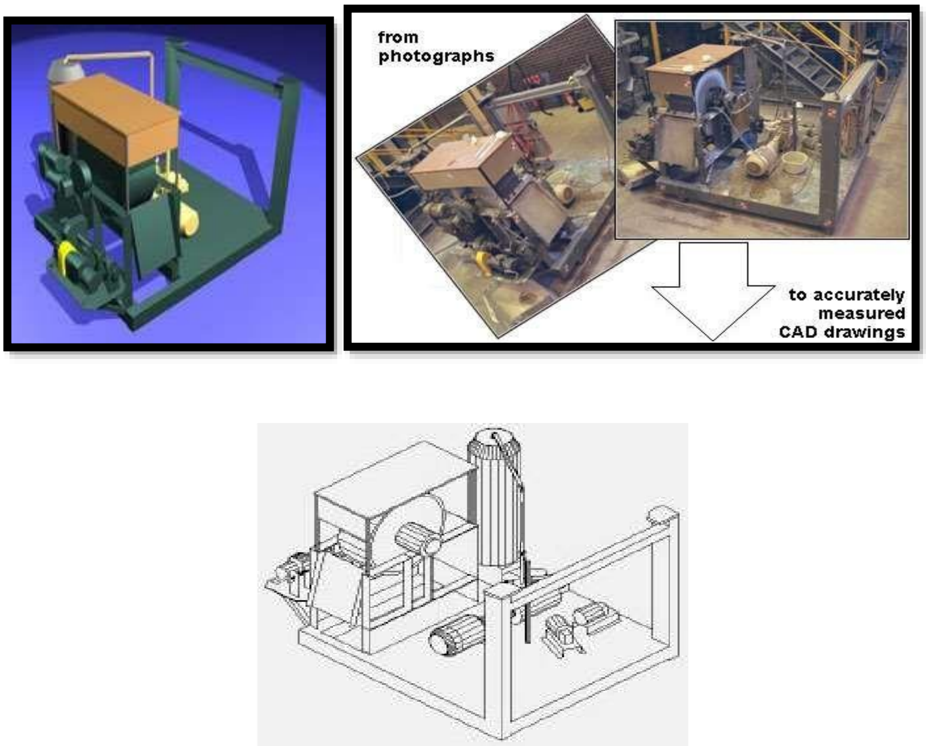



Fig 20: 3D CAD design

- **Military applications:** Mosaic is a aerial photograph of a large area, made by carefully fitting together aerial photographs of smaller areas so that the edges match in location, and the whole provides a continuous image of the larger area. Mosaics are intensely being used by military projects because they provide:

- Synoptic view all over the target area.
- Target planning.
- Topography of the area.
- Decision making, Etc.

Fig 21: Mosaic generated for military Planning.

# Unit 2: Aerial Photographs

**Unit Structure**

## 2.0. Learning objectives

- To understand the basic concept of Aerial Photography
- To study the history of Aerial Photography
- To study the applications and advantages of Aerial Photography

## 2.1. Introduction

**Aerial photography** is the process of capturing of photographs of features of the earth's surface from a certain height or an elevated position using high resolution camera mounted on platforms like helicopters and other light aircrafts which include fixed-wing aircraft, balloons, drones, blimps and dirigibles, pigeons, rockets, kites, vehicle-mounted poles and parachutes. The mounted cameras may be triggered automatically or remotely; hand-held photographs may be taken by a photographer. There are certain things taken into consideration while dealing with fundamental understanding of aerial photography which include scale, film, focal length, overlap, stereoscopic coverage, fiducially marks, roll and frame numbers, and flight lines and index maps.


Figure 1: Antique postcard using kite photo technique (circa 1911) (http://www.wikiwand.com).

Figure 2: Giza pyramid complex, photographed from Eduard Spelterini's balloon on Nov. 21, 1904 (http://www.commons.wikimedia.org).

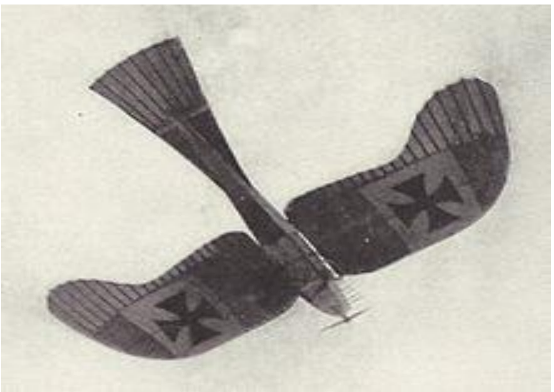


Figure 3: A German observation plane, the Rumpler Taube (http://www.en.wikipedia.org).

Figure 4: A drone carrying a camera for aerial photography (http://www.en.wikipedia.org).

Figure 5: A camera is attached to pigeon for capturing of aerial photos (http://www.northstargallery.com).

## 2.2. History of Aerial Photography

The first known aerial photograph was first practiced in 1858 over Paris, France by the French photographer and balloonist G. F. Tournachon, known as "Nadar". The landscape captured by the photograph was of the French village of Petit-Becetre taken at 80m from ground using a tethered hot- air balloon. However, the photographs did not survive for long and therefore the oldest existing aerial photograph is titled “Boston, as the Eagle and the Wild Goose See It”, depicts Boston from an altitude of 630m, captured by J. W. Black and S. A. King on October 13, 1860 (Figure 6). In addition hot air balloons, pigeons, kites and rockets are also used to carry the cameras in the air to capture the photographs. Aerial photograph from a rocket mounted camera was taken for the first time by the Swedish inventor, Alfred Nobel in 1897. From an aero plane, the first successful aerial photography was taken in 1909, by Wilbur Wright.

Figure 6: Balloon view of Boston captured by J. W. Black and S. A. King on October 13, 1860 (https:// www.smithsonianmag.com/.../this-picture-of-boston-circa-1860).

The famous english meteorologist E.D. Archibald initiated Kite aerial photography in 1882 with the help of an explosive charge on a timer to capture successful photographs from the air. On April 24, 1909, the first ever use of a motion picture camera was mounted on an aircraft over Rome in the 3:28 silent film short, Wilbur Wright und seine Flugmaschine.

The use of aerial photography rapidly developed during the war, as aircrafts were equipped with cameras to verify and record enemy movements and defense systems. In 1913, Germany adopted the first aerial camera, a Gorz. The French army began the war with numerous squadrons of Bleriot observation aircraft laden with cameras for survey and also developed procedures for acquiring print out in record time into the hands of field commanders.

In 1915, C. J. Moore-Brabazon invented the first purpose-built and practical aerial camera aided by the Thornton-Pickard company, greatly enhancing the efficiency of aerial photography. Moore- Brabazon also introduced the inclusion of stereoscopic techniques into aerial photography, permitting the height of objects to be differentiated on the landscape by comparing photographs taken at different angles.

## 2.3. Commercial aerial photography

Francis Wills and Claude Graham White the World War I veterans, founded the first commercial aerial photography company in the UK was Aerofilms Ltd., in 1919. Later on, the Aircraft Manufacturing Company (the De Havilland Aircraft Company), hired an Airco DH.9 along with pilot entrepreneur Alan Cobham. Another successful breakthrough in commercial aerial photography was given by the American Sherman Fairchild who started his own aircraft firm Fairchild Aircraft in 1935, especially for the purpose of aerial survey missions. Later on, Fairchild developed a high altitude camera with nine-lens in one unit that could capture a photo of 600 sq. miles with each exposure from 30,000 feet. Fairchild also designed and develop airplanes with high-wings and enclosed cabins as a more stable and protected platform for photography that lead to his strong commitment in the business of aerial photography. This aerial map (overlapping photographs) of Manhattan Island became a commercial success of Fairchild which was later on used by several New York City agencies and businesses.

## 2.4. Basic Concepts of Aerial Photography

### 2.4.1. Camera

In early days the cameras used for photography were often no more than a light-tight box with a pinhole at one end and the exposed light sensitive material fitted against the opposite end. Later on the pinhole camera was replaced by simple lens camera. The Cameras and their applicability for aerial photography are the simplest and oldest of sensors exploited for remote sensing of the earth's surface. The camera is a framing system which takes a near-instantaneous "snapshot" of an area of the surface. The camera systems are passive optical sensors that use a lens to form an image at the focal plane, the plane at which an image is precisely defined.

### 2.4.2. Film

Black and white film are most common films used in aerial photos, however infrared, colour, and false-colour infrared film are also used for certain special projects. The photographic films are sensitive to light from 0.3 μm to 0.9 μm in wavelength which include the ultraviolet (UV), visible, and near-infrared (NIR). **Panchromatic films** are sensitive to the UV and the visible portions of the spectrum. The panchromatic film is the most common type of film used in aerial photography and produces black and white images.

### 2.4.3. Focal length

It is the distance from the middle of the camera lens to the focal plane (i.e. the film) and is calculated after calibration of the camera. With the increase in focal length, image distortion decreases. The relationship between the focal length (f), object distance (o) and image distance (i) is given below

$$1/f=1/o+1/i \qquad \textbf{(Eq. 1)}$$

### 2.4.4. Scale

It is the ratio of distance between two points on a photo to the actual distance between the same two points on the ground (i.e. 1 unit on the photo equals "x" units on the ground). Another method used to verify and evaluate the scale of a photo is to determine the ratio between the camera's focal length and the plane's altitude above the ground being filmed. Unit Equivalent, Representative Fraction and Ratio are some of the ways that can be used to express the scale. For example

A photographic scale of 1 mm on the image represents 25 meters on the ground would be expressed as follows:

Unit Equivalent - 1 mm = 25 m

Representative Fraction - 1/25 000 Ratio - 1:25 000

Scale can be large or small

**Large Scale-** Larger-scale based photos (e.g. 1: 25,000) cover small regions in greater detail. A large scale photograph means that ground features are expressed in more detailed size at large. The area of ground coverage on the photograph is less than at smaller scales.

**Small Scale-** the photos that are captured on small scale (e.g. 1: 50,000) cover ground features of large regions/areas in less detail. The area of ground coverage captured on the photo is greater than at larger scales. An example for 1: 50,000 scale is given below-

$$\frac{\text{FOCAL LENGTH}}{\text{ALTITUDE (AGL)}} = \frac{152\text{ mm}}{7\,600\text{ m}} = \frac{152\text{ mm}}{7\,600\,000\text{ mm}} = \frac{1}{50\,000} \quad \text{SCALE: 1/50 000}$$

A variety of photographic scales, such as 1: 3,000 (large scale) of selected areas, and 1: 50,000 (small scale) are available at The National Air Photo Library.

The scale at a point on a truly vertical photograph is given by

$$\mathbf{S = f/\ H- h} \qquad \textbf{(Eq. 2)}$$

Where,

S = photographic scale at a point f = camera focal length

H= flying height above datum

h = elevation above datum of the point

### 2.4.5 Exposure

At any point in the image, the exposure is determined by the irradiance at that point multiplied by the exposure time, expressed as

$$\mathbf{E= sd2t/4f2} \qquad \textbf{(Eq. 3)}$$

Where

E= exposure, J $mm^{-2}$

s= scene brightness, J $mm^{-2}$ $sec^{-1}$

d= diameter of lens opening, mm

t= exposure time, sec

f= lens focal length, mm

From the Eq. 2, it can be seen that the exposure varies with respect to shutter speed t and/or the diameter of the lens opening d. The various combinations of d and t will produce equivalent exposures for a given camera.

### 2.4.6 Fiducial marks

these are small registration marks (figure 7) that are exposed on the edges of a photograph. The measurement of distances between fiducial marks are precisely is done when a camera is calibrated, and such information is being used during compilation of topographic map by cartographers.

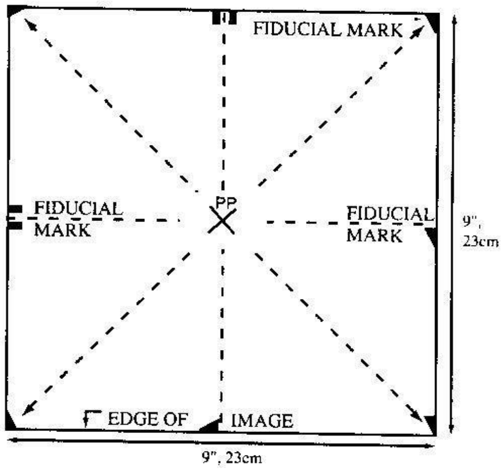



Figure 7: The image showing fiducial marks (http://www.hosting.soonet.ca)

### 2.4.7 Overlap

It is the amount by which one photograph comprises the area covered by another photograph, and is expressed as a percentage (%). The photo survey is designed to get 30% lateral overlap (between photos on adjacent flight lines) and 60% forward overlap (between photos along the same flight line)

### 2.4.8 Stereoscopic Coverage

It is the representation of the three-dimensional (3D) view which results when two overlapping photos (known as stereo-pair), are viewed with the help of a stereoscope. Each photograph of the stereo-pair offers a slightly different view of the same area, which the brain merges and interprets as a 3-D view.

### 2.4.9 Roll and Photo Numbers

It is a type of identification number which allows searching of the photo in NAPL's archive, besides metadata information, the plane's altitude, the focal length of the camera, and the weather conditions. Each photograph is assigned a unique index number according to the photo's roll and frame.

### 2.4.10 Flight Lines and Index Maps

The contractor of aerial survey plots the location of the first, last, and every fifth photo centre, along with its roll and frame number, on a National Topographic System (NTS) map. Photo centres are represented by small circles, and straight lines are drawn linking the circles to show photos on the same flight line. This graphical representation is known as air photo index map, which allows the photos to relate with their corresponding geographical location. On NTS map sheets, small-scale photographs are indexed on 1: 250,000 scale and larger-scale photographs are indexed on 1: 50,000 scale NTS maps.

### 2.4.11 Color-Mixing Process

The color mixing is very important for an observer to see the real true colored picture of the landscape. The trichromatic theory of color vision explains that when blue, green and red elements are stimulated by different amount of light, we perceive color just like the phenomenon behind the rod cells and cone cells of the human eye. The red, green and blue are termed as additive primaries whereas yellow, magneta and cyan are known as complementary colors of blue, green and red light. There is a concept called hue cancellation method which states that when the certain colors are mixed together, the resulting colors are not what would be intuitively expected. For example, when red and green are mixed together, the resultant color is yellow not reddish green.

There are two types of color mixing: Additive and Subtractive.

#### 2.4.11.1. Additive Mixing

The superimposition of two beams of light corresponds to additive mixing.

The additive mixing of colors is unintuitive as it does not related to the mixing of physical substances which would correspond to subtractive mixing. Regardless of being unintuitive, it is theoretically simpler than subtractive mixing.

In the absence of color, the result is black. If all three primary colors (red, blue and green) are showing, the result is white. When red and green colors are combined, the result is yellow and with that of red and blue, the result is magenta. For blue and green combination, the result is cyan.

Additive mixing is used in television and computer monitors to produce a wide range of colors using only three primary colors. A pixel is a combination of the three primary colors. Projection televisions usually have three projectors, one for each primary color.

**2.4.11.2. Subtractive Mixing**

The mixing of physical substances corresponds to subtractive color mixing; therefore it corresponds to our perception about mixing colors. To explain the mechanism, let us mix red paint with yellow paint. The red paint is red because when the ambient light strikes it, the composition of the material is such that it absorbs all other colors in the visible spectrum except for red. The red light, not being absorbed, reflects off the paint. The similar mechanism describes the color of all material objects -- note that light is not a material object -- and so applies to the yellow paint as well.

In subtractive mixing of color, the absence of color is white and the presence of all three primary colors is black. By convention, the three primary colors in subtractive mixing are yellow, magenta and cyan. The secondary colors are the same as the primary colors from additive mixing, and vice versa. Subtractive mixing is used to create a range of colors when printing on paper by combining a small number of ink colors, and also when painting. Upon mixing yellow and blue, Green color is produced and with that of red and yellow, orange is produced.

The color film photography rely on the principle of subtractive color mixture using superimposed yellow, magenta and cyan dyes (Subtractive primaries) to control the proportionate amount of green, blue, and red light that reaches the eye. Therefore, the subtractive mixture of yellow, magenta and cyan dyes on a photograph is used to control the additive mixture of blue, green and red light reaching the observer. To achieve this, color film is manufactured with three emulsion layers that are sensitive to blue, green and red light but contain yellow, magenta and cyan dye after processing.

**2.4.12 Filters**

The use of filters or color screens has been very frequent in ordinary landscape photography. With the help of filters a selective wavelength of light reflected from the scene is allowed to reach the image plane (film). They are placed in front of the lens in the optical path of a camera. Filters are often used for the purpose of correct brightness rendering, calculated for a given color sensitive plate so that the resultant feedback to the light of the spectrum copies the sensitiveness of the eye, which is greatest in the yellow-green. Such filters for use with the common orthochromatic plates are of a general yellow color. The filters used in aerial cameras consist of organic dyes suspended in glass or in a dried gelatin film. The most commonly used filters are absorption filters which allows differentiation of objects with nearly similar spectral response patterns in major portions of the photographic spectrum.

ND Filter or neutral density filter is possibly the most useful filter in the aerial photography. This filter is a sunglass lens for the camera, decreasing light levels without altering color or having any other side effects.

The Camera filters are of two types-

**Screw-on filters** come in different sizes, related to different lenses of the camera. A lens with a 52 mm mount can only work with 55 mm filters.

The second type of filter is a **sheet of glass**, which go down into lens adapters. The glass itself can be used with adapters of all sizes, and the adapters are fairly cheap.

## 2.5. Types of Aerial Photography

### 2.5.1 Oblique Aerial Photographs

Oblique photographs are those photographs that are taken at certain angle with respect to the ground surface (ie not directly overhead as in 'Vertical'). The photographs taken at low angle are known as low oblique photographs whereas those taken at high or steep angle are known as high or steep oblique photographs that include the horizon. Both low and high oblique can be taken as 'wide shots' or 'close-ups'.

Figure 8: Abalone point, Irvine Cove, Laguna Beach an example of low-altitude aerial photography (http://www.sky-photo.net).

Figure 9: Oblique Aerial Photo (http://www.wikiwand.com).

### 2.5.2. Vertical Aerial Photographs

Vertical photographs are taken straight down with the camera tipping directly down at 90˚ (or with <3˚ tilt) to its centre point and cover relatively a smaller area. In the viewfinder, all the four corners of the ground framed must be more or less at equidistant from the film/sensor plane. This helps in producing a map-like perspective and permits the consequential photograph to be 'scaled' and dimensions taken from it. True Verticals are proven to be very useful in mapping and should be considered as a series of overlapping images or mosaics. The vertical photographs are chiefly used in image interpretation and photogrammetry.

Figure 10: Vertical Orientation Aerial Photo (http://www.quora.com).

### 2.5.3. Ortho-Rectified Vertical

In this type of aerial photograph, all the geographical and topographical distortions are removed from a true vertical image and have been corrected optically. The Ortho-rectified photo is a simulation of a photograph captured from an infinite distance, looking directly down to nadir. While capturing the photograph of a landscape, distortions occur as a result of defective optical lenses and digital sensors, the tilt of the camera/sensor (relative to the ground), and other aspects. The images cannot be used for mapping and scale its measurement which are not ortho-rectified. Ortho-rectified photos are commonly used in geographic information systems (GIS) cartography to create maps. These images can be broadly deployed once after their alignment or registration with known coordinates. These orthophotos are extensively used in online mapping systems such as Google Maps. The ‘Google Earth’ overlays satellite imagery or orthophotos over a digital elevation model (DEM) to simulate 3D landscapes.

### 2.5.4. Trimetrogon

This type of photography is a combination of three photographs captured at the same time, one vertical and two high oblique’s, in a direction at 90˚ to the line of flight. The oblique’s are captured at an angle of 60˚ from the vertical, side lap the vertical photography, and resulting composites from horizon to horizon.

### 2.5.5. Mapping

It is a type of aerial photography in which two or more vertical photos are joined or mosaic to produce a larger area.

## Combinations

Depending on their purpose, the combination can be done in several ways, a few are listed below.

**Panoramas**

Panoramas are often produced by stitching several photographs overlapping and adjacent images captured (coupled with computer software) with one hand held camera. A loose term, usually referring to an exceptionally 'wide' shot, which includes a large area of the horizontal view.

**Pictometry**

In pictometry one vertical and four low oblique photos are produced by five rigidly mounted cameras and such images can be used together.

## 2.6. Aerial videography

Aerial video is becoming more popular with innovative approaches and advancements in video technology. With the help of GPS, video may be incorporated with meta-data and afterward synced with a video mapping program. The aerial videos are emerging 'Spatial Multimedia' which can be used for understanding of scenes and tracking of object. Such spatial multimedia is the appropriate and timely bound combination of digital media including still photography, stereo, motion video, panoramic imagery sets, audio, immersive media constructs, and other data with date-time and location information from the GPS. The combination of digital video, global positioning systems (GPS) and automated image processing will help in improving the accuracy and cost-effectiveness of data collection and reduction.

## 2.7. Types of Film

The films widely used in aerial photography include infrared, panchromatic, color and Camouflage detection film-

**a.** **Infrared:** This is a black-and-white film that is sensitive to infrared (IR) waves that can be used to detect artificial camouflage materials and to capture photographs at night if there is infrared radiation.

**b.** **Panchromatic:** This type of film is used in the average hand-held small camera. This film is commonly used film in aerial photography which records the amount of reflected light from objects in tones of gray running from white to black.

**c.** **Color:** This film is the same as that used in the average handheld camera and is timely dependent. It is limited in its use as it requires time to process and its need for clear, sunny weather.

**d.** **Camouflage Detection:** This type of special film helps in recording natural vegetation in a reddish color. When artificial camouflage materials are photographed, they appear purple or bluish.

## 2.8. Applications of Aerial Photography

Aerial photography can be very useful in infinite number of ways. Some important applications of aerial photography include defense and security system, environmental studies, inspection of power lines and grid system, cartography, land-use planning, archaeology, surveillance, commercial advertising and business activities, movie production, etc. Some of these are described below as-

### 2.8.1 Environmental Protection- Nature and Wildlife

Aerial photography provides a great deal of benefits related to the environment is the documentation of a activities/situation and monitoring its change over time with the help of aerial photos in order to raise awareness through campaigning. Through such efforts public opinion can influence/guide the willingness of government to integrate environmental data into existing plans, policies and regulations in order to guard the environment. Destruction of wildlife habitat frequently happening due to unorganized, uncoordinated and defectively planned land development and has been a major cause of threat to the environment and the wildlife.

Figure11: Aerial photograph showing destruction of forest habitat (http://www.sierraclub.org)

### 2.8. 2 Geography & Cartography

Aerial photography has been considered as an essential part of cartography (mapmaking process) in the modern era. The aerial photos offer a straightforward/easy depiction of the physical and cultural landscape of a region at a given time. These aerial photos after interpretation provide a symbolic and pictorial basis frequently critical for the studies by ecologists, historians, geographers, geologists, archaeologists, and other professionals.

### 2.8.3 Engineering & Urban Planning

The concept of smart cities, high profile development of urban sectors is the need of modern age. Therefore, the aerial photos proved to be very important and have gained esteem among developers, planners and engineers for mapping at small scale for the purpose of urban and land development. Integration of information obtained from aerial photos with Geographic Information System (GIS) mapping is very useful for the analysis, strategic planning and evaluation in planning and engineering of urban sectors.

Figure 12: A photograph of urban sector showing the pattern of settlements (http://www.pinterest.com)

### 2.8.4 Land cover and land use classification

The aerial photographs are being frequently used for land use land cover (LULC) information for regional scale planning and development. These aerial photos after registration and digitization can be used to classify the ground features and evaluates the change in area (change detection analysis).

### 2.8.5 Agriculture & Precision Agriculture

Aerial photographs facilitate more precise interventions and techniques in the field of agriculture. Being a farming management notion, precision agriculture is based on observing and reacting to intra- field variations. The precise agriculture depends on modern technologies like Aerial Imagery and information technology Global Positioning System (GPS).

### 2.8.6. Journalism

In past few decades, aerial photos have been used more frequently to carry out the practice of investigation and reporting of incidents/events. They provide precise information about a geographical idea of a particular location and explore the information given to the public.

Figure 13: An aerial view of property damage due to fire incident (http://www.pressgazette.co.uk).

### 2.8.7. Surveillance and Monitoring System

For the purpose of monitoring of earth on a large scale, the aerial photos are used to integrate and complement satellite images in order to validate the interpretation of data. And in situations of rapid change aerial photos on a small scale can directly provide with constant information to the existing Surveillance System. They can also feed surveillance functions of vast properties, frontiers and maritime domains. With the help of systems such as APDER, the aerial photos could provide key information in surveillance in special situations such as regional violence or civil unrest where observatory mechanism and other related resources are limited.

### 2.8.8. Tourism

For some countries the tourism is a back bone of their economy and therefore aerial photography can play a significant role in tourism promotion. The tourism composed of eco-tourism and leisure industries presently uses aerial photography for fresh presentation and proposal strategies. The aerial photos are used for promotion of tourism and their main resources/assets, which consists of a unique landscape and attractive scenery, remarkable cultural heritage, sports activities/facilities and other services. All the organizations and agencies who deal with tourism use aerial photography as one of the main tools to nourish their business. Hotels, resorts, tour guides and travel agents use aerial photos for their advertisement and tourism activities to gain information related to business spots or desired location.

### 2.8.9. Climate Change

Climate change is one of the most threatening factors for the survival of human, flora and fauna, glaciers, forests, and other natural resources. In order to combat with drawbacks of climate change, it is very important to monitor the climate changes on regular intervals. The aerial photographs play such a role in monitoring the changes that could occur in natural landscape such as melting of glaciers, shrinking of forests and water bodies, drought, expansion of settlements and other commercial set ups. Therefore, it is very essential for the researchers to collect information and maintain records in changes over different seasons and years to follow the effects of climate change and associated risks to ecosystems.


Figure 14: Aerial photographs depicting melting of Grinnell glacier in Montana, USA (http://www.demilked.com).

### 2.8.10. In other earth sciences

The aerial photographs can also be very useful to investigate the mechanism of natural changes, such as variations in land resources, precipitation and geology over time that may lead to disasters such as droughts and landslides.

## 2.9. Advantages of Aerial Photography over ground-based observation

-Aerial photography pro vides an advanced vantage point.

-It offers a permanent recording facility.

-It has broader spectral sensitivity than the human eye.

-It provides a better spatial resolution and geometric fidelity than several ground-based sensing methods.

## 2.10. Conclusions

At the end of the module, the student would have understood the basic concept of aerial photography and gained an insight into the history and types of films used in aerial photography. Besides, the applications of aerial photography and its advantages over ground-based methods have been discussed in this module.

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# Unit 3: Remote Sensing

**Unit Structure**



## 3.0. Learning objectives

After studying this unit you will be able to explain:

- This unit will help you to understand the basic principle of remote sensing and the processes involved. For this purpose, we will begin with the fundamentals of the electromagnetic energy and then consider how the energy interacts with the atmosphere and Earth surface features.
- We would also discuss the role that reference data play in the data analysis procedure and describe how the spatial location of reference data observed in the field is often determined.
- Energy interactions with earth surface materials

## 3.1. Introduction

Humans are closely associated with remote sensing in day to day activities by collecting and inferring useful information about the surroundings sensed through the eyes. Our eyes act as sensors which are limited to record only the visible portion of the electromagnetic energy and our brain act as a processing unit which stores the viewed information for a limited number of days. This limitation forced mankind to develop a technique capable of acquiring information about an object or phenomena covering almost the entire range of electromagnetic spectrum. The data so acquired is stored in some medium (e.g. DVDs, CDs etc.) for future interpretation and analysis. Present day sensors are installed on board satellite platforms and are capable of imaging large portions of earth and continuously transfer the digital data electronically to the ground stations.

The science of Remote Sensing has continuously evolved in the data acquisition methods as well as data processing techniques and the variety of applications it is used for. The remote sensing technology has advanced particularly towards variety of applications related to land, water and atmosphere issues e.g. water resources development and management, soil and mineral explorations, agricultural and land use practices, air quality monitoring, disaster management and mitigation, ocean studies and many more.

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 contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 1994). This implies that as we are reading the words that make up the sentences, our eyes act as remote sensor that respond to light reflected from this page. These responses based on reflected light help us distinguish between white areas of the paper and dark areas reflected from the letters of the page. These data are analyzed or interpreted in our brain to explain the dark areas on the page as a collection of letters forming words. This is continued further with words forming sentences and the information carried in the sentence is interpreted.

## 3.2 Definition and Scope

As discussed in the above section, our eyes are an excellent example of a remote sensing device that are capable of gathering information about the surroundings by judging the amount and nature of the reflectance of visible light energy from some external source (such as the sun or any artificial source of light) as it reflects off objects in our field of view. Gathering information where sensor and the object are not in direct contact with each other may be termed as remote sensing, for example, reading news paper, looking across window, perspective view form high terrace etc. In contrast, a thermometer, which must be in contact with the phenomenon it measures, is not a remote sensing device.

In the broadest sense, the term remote sensing can be defined as the science of acquiring information about the earth using instruments which are ant in direct contact with the earth's surface or features, usually from aircraft or satellites. Instrument aboard satellite or aircraft is usually a sensor which is capable of acquiring information in the entire region of electromagnetic spectrum (i.e. visible light, infrared or radar etc.). Remote sensing offers the ability to observe and collect data for large areas relatively quickly, and is an important source of data for Geographical Information System (GIS) interface.

Every remote sensing process involves an interaction of the incident radiation falling over the target of interest in a sense that, the radiation incident over the target is altered on account of the physical properties of the target and reflect back the incident radiation which is recorded by the sensor. This is illustrated by the use of imaging systems (referred as optical remote sensing) where the following seven elements of remote sensing are involved (Fig. 1). It should also be noted that remote sensing also involves the sensing of emitted energy and the use of non imaging sensors (referred as thermal remote sensing). The seven elements on the basis of which remote sensing technique works are enumerated as follows;

i) Source of Illumination (I) - The foremost requirement for any remote sensing process is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

ii) Radiation and the Atmosphere (II) – as the energy propagates from its source to the target, it interacts with the atmosphere as it passes through. This interaction may take place a second time as the energy travels from the target and back to the sensor.

iii) Interaction with the Target (III) - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the characteristics of both the target and the radiation.

iv) Recording of Energy by the Sensor (IV) - after the energy has been scattered or Emitted from the target, a sensor is required to collect and record the electromagnetic radiation.

v) Transmission, Reception, and Processing (V) - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

vi) Interpretation and Analysis (VI) - the processed image is interpreted, visually or digitally or electronically, to extract information about the target which was illuminated.

vii) End users and application (VII) - the last element of the remote sensing process is achieved when the useful information is extracted from the imagery reveal some new information, or assist in solving a particular problem.

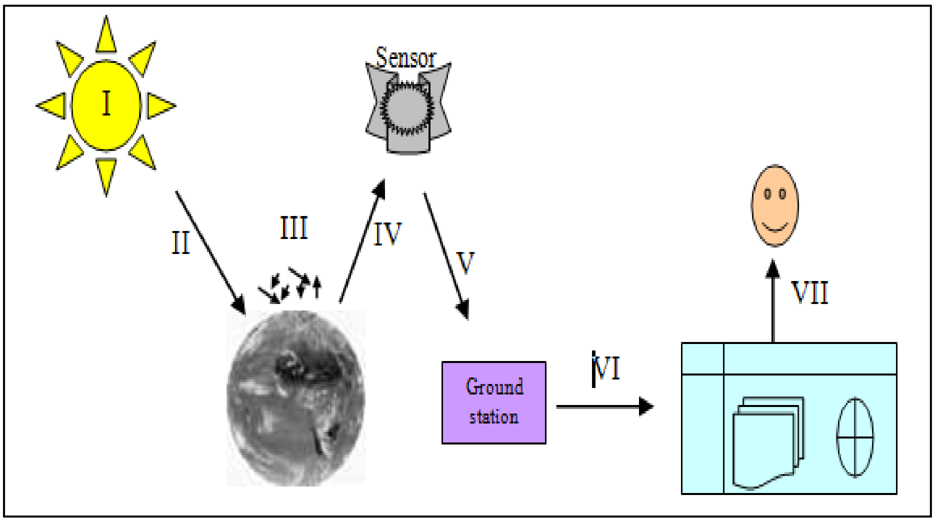



Fig. 1 Components of remote sensing.

On extrapolating this entire process of reading to earth's surface features; remote sensing involves the use of various sensors to obtain information about the objects, area or phenomenon being investigated. Figure 1.1 schematically illustrates the generalized processes and elements involved in electromagnetic remote sensing of earth resources. The two basic processes involved are (i) data acquisition, and (ii) data analysis.

### 3.2.1. Data Acquisition

The elements of data acquisition process are:

a) Source of energy

b) Propagation of energy through the atmosphere

c) Energy interactions with earth surface features

d) Retransmission of energy through the atmosphere

e) Airborne and/or space borne sensors

f) Sensors- These interactions result in the generation of sensor data in pictorial and/or digital form. Sensors are used to record variations in the way the Earth surface features reflect and emit electromagnetic energy.

### 3.2.2 Data Analysis

The data analysis process (g) involves examining the data using various viewing and interpretation devices to analyze pictorial data and/or a computer to analyze digital sensor data. This is further complemented by reference data that includes soil maps, crop statistics, or field-check data to extracts information about the type, extent, location and condition of the various resources by the analyst. This information is then compiled (h), generally in the form of hardcopy maps and tables or as computer files that can be merged with other layers of information in a geographic information system (GIS). Finally, the information is presented to the users (i), who apply it to their decision- making process.

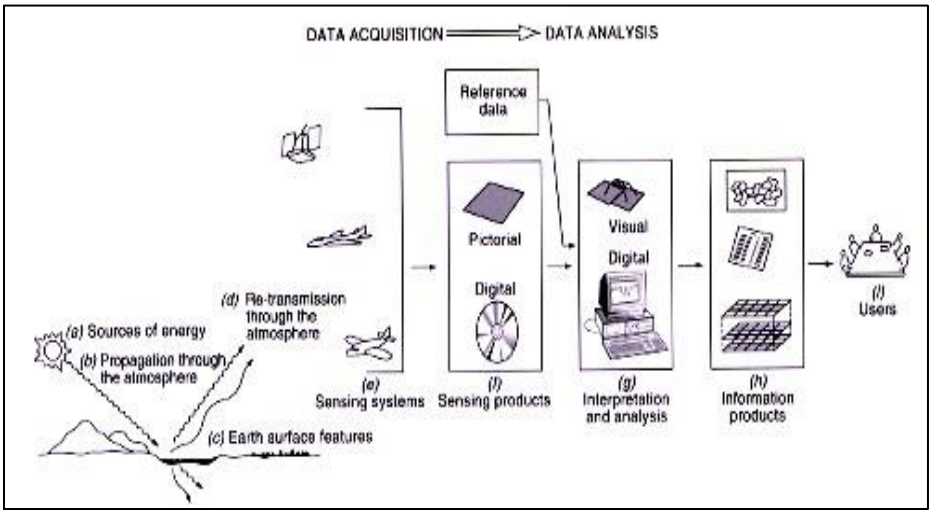



Figure 2: Electromagnetic remote sensing of Earth resources

## 3.3. Energy Sources and Radiation Principles

As we all know, electromagnetic energy travels in a harmonic, sinusoidal fashion at the velocity of light, (c = 3x108m/s). It incorporates electric and magnetic waves, both perpendicular to each other and perpendicular to the direction of motion of wave. These electromagnetic radiations exhibit both particle and wave nature. The distance from one wave peak to the next is wavelength λ, and the number of peaks passing a fixed point in space per unit time is the wave frequency v.

From basic physics, waves obey the general equation

$$c = v\,\lambda \qquad (1.1)$$

Since c is essentially a constant (3×108 m/sec), frequency v and wavelength λ for any given wave are related inversely.

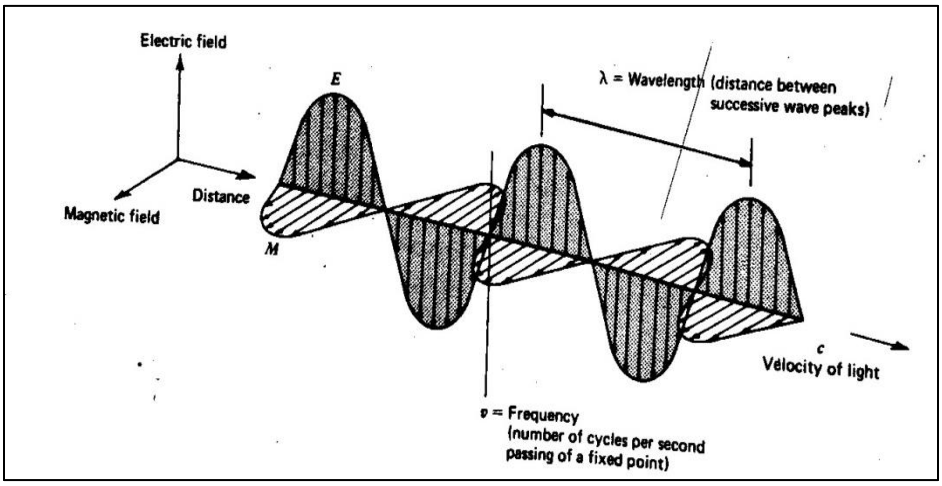


Figure 3: Electromagnetic wave. Components include a sinusoidal electric wave (E) and a magnetic wave (M) perpendicular to each other as well as to the direction of propagation.

In remote sensing, it is a common practice to categorize electromagnetic waves by their wavelength location in the electromagnetic spectrum. The electromagnetic spectrum comprises of an array of wavelength or frequency of electromagnetic radiations in ascending or descending order. These radiations exist in a continuum and there is no distinct demarcation between these radiations in a spectrum.

The different wavelength bands of electromagnetic spectrum are as follows:

1. Cosmic rays: These are very high frequency waves that originate from sun.
2. Gamma rays: These follow cosmic rays with a wavelength less than 0.01nm.
3. X-rays: These waves range from 0.01 to 10nm.
4. Ultraviolet (UV): This energy adjoins the blue end of the visible portion of the spectrum and has wavelengths of 10 – 310 nm.
5. Visible: This corresponds to the spectral sensitivity of the human eye and extends from approximately 0.4 µm to 0.7 µm. The color blue has the range of 0.4 to 0.5 µm, green from 0.5 to 0.6 µm and red from 0.6 to 0.7 µm.
6. Infrared: Adjoining the red end of visible region are three different categories of infrared (IR) waves: near IR (from 0.7 to 1.3 µm), middle or short-wave IR (from 1.3 to 3 µm) and thermal IR (3 to 14 µm).
7. Microwave: These wavelengths follow infrared region of the spectrum and lie in the wavelength of 1mm to 1m.
8. TV and Radio waves: These waves extend beyond 1mm of the microwave region.

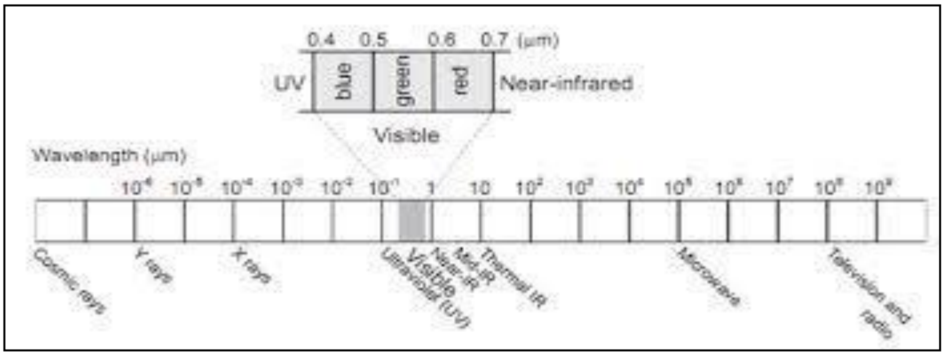



Figure 4: Electromagnetic spectrum

Although many characteristics of electromagnetic radiation are most easily described by wave theory, the particle theory suggests that electromagnetic radiation is composed of many discrete units called photons or quanta. The energy of a quantum is given as:

$$Q=hv \qquad (1.2)$$

where, Q= energy of a quantum, joules (J) h= Planck's constant, 6.626× 10-34 J sec v= frequency

We can relate the wave and quantum models of the electromagnetic radiation behavior by solving Eq. 1.1 for v and substituting into Eq. 1.2 to obtain

$$Q = hc\,\lambda \qquad (1.3)$$

Thus, an inverse relationship exists between energy and wavelength. This has important implications in remote sensing since naturally emitted long wavelength radiations, such as microwave emission from terrain features, is more difficult to sense than radiation of shorter wavelengths, such as emitted thermal IR energy. The low energy content of long wavelength radiation means that, in general, systems operating at long wavelengths must view large areas of the Earth at any given time in order to obtain a detectable energy signal.

Based on the source of energy, remote sensors are classified as passive and active sensor. Passive sensors use sun as a source of energy; examples include thermal scanners that sense thermal infrared energy. Some sensors use their own source of energy to observe the features of the earth. Examples include RADAR (Radio Detection and Ranging) and LIDAR (Light Detection and Ranging). Photographic camera can act as a passive sensor in sunlight while it becomes an active sensor while utilizing a flash.

## 3.4. Energy Interactions in the Atmosphere

All radiations detected by remote sensors passes through some distance, or path length of atmosphere, irrespective of its source. The net effect of the atmosphere varies with these differences in the path length and also varies with the magnitude of energy signal being sensed, the atmospheric conditions present and the wavelengths involved. So, atmosphere can have a profound effect on the intensity and spectral composition of radiation available to any sensing system. These effects are caused principally through the mechanisms of atmospheric scattering and absorption.

### 3.4.1 Scattering

Atmospheric scattering is the unpredictable diffusion of radiation by particles in the atmosphere. There are three types of scattering:

(a) Rayleigh scattering
(b) Mie scattering
(c) Non-selective scattering

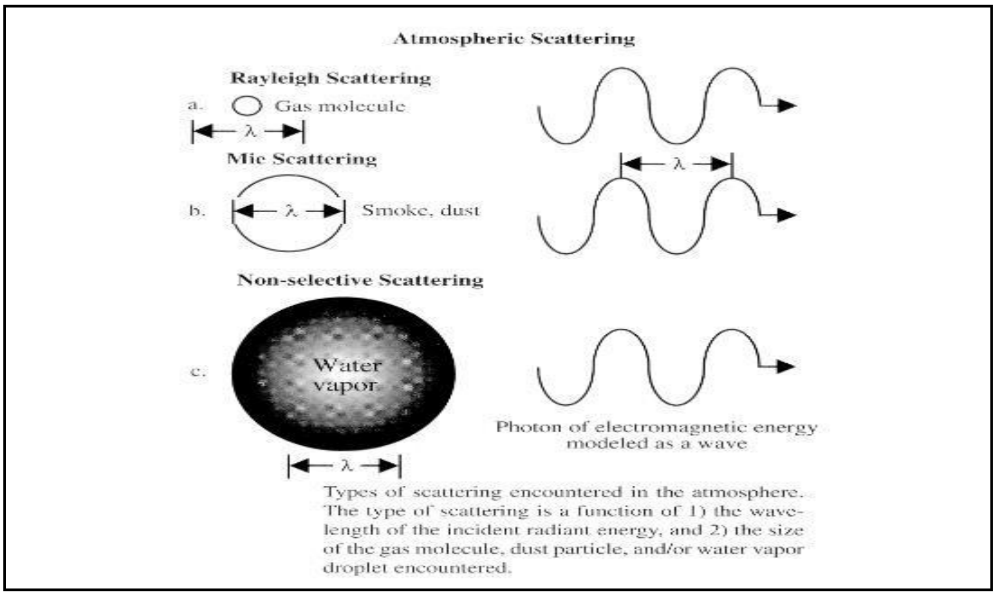



Figure 5: Types of scattering

#### 3.4.1.1. Rayleigh scattering

This occurs when radiation interacts with atmospheric molecules and other tiny particles that are much smaller in diameter than the wavelength of the radiation. The effect of Rayleigh scatter is inversely proportional to the fourth power of wavelength. Hence, there is much stronger tendency for short wavelengths to be scattered by mechanism than long wavelengths. This is the reason why sky appears blue during daytime; while black during night-time. At sunrise and sunset, however, the sun's rays travel through a longer atmospheric path length than during midday. With the longer path, the scatter of short wavelengths is so complete that we see only the less scattered, longer wavelengths of orange and red. Rayleigh scatter is responsible for causing haze in imagery that reduces the contrast of the image.

#### 3.4.1.2. Mie scattering

It occurs when the diameter of atmospheric particles is almost equal to the wavelengths of the energy being sensed. Water vapor and dust are major causes of Mie scatter. This type of scattering tends to influence longer wavelengths compared to Rayleigh scatter; and is significant in slightly overcast skies.

#### 3.4.1.3. Non-selective scattering

This type of scattering happens when the diameters of the particles causing scatter are much larger than the wavelengths of the energy being sensed. Example includes scattering by water droplets. They commonly have a diameter in the range 5 to 100 μm and scatter all visible and near to mid-IR wavelengths about equally, that's why it is said to be non-selective. This implies that equal quantities of blue, green and red light are scattered; hence fog and clouds appear white.

### 3.4.2. Absorption

The atmosphere prevents, or strongly attenuates, transmission of radiation through the atmosphere. Atmospheric absorption results in the effective loss of energy to atmospheric constituents. Water vapor, carbon dioxide and ozone are the most efficient absorbers of solar radiation.

1. Ozone (O3): absorbs ultraviolet radiation high in atmosphere
2. Carbon-dioxide (CO2): absorbs mid and far-infrared (13-17.5microm) in lower atmosphere
3. Water vapor (H2O): absorbs mid-far infrared (5.5-7.0, >27microm) in lower atmosphere.

- Therefore, the concept of Atmospheric Windows comes into pictures, which are those wavelengths that are relatively easily transmitted through the atmosphere. Thus, the wavelength ranges in which the atmosphere is particularly Trans missive of energy are referred to as atmospheric windows.

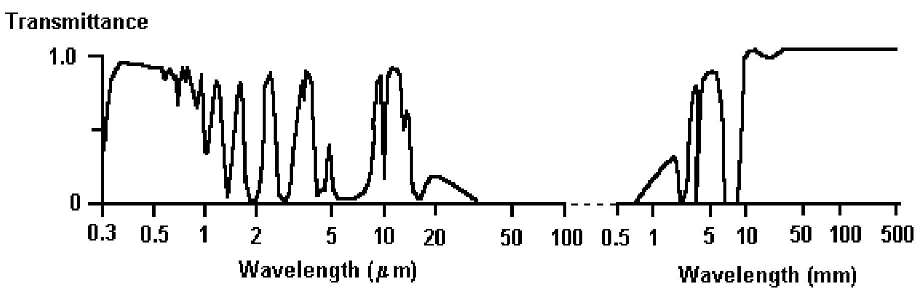


Figure 6: Atmospheric Window

(http://www.crisp.nus.edu.sg/~research/tutorial/atmoseff.htm#windows)]

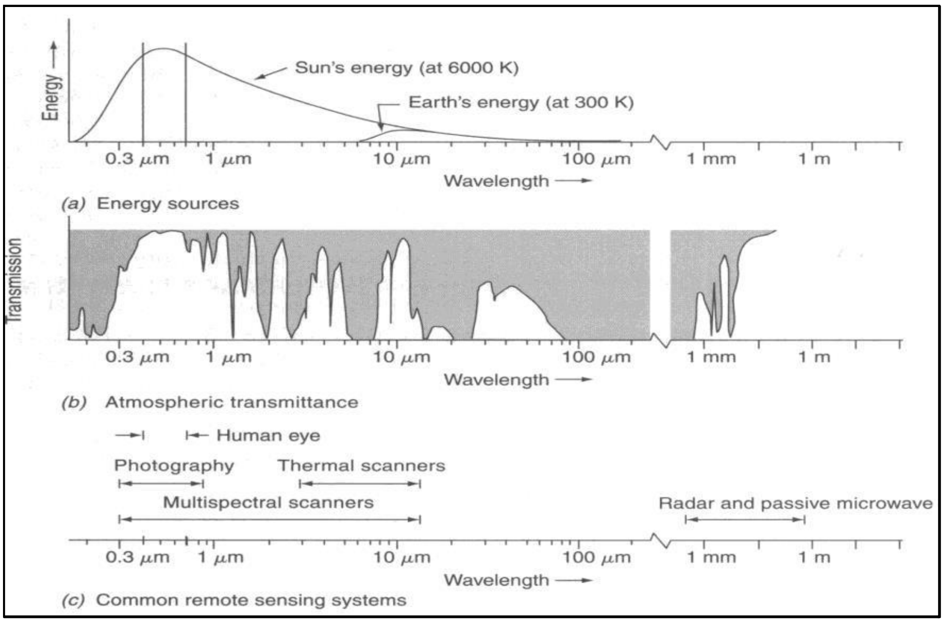



Figure 7: Spectral characteristics of (a) energy sources, (b) atmospheric transmittance, and (c) common remote sensing systems

The interrelationship between the energy sources and atmospheric absorption characteristics is shown in Figure 1.5. Figure 1.5a shows the spectral distribution of the energy emitted by the sun and (b) the earth features. In figure 1.5b, spectral regions in which the atmosphere blocks energy are shaded. Remote sensing data acquisition is limited to the non-blocked spectral regions, the atmospheric windows.

UV & visible: 0.30-0.75 μm Near infrared: 0.77-0.91 μm

Mid infrared: 1.55-1.75 μm, 2.05-2.4 μm

Far infrared: 3.50-4.10 μm, 8.00- 9.20 μm, 10.2-12.4 μm Microwave: 1mm-1m

The atmospheric windows are important for RS sensor design; which is based on the following criteria:

(1) The spectral sensitivity of the sensors available

(2) The presence or absence of the atmospheric windows in the spectral range in which one wishes to sense and

(3) The source, magnitude and spectral composition of the energy available in these ranges.

## 3.5. Energy Interactions with Earth Surface Features

When electromagnetic energy is incident on any given Earth surface feature, three fundamental interactions with the feature are possible. These are illustrated in Figure 8 for an element of the volume of a water body. Various fractions of the energy incident on the element are reflected, absorbed and/or transmitted. Applying this principle of conservation of energy, we can state the inter- relationship among these three energy interactions as

$E1(\lambda) = ER(\lambda) + EA(\lambda) + ET(\lambda)$ (1.6)

Where

E1 = incident energy ER = reflected energy EA = absorbed energy

ET = transmitted energy with all energy components being a function of wavelength λ.

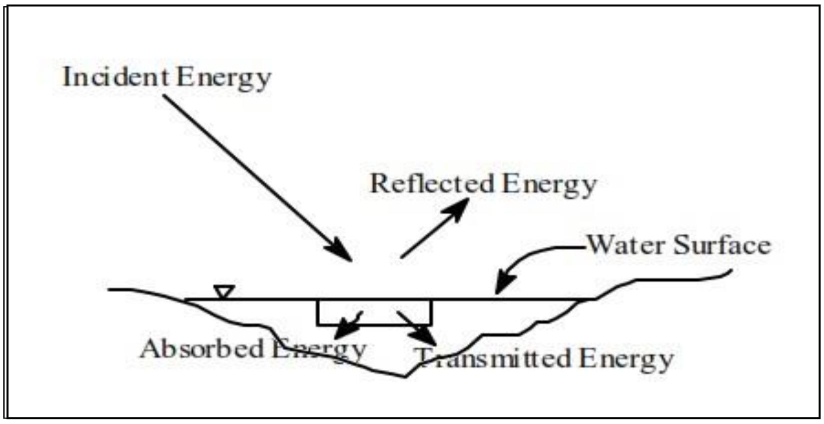



Figure 8: Basic interactions between electromagnetic energy and an Earth surface feature

From Equation 1.6, following two points become evident:

(1) The proportions of energy reflected, absorbed and transmitted will vary for different Earth features, depending on their material type and condition. These differences permit us to distinguish different features on an image.

(2) The wavelength dependency means that, even within a given feature type, the proportion of reflected, absorbed and transmitted energy will vary at different wavelengths.

Thus, two features may be indistinguishable in one spectral range and be very different in another wavelength band. Within the visible portion of the spectrum, these spectral variations result in visual effect called color. Because many remote sensing systems operate in the wavelength regions in which reflected energy predominates, the reflectance properties of the Earth features are very important. Hence, it is often useful to think of the energy balance relationship expressed by Equation 1.6 in the form

$$ER(\lambda)=E1(\lambda)-[EA(\lambda)+ET(\lambda)] \qquad (1.7)$$

That is, the reflected energy is equal to the energy incident on a given feature reduced by the energy that is either absorbed or transmitted by that feature.

The reflectance characteristics of the Earth surface features may be quantified by measuring the portion of incident energy that is reflected. This is measured as a function of wavelength and is called spectral reflectance; ρλ .It is mathematically defined as

ρλ = ER (λ)

E1 (λ) = $energy\ of\ wavelength$ λ reflected from the object × 100 (1.8)

$energy\ of\ wavelength$ λ incident upon the object

Where, ρλ is expressed as a percentage.

A graph of the spectral reflectance of an object as a function of wavelength is termed as spectral reflectance curve. The configuration of spectral reflectance curves gives us insight into the spectral characteristics of an object and has a strong influence on the choice of wavelength regions in which remote sensing data are acquired for a particular application.

## 3.6. Data Acquisition and Interpretation

The detection of electromagnetic energy can be performed either photographically or electronically. The process of photography uses chemical reactions on the surface of a light sensitive film to detect energy variations within a scene.

Electronic sources generate an electric signal that corresponds to the energy variations in the original scene; and offer broader spectral sensitivity. An example is a video camera.

In remote sensing, term photograph is reserved exclusively for images that were detected as well recorded on the film. The more generic term image is used for any pictorial representation of image data. As the term image relates to any pictorial product, all photographs are images. Not all images however, are photographs.

A common exception to the above terminology is use of the term digital photography. Digital cameras use electronic detectors rather than film for image detection.

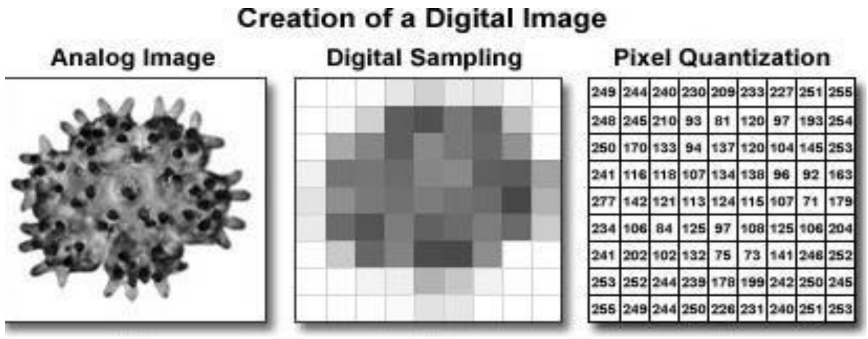



Figure 8: Digital Photography

- Though the image shown in Figure 8(a) appears to be a continuous tone photograph, it is actually composed of two-dimensional array of discrete picture elements or pixels. The intensity of each pixel corresponds to the average brightness or radiance, measured electronically over the ground area corresponding to each pixel. Whereas the individual pixels are virtually impossible to discern in (a), they are readily observable in the enlargements shown in (b) and (c). Typically, the DNs constituting a digital image are recorded over numerical ranges as 0 to 255 (8-bit data), 0 to 511 (9-bit), 0 to 1023 (10-bit) or higher. 7. Reference Data

The acquisition of reference data is referred by the term 'ground truth', and involves collecting measurements or observations about the objects, areas or phenomena that are being remotely sensed. Reference data involves field measurements of temperature and other physical/chemical properties of various features.

Reference data might be used to serve any or all of the following purposes:

- To aid in the analysis and interpretation of remotely sensed data
- To calibrate a sensor
- To verify information extracted from remote sensing data

Ground based measurement of the reflectance/emittance of surface materials to determine their spectral response pattern is one form of reference data collection. An example is spectro-radiometer that measures electromagnetic spectrum by recording data in very narrow bands simultaneously.

## 3.7. The Electromagnetic Radiation

Electromagnetic radiation (EMR), also called as electromagnetic energy, and refers to all energy that moves with the velocity of light in the form of waves. The source of EMR is the subatomic vibration of photons and is measured in terms of wavelength. Sun is the main source of EMR that travels through space in the form of waves that are either reflected or absorbed by the objects, mainly on account of the size of wavelength which is described by the distance of successive wave peaks and is represented by a Greek letter lambda ($\lambda$) (Fig. 9).

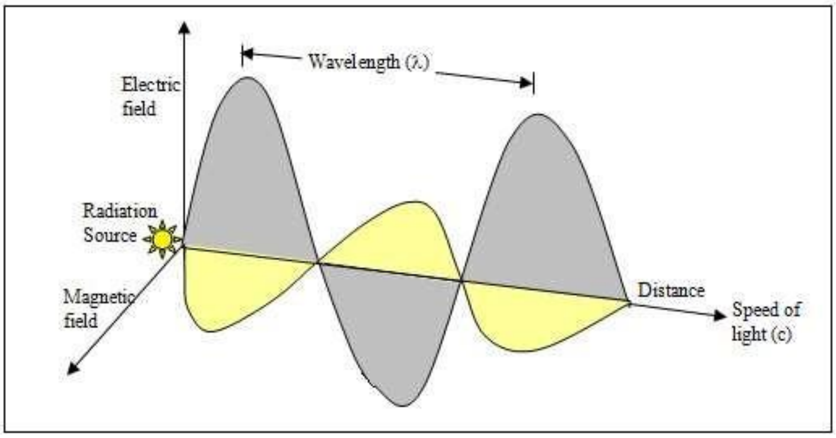



Fig. 9. Propagation of electromagnetic waves with the speed of light.

Wavelength is measured in metres (m) or some fraction of metres such as nanometres (nm, 10-9 metres), micrometres (μm, 10-6 metres) or centimetres (cm, 10-2 metres). Frequency refers to the number of cycles of a wave passing a fixed point per unit of time and is normally measured in hertz (Hz). Wavelength and frequency are inversely related to one another, in other words as one increases the other decreases. This relationship is expressed as:

$$c = \lambda \times \nu \qquad (1)$$

Where: c = speed of light ($3 \times 10^8$ m/s), $\lambda$ is the wavelength in (m, cm, μm or nm) and $\nu$ is the frequency in Hertz (cycles/second). It can be inferred from equation (1) that radiation with a small wavelength will have a high frequency whereas, radiation with a high wavelength will have a low frequency, since this frequency variation is a function of sub atomic vibration of photons. This vibration of photons in a matter releases energy which is measured in terms of temperature. To be more specific, objects releases energy above absolute zero temperature which is referred to as electromagnetic energy. Hot objects emit higher energy as compared to the cold objects that emit less amount of energy.

## 3.8. Electromagnetic spectrum

The electromagnetic spectrum covers the entire range of photon energies arranged in the increasing order of wavelengths on a logarithmic scale (See fig. 10). The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and X rays) to the longer wavelengths (including microwaves and radio waves).

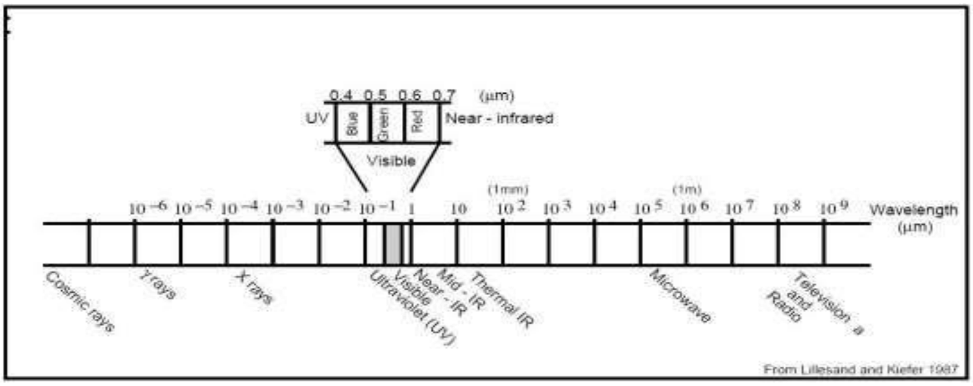



Fig. 10 The electromagnetic spectrum (Lillesand Kiefer, 1987).

Almost the entire range of electromagnetic spectrum is useful for remote sensing in a way that every band provides unique information about the object of interest. Sensors on board earth resources satellites operate in visible, infrared and microwave regions of the spectrum. The spectrum regions are discussed in order of increasing wavelength and decreasing frequency.

**(i) Ultraviolet:** The ultraviolet (UV) region of electromagnetic spectrum lies just beyond the violet portion of the visible wavelengths. The UV region has short wavelengths (0.3 to 0.446 μm) and high frequency. UV wavelengths are used in geologic and atmospheric science applications. Geologic application includes material exploration since many rocks and minerals exhibit fluoresce property and emit visible light in the presence of UV radiations. Also, almost 80 to 90% of the UV light is generally absorbed by Ozone (O3) hence becomes an integral tool related to the atmospheric studies.

**(ii) Visible light:** This is the portion of EMR to which our eyes are sensitive and is perceived as colours. The visible light covers a very small portion of the spectrum, ranging from approximately 0.4 to 0.7 μm (micrometer) and due to this small wavelength range, the visible portion of the spectrum is plotted on a linear scale so that individual colours can be discretely depicted (Fig 4). The visible light comprises of discrete colours with red at the long wavelength end and violet at the short wavelength end.

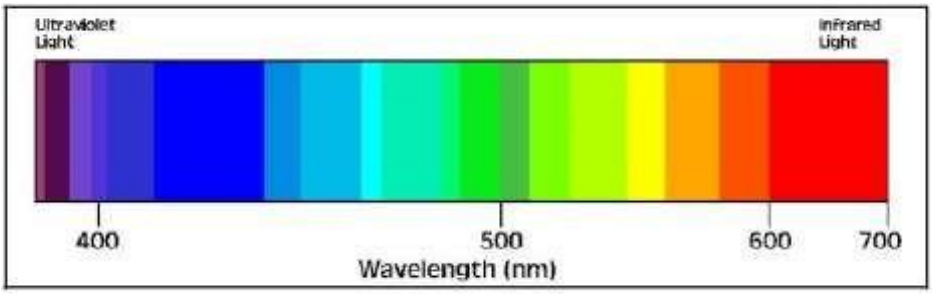



Fig. 11. The visible spectrum.

The visible colours and their corresponding wavelengths are listed below in micrometers (μm).

- Violet: 0.4 to 0.446 μm
- Blue: 0.446 to 0.500 μm
- Green: 0.500 to 0.578 μm
- Yellow: 0.578 to 0.592 μm
- Orange: 0.592 to 0.620 μm
- Red: 0.620 to 0.700 μm

**(iii) Infrared:** The infrared region (IR) which covers the wavelength range from approximately 0.7 μm to 100 μm, covering 100 times more space than the visible portion of the spectrum. The IR region is generally divided into two categories based upon their radiation characteristics i.e. (a) reflected IR and

(b) The emitted or thermal IR. The reflected IR region is used for specific remote sensing applications in ways similar to the radiations in the visible portion. The reflected IR covers wavelengths approximately from 0.7 μm to 3.0 μm and is mainly employed for monitoring the status of healthy and unhealthy vegetations, as well as for distinguishing among vegetation, soil and rocks. The thermal IR differs from visible and reflected IR in a way that this energy is radiated or emitted from the earth surface or objects and characterizes in the form of heat. The thermal IR covers the wavelengths from approximately 3.0 μm to 100 μm as these wavelengths are used for monitoring the temperature variations of land, water and ice.

**(iv) Microwave:** This portion of the spectrum is of recent interest to remote sensing and the wavelength ranges approximately from 1 mm to 1 meter. The shorter wavelengths have the properties similar to thermal infrared region while the longer wavelengths are used for radio broadcasts. Microwave remote sensing is used in the studies of meteorology, hydrology, oceans, geology, agriculture, forestry and soil moisture sensing.

In reference to figure 11, figure 12 illustrates the comparison between wavelength, frequency and energy of the electromagnetic spectrum.

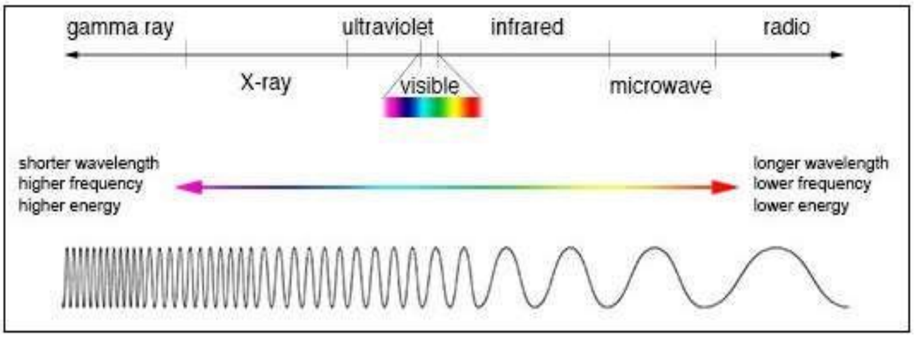



Fig. 12. Comparison between wavelength, frequency and energy of the electromagnetic spectrum (Source: NASA's Imagine the Universe).

## 3.9. Interactions with the Atmosphere

The earth's atmosphere is capable of transmitting the entire electromagnetic radiation used for a variety of remote sensing applications; however, the electromagnetic radiations get affected as these passes through different layers of atmosphere. This can be ascertained with the fact that the quality of image captured through aircraft borne sensor is less affected by atmosphere as compared to the quality of image captured by satellite borne sensor which is severely affected due to the fact that radiations passes through the entire depth of the earth's atmosphere. Hence fundamental knowledge of electromagnetic energy interaction with atmosphere forms an integral part of remote sensing based analysis of spatial data.

The incoming electromagnetic radiation gets affected by the particles of various sizes and gases (e.g. dust, smoke, haze and other atmospheric impurities) present in the atmosphere in suspended form therefore causing significant change in an acquired image in terms of brightness and colour. The electromagnetic energy passing through the earth's atmospheric layers is subjected to alterations by two important physical processes, namely: (i) scattering, and (ii) absorption.

### (i) Scattering

Scattering of electromagnetic radiation takes place when gas molecules and particles present in the atmosphere interact with it and redirects it from its original path (Fig. 6). The amount of scattering depends on several factors including the wavelength of the radiation, the abundance and size of the particles or gases, and the distance the radiation travels through the atmosphere.

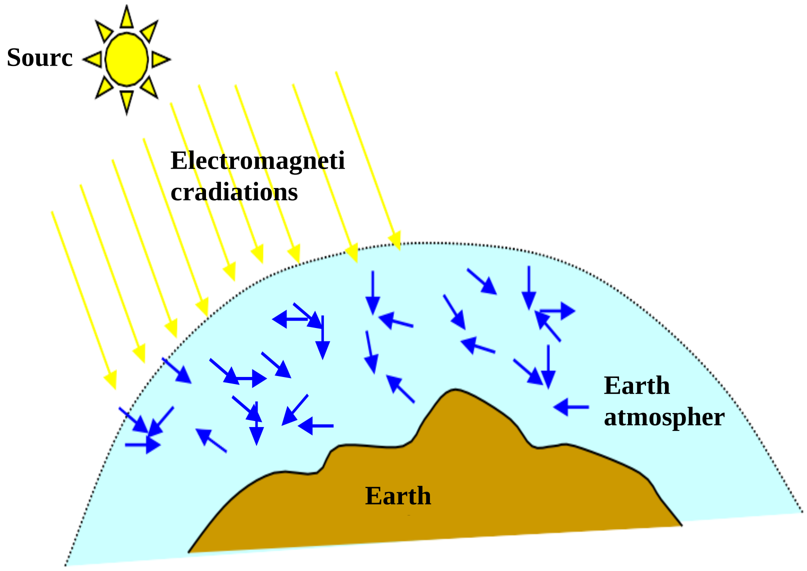



Fig. 13. The phenomena of scattering of electromagnetic energy.

Generally there are three types of scattering which take place through the earth's atmosphere, namely; Rayleigh scattering, Mie scattering and nonselective scattering.

**Rayleigh scattering:** Rayleigh scattering takes place when the suspended particles are very small (mainly comprising of oxygen molecules or dust particles) as compared to the wavelength of the radiation. This type of scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths and therefore the law is governed by the principle of reciprocal of fourth power of the wavelength; expressed as:

$$\textbf{Rayleigh scattering} = 1/\lambda^4 \qquad (7)$$

Where, $\lambda$ is the wavelength in meters. This type of scattering is dominant in the upper layers of atmosphere where tiny dust particles and gas molecules predominates. Rayleigh scattering is responsible for the blue color of the sky, since blue light is scattered the most on account of the size of wavelength smaller than the size of dust particles and gas molecules. Same reasoning applies for the appearance of orange color of the sky at dusk, i.e. when sun is low in the horizon, it creates longer path length to the incoming radiations resulting in the scattering of red the light.

**Mie scattering:** This type of scattering occurs when the particles are just the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering wherein the longer wavelengths are scattered the most. Mie scattering is more dominant in the lower layers of atmosphere (i.e. within 0 to 8 km). In the lower layers of atmosphere larger particles are in abundance and influence a broad range of wavelengths in and near the visible spectrum.

**Nonselective scattering:** This scattering phenomenon occurs when the particles are much larger than the wavelength of the incoming radiation thereby leading to approximately equal scattering of all wavelengths (i.e. blue + green + red light = white light). Water droplets and large dust particles are mostly responsible for causing this type of scattering. Due to this scattering, clouds appear white in color and so as a blurry white foggy appearance to the suspended water droplets during winter seasons.

**(ii) Absorption**

There are gases namely; ozone (O3), carbon dioxide (CO2) and water vapor (H2O) that are responsible for most of the absorption of electromagnetic radiations through partially preventing or strongly weakening the radiations as these passes through the atmospheric layers. Formation of ozone is the result of interaction of high energy ultraviolet radiations with oxygen molecules (O2) present at an altitude of 20 to 30 km in the stratosphere. Presence of ozone layer forms a protective layer in the atmosphere by absorbing the harmful ultraviolet radiations that may otherwise cause skin burns or other severe skin diseases if exposed to sun light.

Carbon dioxide (CO2) occurs in low concentrations (approximately 0.035% by volume of a dry atmosphere), mainly in the lower layers of atmosphere. CO2 effectively absorbs radiation in the mid and far infrared regions (mostly in the range 13 to 17.5 μm) of the electromagnetic spectrum.

Lastly, water vapours (H2O) present in the lower atmosphere (concentration normally varies from 0 to 3% by volume) are more effective in absorbing radiations as compared to other the atmospheric gases. Two important regions of spectrum ranging from 5.5 to 7.0 µm and above 27 µm, are significantly absorbed up to 75% to 80%.

The regions or bands of the electromagnetic spectrum which are not severely influenced by atmospheric absorption and thus are partially or completely transmitted through, are useful to remote sensors, are called atmospheric windows. In other words, gas molecules present in the atmosphere selectively transmit radiations of certain wavelengths and those wavelengths that are relatively easily transmitted through the atmosphere is referred to as atmospheric windows (Fig. 7).

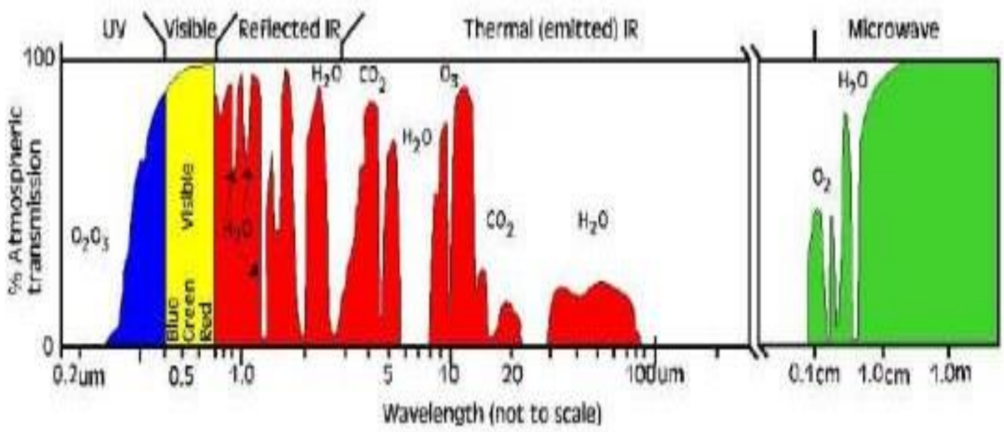



Fig. 14. Atmospheric windows with wavelength on x-axis and percent transmission measured in Hertz on y-axis. High transmission corresponds to an atmospheric window which allows radiations to penetrate electromagnetic radiation to penetrate the earth's atmosphere.

Fortunately, around 90 to 95% of the visible light passes through the atmosphere otherwise there would never be bright sunny days on earth. The atmosphere is almost 100% translucent for certain wavelengths of mid and near infrared spectrum which makes possible remote sensing analysis of satellite images in these regions possible with a minimum distortion. The thermal infrared range from 10 - 12 μm is used in measuring surface temperatures of the ground, water and clouds Ozone blocks ultraviolet radiation almost completely and almost all radiation in the range of 9.5 to 10 μm is absorbed.

**Self assessment exercise 2**

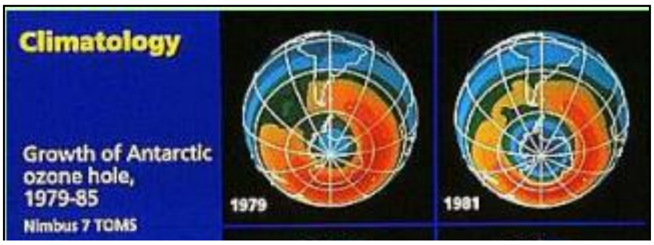
1. Explain why most remote sensing sensors avoid detecting and recording wavelengths in the ultraviolet portion of the spectrum.

2. What do you think would be some of the best atmospheric conditions for remote sensing in the visible portion of the spectrum?

**The Ozone hole**

Whilst on the subject of atmospheric absorption, it is expected that a brief note on topical science, namely the discovery of the 'ozone hole' by satellite remotesensing would be of interest to the readers. (Figure 15 illustrates the growth of the ozone hole 1979-1985).

It is widely known that stratospheric ozone depletion due to human activities has resulted in an increase of ultraviolet radiation on the Earth's surface. Ozone depletion has been monitored by the Total Ozone Mapping Satellite (TOMS) mission based on the observation that less radiation at very short ultraviolet wavelengths (0.1 µm – 0.3 µm) was being absorbed by the atmosphere, most significantly over the arctic regions. Ozone absorbs UV radiation and so less absorption means that more UV radiation is transmitted through to the Earth's surface. This is leading to increasing concern about the possibility of skin cancers for people exposed to these higher doses.




## 3.10. Interactions with the Earth's Surface

Electromagnetic radiations that are not completely absorbed or scattered in the atmosphere, travels through the entire depth of the atmosphere before finally reaching the earth's surface. The radiations strike the surface and again redirected towards the atmosphere for the second time before being sensed or recorded by the sensor and this total distance to and fro is called as the path length. For radiations emitted from the earth's surface the path length will be half of the path length of the radiation emitted from the sun. Generally three type of interaction takes place when the radiations strike or are incident (I) upon the surface and these include; reflection (R), absorption (A); and transmission (T). Therefore, the total energy of radiations incident upon the surface follows the law of conservation of energy or the energy balance written as:

$$E_i = E_r + E_a + E_t \quad \text{------------------------------------8}$$

Where,

Ei is the incident energy, $E_r$ is the reflected energy, $E_a$ is the absorbed energy and $E_t$ is the transmitted energy. The type and degree of interaction of radiations varies in accordance to the size and surface roughness for different objects as well as varying wavelengths. Figure 8 illustrates the radiations striking the earth's surface.

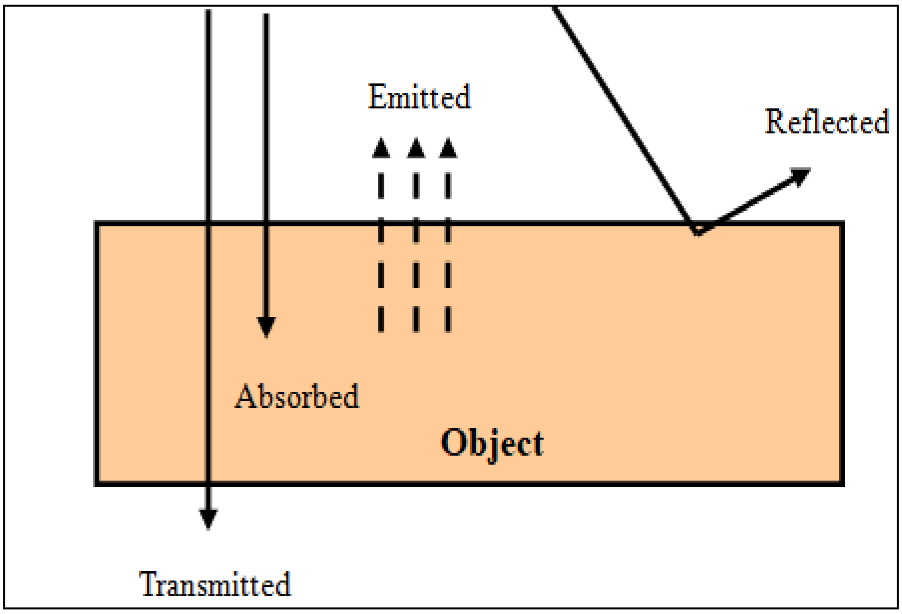
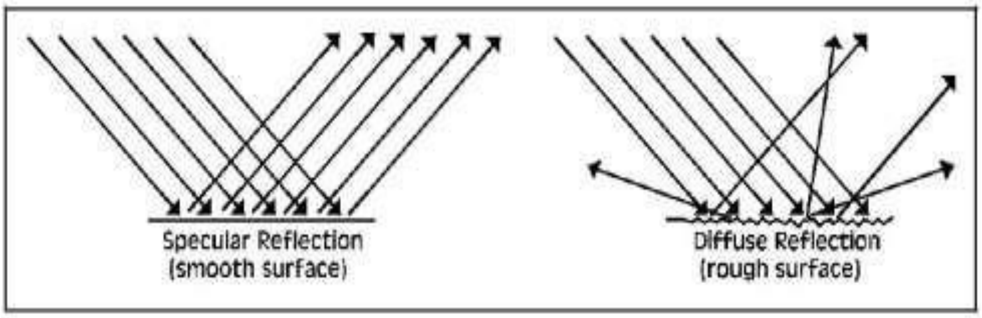



Fig. 16. Interaction of electromagnetic radiation with the surface or object.

**Reflection:** Reflection occurs when a radiation is re-directed as it strikes an opaque surface. The degree of re-direction depends upon the magnitude of surface roughness compared to the wavelength of the incident radiation. Reflection or re-direction of radiation occurs in two types depending upon the characteristics of the surface or feature of interest. In general there are two types of reflection, specular and defuse reflection (refer Fig. 9). If the surface is smooth relative to the wavelength, specular reflection occurs where almost all incident radiation is reflected in a single direction maintaining angle of reflection equal to the incident angle (e.g. mirror, still water body or smooth metal surface).

Diffuse reflection occurs over the rough surfaces where incident radiations are reflected almost uniformly in all directions. If the wavelengths are much smaller than the surface roughness variations, diffuse reflection will dominate (e.g. loam soil would appear fairly smooth to long wavelength microwaves in contrast to visible spectra wavelengths).




(a) (b)

Fig. 17 (a) Specular reflection over a smooth surface and (b) diffuse reflection over surface irregularities.

**Transmission:** Transmission of radiation takes place when radiation passes through the object or feature without any considerable fading or attenuation. For a known thickness of the object, the ability of a medium to transmit energy is measured as a transmittance (t);

$$t = \frac{Transmitted\ \ radiation}{Incident\ \ radiation} \qquad (9)$$

## 3.11 Image Resolutions

The fundamental parameters that describes the quality and characteristics of spatial data (imagery) include; spatial resolution, temporal resolution and radiometric resolution.

### 3.11.1 Spatial resolution

Of the three resolutions, spatial resolution has its significance since it defines the degree of clarity of the ground features represented in a pixel. In other words, spatial resolution is defined as the area of the earth surface covered in one pixel of an image. For instance, if a satellite image has a 5 m resolution; it means that 1m x 1m area on the earth's surface is represented in a pixel. If very large ground area, say of the order of square kilometres, the spatial resolution will be coarse and vice versa. Figure 10 illustrates spatial resolutions that an image can have.

Fig. 18 Spatial resolution of an image: (Left) nominal 1m spatial resolution (middle) 5m spatial resolution (right) 30m spatial resolution.

### 3.11.2 Temporal resolution

Temporal resolution is the time taken by the sensor on board space satellite to capture successive images of the same location over the earth's surface. In other words temporal resolution is the revisit time or repeat cycle of the satellite over the same region or location over the earth's surface. The frequency of revisit of different satellites varies from multiple times in a single day to almost about a month's period (e.g. the temporal resolution of IRS series is 24 days, SPOT series is 26 days, IKONOS is 2.9 days etc,).

### 3.11.3 Radiometric resolution

Radiometric resolution refers to the finest difference in the radiation or energy levels in terms of digital numbers that a sensor can record in a single pixel and thereby imparts quality to the image in terms of finer details. The finer the radiometric resolution of a sensor, most minuscule details can be extracted in order to get more meaningful interpretation.

Any digital Image uses a binary format to store the data which is represented by a grid where each cell bears a unique number in accordance to the brightness levels recorded by the sensor and these numbers known as digital numbers. The physical value of the brightness level recorded is converted into digital numbers which are stored in the cells of an image grid. For an image, digital numbers range from 0 to a selected power of 2 which corresponds to the number of bits used for coding numbers i.e. each bit records an exponent of power 2 (e.g. 1 bit = 21 = 2) and the total number of brightness levels available depends on the number of bits of energy recorded. If a sensor uses 8 bits to record the data, there would be 28 = 256 digital values available (i.e. 256 shades between black and white), ranging from 0 to 255. However, if only 6 bits are used, then only 26 = 64 values ranging from 0 to 63 would be available in an image. Thus, radiometric resolution would be poor for 6 or 4 bit image as compared to 8 or 16 bit image. Figure 11 depicts radiometric resolution of 11 bit image.

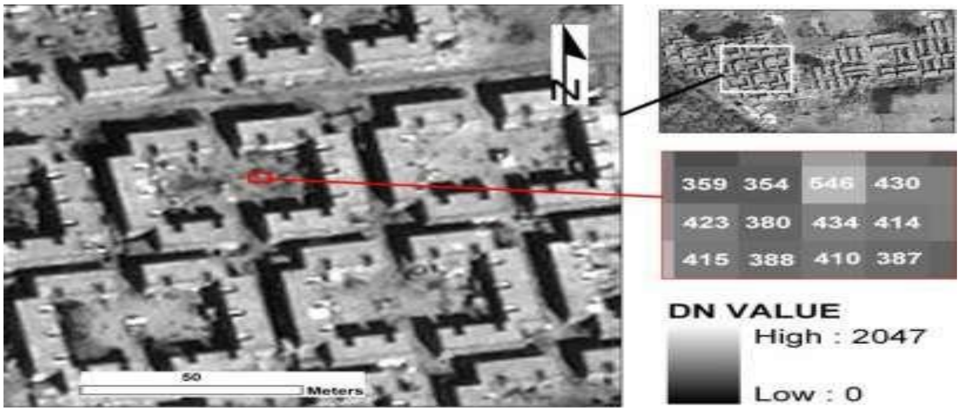



Fig. 19 An example of an 11 bit image. Each pixel contains a value between 0 and 2047 according to the strength of the EMR measured at the sensor; values termed as Digital Numbers (DN); (Lillesand Kiefer, 1987).

### 3.11..4 Spectral resolution

Spectral resolution refers to the specific wavelength intervals in the electromagnetic spectrum that a sensor can record. For example, band 1 of the Landsat TM sensor records energy between 0.45 and 0.52 mm in the visible part of the spectrum. Wide intervals in the electromagnetic spectrum are referred to as coarse spectral resolution, and narrow intervals are referred to as fine spectral resolution. For example, the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 and 0.73 mm. On the other hand, band 3 of the Landsat TM sensor has fine spectral resolution because it records EMR between 0.63 and 0.69 mm (Jensen 1996). Figure 12 illustrates all four types of resolutions for Landsat TM.

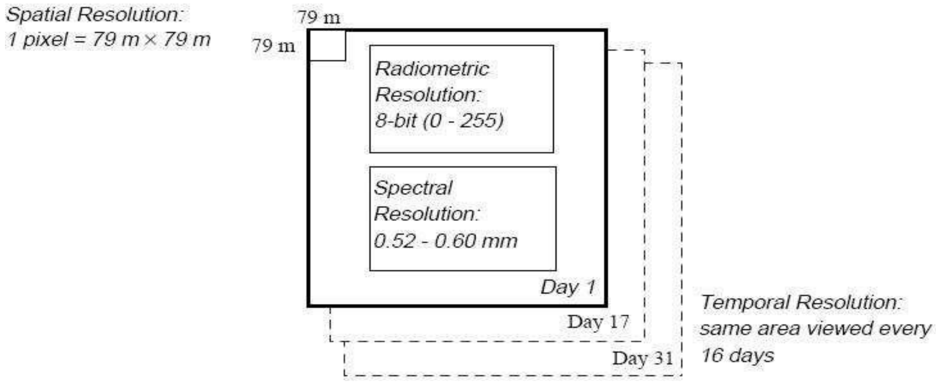



Fig. 20. Landsat TM—Band 2 (Four Types of Resolution); Source: EOSAT.

## 3.12. Applications of Remote Sensing

Any design of successful remote sensing efforts involve,

(1) Problem defining

(2) Evaluating the potential for solving the problem through remote sensing techniques

(3) Data acquisition related to the problem

(4) Data interpretation procedures

(5) Assessment of accuracy of the information collected

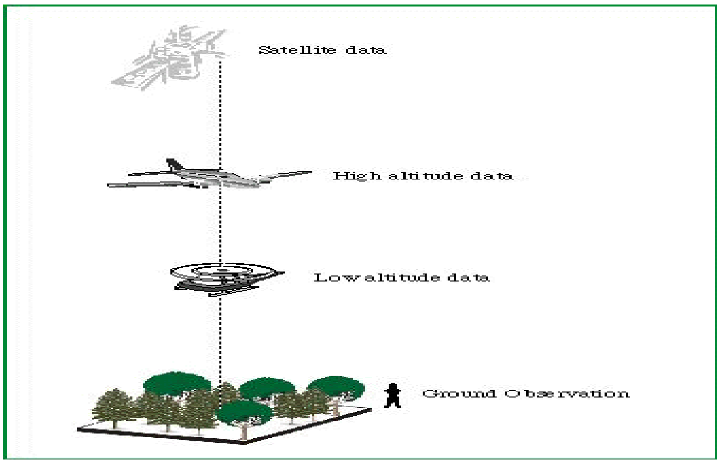



Figure 21. : Multistage remote sensing concept

The success of many applications of remote sensing is improved considerably by making a multiple-view approach to data collection. This may involve:

1. Multistage sensing: Data about a site is collected from multiple altitudes.

2. Multispectral sensing: Data is acquired simultaneously in several spectral bands.

3. Multitemporal sensing: Data about a site is collected on more than one occasion.

In the multistage approach, satellite data maybe analyzed in conjunction with high altitude data, low altitude data and ground observations. Thus, more information is obtained by analyzing multiple views of the terrain than by analysis of any single view. Further, it is pertinent to mention that any successful application of remote sensing requires appropriate data acquisition and data interpretation techniques besides conventional methods. Remote sensing data are currently being used in conjunction with GIS to acquire best possible solutions to problems.

Some of the important applications of remote sensing technology includes:

a) Environmental monitoring and assessment (global warming etc.).

b) Land use and land cover global change detection and monitoring.

c) Prediction of agricultural yield and crop health monitoring.

d) Sustainable resource exploration and management.

e) Ocean and wetland studies.

f) Weather forecasting.

g) Defence and military surveillance.

h) Broadcasting and tele-communication.

## 3.13. Reference

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# Unit 4: RS Platforms and Sensors I

**Unit Structure**



## 4.0. Learning objectives

At the end of this unit you will be able to briefly explain:

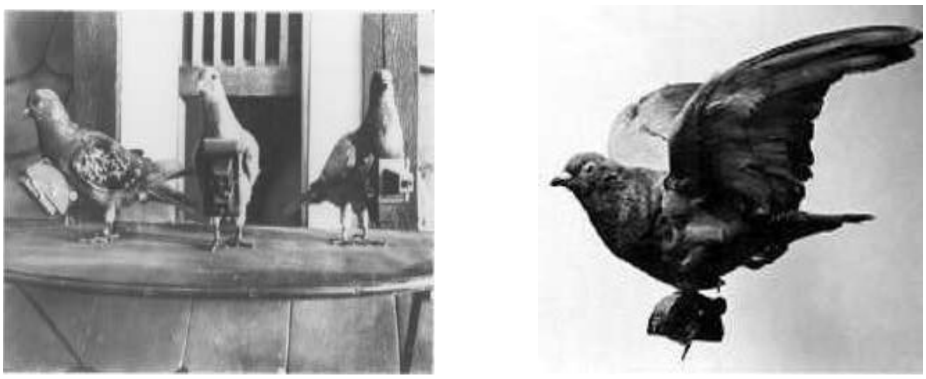
- Historical evolution of remote sensing and the detailed information related to India's space programme.
- The two important types of satellite orbits, which are required for obtaining a full, image coverage of the Earth.
- Classification of sensors; active and passive remote sensing sensors.
- The essential features of various important weather and communication satellites.

## 4.1 Introduction

The underlying principle as well as the basic concepts remote sensing that are required for understanding the process involved in the technology have been explained in detail in module 1. The electromagnetic energy emitted from the sun or reflected back from the target is recorded by the sensors that may be mounted on a truck or onboard aircraft or space satellite. The sensor platform combination determines the characteristics of the resulting data or image, henceforth, the resulting data is utilized for interpretation about the surface feature characteristics. The following module takes a closer look at the sensor and sensing platform combinations as well as the type of data collected by different sensors. This module also addresses on the historical developments and evolution in remote sensing technology in context to Indian space missions as well as foreign space missions.

## 4.2 Historical Development of Remote Sensing

The evolution of remote sensing technology started way back to more than 120 years with the invention of the primitive camera capable of capturing still photographs on the earth. Towards mid 1800's, looking down the earth's surface from higher altitude triggered installation of the camera on hot air ballons so as to capture perspective pictures of the ground surface that aided in the preparation of topographic and navigational maps. Perhaps the most novel platform for camera installation in the early nineteenth century was the pigeon fleet that operated as a novelty in Europe (Fig. 1).

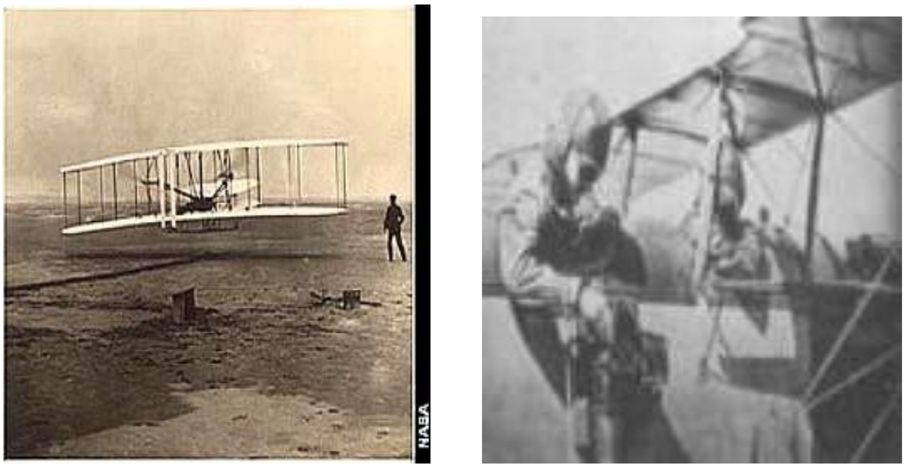


(a) (b)

Fig. 1 The pigeon fleet installed with cameras.

During the first World War, cameras were installed on aircrafts that provided perspective photographs of fairly large ground areas that proved to be fruitful during military reconnaissance and operations. Since then aerial photographs were primarily been used for observing the earth's surface from a vertical or oblique perspective (Fig. 2). Aircraft mounted cameras provided more reliable and stable photographs than pigeons or balloons. It was after World War II that aerial photographs were made available for civilian use and the applications were mainly focused on geology, forestry, agriculture, land use practice and topography. Availability of photographs for various applications lead to the better camera resolutions and photographic film quality. During

II world war, notable development took place in the field of aerial photography and photo interpretation. During this period, imaging systems were developed that were capable of recording the energy in the infrared and microwave region of electromagnetic spectrum. Near-infrared and thermal-infrared imaging proved very valuable to monitor the health of vegetation. In fact, radar imaging or microwave imaging enabled data recording during night was used for military operations hence proved valuable for night time bombing.

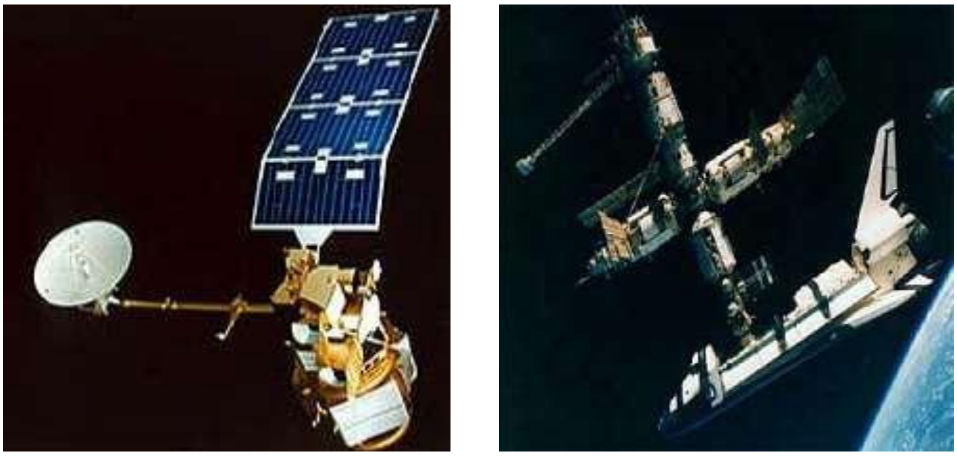


(a) (b)

Fig. 2 Cameras installed on airplanes in the early nineteen hundred.

During early 1940's, both Russia and America started their space missions to image land surfaces using several types of sensors installed onboard spacecraft. Thereafter, satellite remote sensing advanced to a global scale and escalated the cold war until satellite data was made available for civilian or research purposes in the early 1980's. Cameras were attached to V-2 rockets that were launched in 1946 after the World War II to high altitudes from White Sands, New Mexico. These rockets, while never attaining orbit, took pictures as the vehicle ascended or gained altitude. With the advancements towards more extensive space program in the mid 1960s, Earth-orbiting cosmonauts and astronauts acquired photographs of earth and moon from their spacecraft.

The world's first artificial satellite, Sputnik 1 was launched on 4th October 1957 by Soviet Union (Fig. 3), since then, improvements in sensor configuration aboard various earth observing satellites such as Landsat, Nimbus and more recent missions such as RADARSAT and UARS provided global images in different regions of electromagnetic spectrum proved to be useful for various civil, research, and military purposes. Space probes to other planets also provided an opportunity to carry out studies in extraterrestrial environments. Synthetic aperture radar (SAR) aboard the Magellan spacecraft provided detailed topographic maps of Venus, while sensors aboard SOHO provided a platform for studies to be performed on the Sun and the solar wind, just to name a few examples.



(a) (b)

Fig. 3 (a) The first artificial satellite launched by Soviet Union in 1957 (b) NASA's space shuttle 'Columbia' to monitor Earth resources.

Extensive studies were carried out in various parts of the globe towards development of satellite image processing and interpretation tools. Research groups in NASA research center developed Fourier transform techniques that enabled notable enhancement of satellite data. With the improvements in the availability of satellite images integrated with image processing tools has lead to numerous applications of remote sensing in various domains. Remote sensing has significantly proven its crucial role towards better understanding of the earth processes in detail at both regional and global scales.

**Self assessment exercise**

1. Briefly discuss the historical evolution of remote sensing technology.
2. Discuss some of the civilian applications of remote sensing technique.

### 4.2.1 History of India's Space Programme

Although Indian scientists before independence had confined knowledge about the rocket science and space technology since the technology was being used during world wars. It was only after India achieved independence, the process of exploring the space actually accelerated. Dr. Vikram Sarabhai founded the Physical Research Laboratory (PRL) in Ahmedabad on November 11, 1947 that proved to be the first step that India took towards becoming one of the leading space power. It was in 1969, The Indian Space Research Organization (ISRO) was established that superseded the erstwhile Indian National Committee for Space Research (INCOSPAR), which was established in 1962 by Dr. Vikram Sarabhai along with the efforts of independent India's first Prime Minister Jawaharlal Nehru. ISRO is the space agency of the Indian government headquartered in the city of Bengaluru. Its vision is to "harness space technology for national development, while pursuing space science research and planetary exploration". The establishment of ISRO institutionalised the space activities of India and is managed by the Department of Space, which reports to the Prime Minister of India.

India's first major success was achieved on April 19, 1975 with the launch of launched its indigenous satellite named as Aryabhata into space. It was launched by the Soviet Union from Kapustin Yar using a Cosmos-3M launch vehicle. The 'Aryabhata' was named after a 5th century Indian mathematician, who founded concepts of the numerical value zero and many astronomical calculations in around 500 AD.

India has launched a total of 81 indigenous satellites (as of January 2016) offering a number of applications since its first launch in 1975. A series of satellites that have been launched includes the Apple (1981), Bhaskara –I (1979) and Bhaskara –II (1981), INSAT-1 series (1A, -1B, -1C and -1D), INSAT-2 series (2A, -2B, -2C and - 2D), IRS-Series (1A, -IB, -1E, -P2, -1C, -P3, -1D, P6), Rohini (1A, 1B, 2 and 3) to name a few. India has also developed various Launch vehicles that make a space programme independent and are the most important technological measure of its advancement. Prominent among them are Satellite Launch Vehicle (SLV), Augmented Satellite Launch Vehicle (ASLV), Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV). Table 1 shows some important dates in the development and advancement of Indian remote sensing programme.

**Table 1. Historical developments and advancements of Indian space mission**

| Year | Milestones in space programme |
|---|---|
| 1969 | Indian Space Research Organisation (ISRO) formed |
| 1972 - 76 | ISRO conducts air-borne remote sensing experiments |
| 1975 | Aryabhatta, the first Indian Satellite launched |
| 1979 | Bhaskara-I and Rohini satellites successfully launched |
| 1981 | An experimental geo-stationary satellite 'APPLE' launched |
| 1982 - 83 | INSAT 1A and1B multipurpose geo-stationary satellites successfully launched for telecommunications, broadcasting and meteorological needs |
| 1988 - 99 | INSAT 1C, 1D, 2A, 2B, 2C, 2D, and 2E series of improved multipurpose geo-stationary satellites launched |
| 1988 | First Indian Remote Sensing (IRS-1A) polar orbiting satellite launched to explore the areas of agriculture, water resources, forestry and ecology, geology, water sheds, marine fisheries and coastal management |
| 1991 - 99 | IRS-1B, 1C, 1D, IRS-P1, P2, P3 and P4 (Oceansat-1) launchedon indigenous Polar Satellite Launching Vehicle (PSLV) for natural recourse management studies, disaster mitigation studies town planning etc. |
| 2003 | IRS-P6 (Resoursesat-1) launched with improved spatial and spectral resolutions |
| 2005 | IRS-P5 (Cartosat-1) launched suitable for cadastre and infrastructure mapping and analysis |
| 2005 | INSAT 4A Advanced satellite for direct to home television broadcasting services. |
| 2007 | INSAT 4B identical to INSAT 4A firther augments the capability of INSAT 4A for improved broadcasting services. |
| 2007 | Radar Imaging Satellite (RISAT) launched capable of taking images in cloudy and snow covered regions and also bothduring day and night |
| 2008 | Cartosat-2A launched to enhance disaster monitoring and damage assessment |
| 2009 | Oceansat-2 launched to aid in the analysis for operational Potential Fishing Zones. Satellite is mainly designed for Ocean biology and sea state applications |
| 2010 | Cartosat-2B launched that carries advanced imaging sensorsfor disaster monitoring and to study damage assessment |
| 2011 | Resourcesat-2 improved version of Resourcesat-1. |
| 2011 | GSAT-8 / INSAT-4G communication satellites operating inL1 and L5 bands. |
| 2012 | RISAT-1 first indigenous all weather RADAR imaging satellite that is intended to facilitate agriculture and disasterbased studies. |

| | |
|---|---|
| 2013 | IRNSS-1A first satellite in the regional navigation satellite system. It is one of the first spacecraft constituting the IRNSS space system. |
| 2014 | IRNSS-1B and 1C are the second and third series of IRNSS space system. |
| 2015 | IRNSS-1D fourth satellite in space navigation series. |
| 2015 | GSAT-6 and GSAT-15 communication satellites. |
| 2016 | IRNSS-1E fifth satellite in space navigation system. |

*Source: https://en.wikipedia.org/wiki/List_of_Indian_satellites*

### 4.2.2 History of International Space Programme

There had been numerous celestial studies carried out from the earth using optical telescopes until second World War, that reckoned the development of powerful rockets capable of direct space exploration a technological possibility. The first artificial satellite, Sputnik I, was launched by the USSR (now Russia) on Oct. 4, 1957, followed by Explorer I, first satellite launched by United States in the year 1958. America's immediate space launch was popularly projected as international competition and envisioned as the "space race." The first Moon landing by the American Apollo 11 spacecraft in the year 1969 is often considered as a landmark of initial space exploration period. The Soviet space program achieved many milestones, including the first living being in orbit in 1957, the first human spaceflight (Yuri Gagarin aboard Vostok 1) in 1961, the first spacewalk (by Aleksei Leonov) in 1965, the first automatic landing on another celestial body in 1966, and the launch of the first space station (Salyut 1) in 1971. Since then, countries namely; People's Republic of China, European Union, Russia, Japan, Canada, United States, France and India have initiated successful space missions by launching multitude of satellites for defense as well as research purposes. Although earth-orbiting satellites have so far been accounted with the majority of launches, manned space missions to the Moon and Mars have explicitly been advocated by the above mentioned countries during the 21st century. Table 2 illustrates some of the historical developments and advancements associated with international space programme.

| Year | Country | Space mission |
|---|---|---|
| 1957 | Soviet Union (Russia) | • Sputnik 1 first space satellite launched in October<br>• Sputnik 2 was launched in Novemberwith a dog named Laika. |

| | | |
|---|---|---|
| 1958 | USA | Explorer 1 was the first satellite launched by the United States when it was sent into orbit on January 31, 1958. It was designed and built by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. |
| 1960 | Soviet Union (Russia) | The Soviet craft Sputnik 5 was launched,carrying the dogs Strelka and Belka. They became the first living beings to survive a tripinto space. |
| 1961 | Soviet Union (Russia)and USA | • April 12 - Russian cosmonaut Yuri Gagarin became the first human in space.<br>• May 5 - Astronaut Alan Shepard became the first American in space.<br>• May 25 - President Kennedy challenged the country to put a man on the moon by the end of the decade. |
| 1966 | Soviet Union (Russia)and USA | • February 3 - The Russian spacecraft Luna9 became the first spacecraft to land on the moon.<br>• June 2 - Surveyor 1 became the first American spacecraft to land on the moon. |
| 1969 | USA | Neil Armstrong became the first men on themoon. |
| 1970 | USA | Apollo 13 was launched |
| 1971 | Soviet Union (Russia) | The Sovietlaunched |
| 1973 | USA | The U.S. launched its first space station,Skylab. |
| 1976 | USA | The American probe Viking 2 discoveredwater frost on the Martian surface. |
| 1977 | USA | August and September - Voyagers 1 and 2 were launched. (Voyager 2 was launched before Voyager 1, but Voyager 1 was on a faster trajectory). |
| 1981 | USA | Columbia became the first Space Shuttle to be launched. |
| 1983 | USA | The second Space Shuttle, Challenger, waslaunched. |
| 1984 | USA | The third Space Shuttle, Discovery, was |
| 1992 | USA | The Space Shuttle Endeavor was launched on |
| 1993 | USA | The Space Shuttle Endeavor made the first servicing mission of the Hubble Space Telescope. |
| 2005 | USA | Space Shuttle Discovery was launched with seven astronauts aboard; this was America's first manned space shot since the 2003Columbia disaster. |
| 2007 | USA | NASA launched its Phoenix Mars Lander. |
| 2008 | USA | NASA's Phoenix Mars Lander landed safely and began sending images home after a 10-month, 422 million-mile journey. |

| | | |
|---|---|---|
| 2009 | USA | The NASA spacecraft Kepler was launched.Its mission is to search for planets outside our solar system, in a distant area of the MilkyWay. |
| 2011 | USA | • July 8 - The space shuttle Atlantis became the last American space shuttle tobe launched into space.<br>• July 16 - NASA's Dawn spacecraft became the first man made craft to orbitan asteroid.<br>• November 26 - NASA launched Curiosity, the biggest, best equipped<br>• robot ever sent to explore another planet.It will reach Mars in 2012. |
| 2012 | USA | NASA's Curiosity rover successfully landedon Mars. As large as a car, it carried an array of advanced new instruments and experiments. |
| 2013 | USA | NASA launched the unmanned LADEE spacecraft from NASA's Wallops Flight Facility in Virginia. It was the U.S. space agency's third lunar probe in five years. |

Source: The U.S. National archives and records administration

## 4.3. Platform and Sensors

A device capable of measuring and recording the electromagnetic energy is referred to as a sensor. For a sensor to collect and record electromagnetic energy reflected or emitted from a target or feature space of interest, it must be installed on a stable platform that may either be ground based, aircraft or alloon based (or some other platform within the Earth's atmosphere), or spacecraft or satellite above the Earth's atmosphere.

1. **<u>Sensors installed on ground based platforms</u>**

Sensors installed over ground-based platforms records detailed information about the feature or surface area such as a crop field or road intersection of limited extent (i.e. 200 to 400 sq m) which may be compared with information collected from aircraft or satellite sensors as per the requirement of the researcher. In some cases, data collected from ground based sensors can also be utilised to characterize and interpret the target feature that is also being imaged by other sensors, thereby integrating the information in the imagery for better analysis. Sensors may be installed or mounted on a ladder, tall building, crane, etc as illustrated in Fig. 4.

Fig. 4 Ground based sensor mounted on a truck crane.

2. **Sensors mounted on air based platforms**

Airborne remote sensing is carried out using specially designed aircrafts or hot air balloons depending on the operational requirements and the availability of budget. Airborne platforms are employed owing to their mobilization flexibility and capability of recording data covering large spatial areas as compared to the ground based sensors. The speed, altitude as well as orientation of the aircraft must be carefully chosen so as to have minimum influence on the scale, resolution and geometric characteristics of the recorded images. Airborne remote sensing is deployed when study areas are inaccessible for ground based platforms such as hilly region s or dense forest cover. Remote sensing aircraft can be of many types, i.e. very small in size, slow, and low flying, to twin-engine turboprop (see Fig. 5) and small jets capable of flying at very high altitudes. Unmanned platforms (UAVs) are becoming increasingly important, particularly in military and emergency response applications, both international and domestic. Modifications to the fuselage and power system to accommodate a remote sensing instrument and data storage system are often far more expensive than the cost of the aircraft itself. While the planes themselves are fairly common, choosing the right aircraft to invest in requires a firm understanding of the applications for which that aircraft is likely to be used over its lifetime. Aerial platforms are primarily stable wing aircraft, although helicopters are occasionally used. Aircrafts are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.


Fig. 5 Aircraft used as platform to record data pertaining to earth surface.

3. **Sensors mounted on space based platforms**

Space borne remote sensing is carried out from the outer space or at an altitude higher than the earth’s atmosphere and utilizes space shuttle or more commonly satellites as platforms. Satellites are manmade objects that revolve around the earth and sensors installed onboard captures data of the earth’s surface covering areas of more than hundreds of square kilometers. Because of their orbits, satellites permit repetitive coverage of the earth's surface on a continuing basis. Cost is often a significant factor in choosing among the various platform options. Ever since the launch of the first earth resources satellite (i.e., Landsat in 1972), satellite-based remote sensing has continuously served towards the betterment of science and technology. With increasing number of satellites being launched, interestingly the demand for data acquired from airborne platforms continues to grow. One obvious advantage satellites have over aircraft is global accessibility; there are numerous governmental restrictions that deny access to airspace over sensitive areas or over foreign countries. Satellite orbits are not subject to these restrictions, although there may well be legal agreements to limit distribution of imagery over particular areas.

Fig. 6 Space based sensor mounted on a space shuttle.

Different types of orbits are required to achieve continuous monitoring (meteorology), global mapping (land cover mapping), or selective imaging (urban areas). The following orbit types are more common for remote sensing missions;

- **Polar orbit:** has inclination angle between $80^0$ and $100^0$that confines the satellite motion in westward direction. Polar orbit enables observation of the whole globe including the poles. Satellites with polar orbit are launched at 600 km to 1000 km altitude.
- **Sun-synchronous orbit:** also referred as near polar orbit, having inclination angle between $98^0$ and $99^0$ which is relative to a line running between the North and South poles thereby enabling the satellite to always pass overhead at the same time. The platforms are designed to adopt an orbit in north-south direction, which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. Most sun synchronous orbits crosses the equator at mid morning at around 10:30 hour local sun time. At that moment the sun angle is low and the resultant shadows reveals terrain relief. Examples of sun synchronous satellites are Landsat, IRS and SPOT.
- **Geostationary orbit:** has $0^0$ (zero degrees) inclination angle i.e. satellite is placed above the equator at an altitude of 36,000 km. The orbital period is kept equal to the rotational period of the earth that results in fixed position of satellite relative to the earth (i.e. satellites observes and collects information continuously over specific areas and always views the same portion of the earth). Due to their high altitude, geostationary weather satellite monitors weather and cloud patterns covering an entire hemisphere of the earth. Geostationary orbits are commonly used for meteorological and telecommunication satellites.

## 4.4 Classification of Sensors

Sensors are the devices used to record the electromagnetic radiations emitted or reflected from the target features and acquire images used in variety of remote sensing applications. In remote sensing, sensors are capable of acquiring information about the target feature to which human eye is insensitive to recognise specially the radiations in other parts of the electromagnetic spectrum than in the visible portion. Sensors are broadly classified into three categories: Optical sensor, Microwave sensor and Thermal sensor.

### 4.4.1 Optical sensors

An optical sensor utilizes the energy from sun which is the source of illumination by recording the energy reflected or emitted from the target feature. Optical sensors record the reflected or emitted energy in the visible, near infrared and short-wave infrared regions of the electromagnetic spectrum. The amount of energy recorded by the sensor depends upon the spectral reflectance characteristics of target features, since, different materials reflect and absorb differently at different wavelengths. For instance, optical sensors are sensitive mainly to the electromagnetic radiations lying in the range of 0.4 µm to 0.76 µm (visible band) as well as 0.76 µm to 0.9 µm (near and mid infrared band), which are the wavelengths insensitive to human eye. Images acquired from optical sensors finds usefulness in variety of applications such as post-earthquake damage assessment, landslide damage assessment, oil spills, vegetation monitoring, flood assessment and relief measures, land use and land cover classification, temporal change detection analysis and many more. Optical remote sensing systems are classified into the following types, depending on the number of spectral bands used in the imaging process.

- **Panchromatic imaging system (PAN):** The imaging sensor is a single channel detector sensitive to wide range of wavelengths of light typically covering the entire or large portion of visible band of the spectrum thus resulting in grey scaled image (i.e. images containing different shades of black and white). The PAN sensor records or measures the reflectance in terms of apparent brightness of the targets. The spectral information or "colour" of the targets in the resulting image is completely wiped off (Fig. 7). Examples of panchromatic imaging systems are:
    - IKONOS PAN
    - SPOT PAN
    - IRS PAN
    - Quick bird PAN

Fig. 7 Panchromatic image extracted from SPOT PAN sensor with ground resolution 10 m. (Source:http://www.crisp.nus.edu.sg/~research/tutorial/opt_int.htm).

- **Multispectral imaging system:** the Multispectral Scanner (MSS) is one of the important Earth observing sensors introduced in the Landsat series of satellites that uses an oscillating mirror to continuously scan the earth surface perpendicular to the spacecraft velocity. Every mirror sweep scans six lines simultaneously in each of the four spectral bands and images of the objects are recorded across the field of view. The resulting image is a multilayer image which contains both the brightness and spectral (colour) information of the targets being recorded. Examples of multispectral systems are:

  - o LANDSAT MSS
  - o IRS LISS
  - o SPOT XS
  - o IKONOS MS

The Multi-Spectral Scanners are further divided into the following two types:

(i) Whiskbroom Scanners

(ii) Pushbroom Scanners

**(i) Whiskbroom Scanners:** The whiskbroom scanner is an optical machenical device which is also known as across track scanner. These scanners uses a rotating mirror and a single detector which scans the scene along a long and narrow band. The orientation of the mirror is such that on completing one rotation, the detector scans across the field of view between 90° and 120° to obtain images in narrow spectral bands ranging from visible to middle infrared regions of the spectrum. The angle extended by the mirror in one complete scan known as the Total Field of View (TFOV) of the scanner. Whereas the solid angle extended from a detector to the area on the ground it measures at any instant is termed as Instanteneous Field of View (IFOV); refer Fig. 8. Figure 9 (a) depicts the scanning mechanism of whiskbroom scanners.

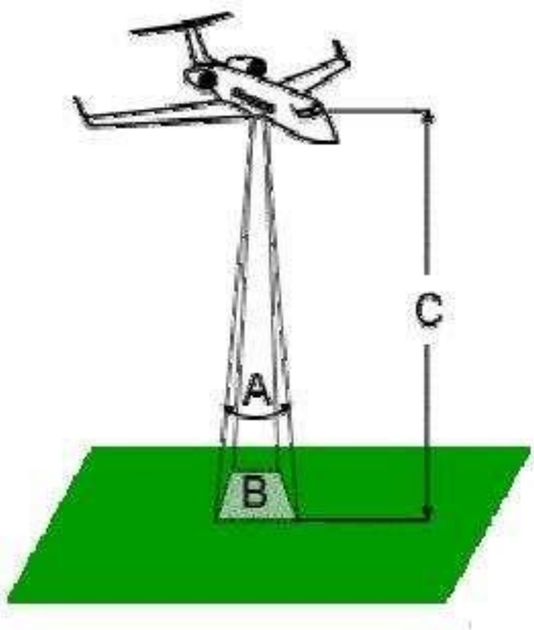



Fig. 8 Instantaneous Field of View (IFOV) for a typical scanner.

**(i) Pushbroom Scanners:** also termed as along track scanners and does not have a mirror looking off at varying angles. Instead, there is a line of small sensitive detectors stacked side by side each having tiny dimension on its plate surface; these may be several thousand in number and each detector is a charge coupled device (CCD). In other words, these scanners consist of a number of detectors equivalent to the swath of the sensor divided by the size of the spatial resolution or pixel size (Fig. 9 b). For example, the swath of High Resolution Visible Radiometer – 1 (HRVR – 1) of the French remote sensing satellite SPOT is 60 km and the spatial resolution is 20 metres. If we divide 60 km x 1000 metres/20 metres, we get a number of 3000 detectors that are deployed in SPOT HRV – 1 sensor. The detectors are placed linearly in an arrayed fashion and each detector collects the energy reflected by the ground cell (pixel).

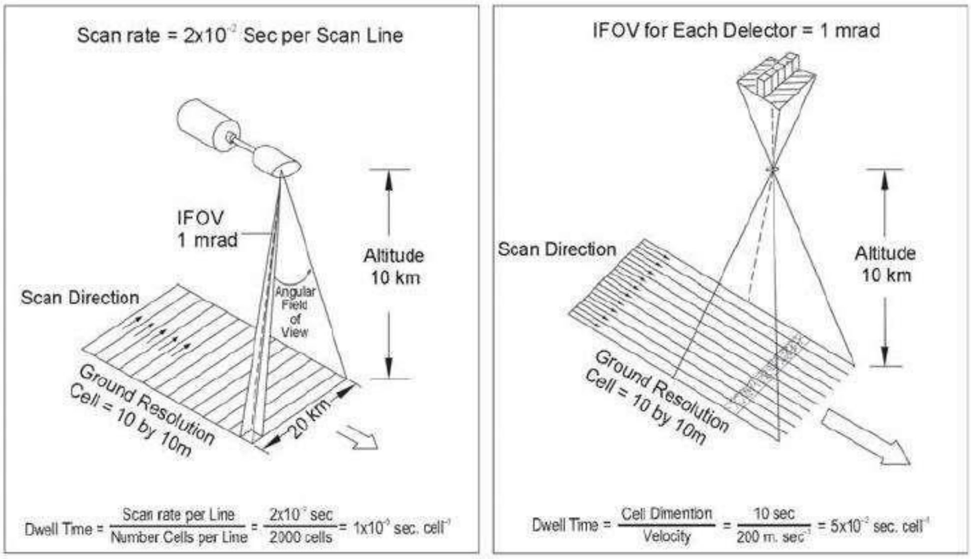



Fig. 9 (a) Whiskbroom scanner(b) Pushbroom scanner

- **Hyper spectral Imaging system:** Hyper spectral sensors are also referred to as imaging spectrometers that acquire images in a very narrow and large numbers of contiguous spectral bands (i.e. typically collect 200 or more bands of data) throughout the visible, near-IR, mid-IR, and thermal-IR regions of the electromagnetic spectrum (Fig. 10). Hyper spectral sensors employ either across-track or along-track scanning mode and the images acquired are used for characterisation and interpretation of surface features with high accuracy and detail on account of their spectral details. Every individual pixel in hyper spectral image contains a continuous reflectance spectrum of hundreds of spectral bands. A Landsat TM records an integrated response from a data point in 7 spectral bands of approximately 0.26 μm wide. Whereas, a hyper spectral sensor records the spectral response of the same point in large number of bands in the order of 0.01μm. Due to the large number of narrow bands in hyper spectral image, expensive ground surveys and laboratory testing have been widely replaced and therefore, hyper spectral data of very fine spectral resolution finds its usefulness in studies related to the mineral exploration in an area, water requirements of plants, vegetation health monitoring, soil type classification etc. Hyper spectral imaging sensors produce a complete coverage of spectral signatures of features with minimum wavelength omissions. Ground based or hand held versions of these sensors also exist and are used mainly for accuracy assessment purposes and for calibration of satellite data.

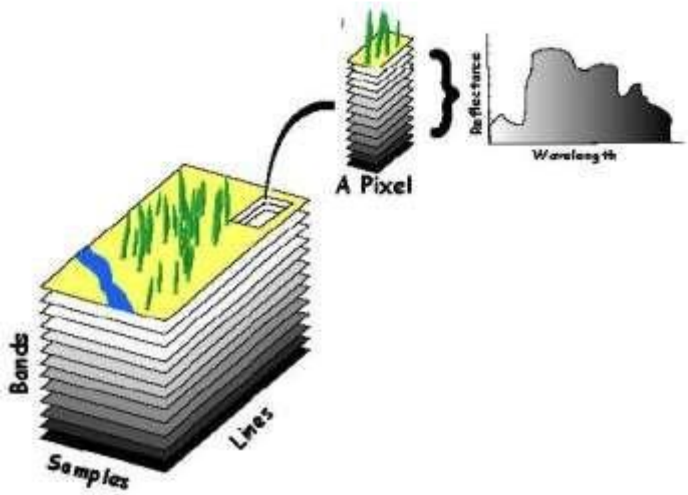



Fig. 10 Images acquired simultaneously in 200 or more spectral bands and the wavelength range depicted by the pixels; Source: Basics of remote sensing, Unit I; ESA website.

### 4.4.2 Microwave sensors

The microwave region of electromagnetic spectrum extends from wavelength approximately 1 cm to 1 m. The longer microwave wavelengths have special characteristics of penetrating the cloud cover, heavy precipitation, haze or dust and are not susceptible to atmospheric scattering which otherwise shorter optical wavelengths are prone to be scattered These property allows microwave remote sensing in almost all weather and environmental conditions and at any duration of time. In addition, microwave remote sensing also provides useful information on sea wind and wave direction, which are derived from frequency characteristics, Doppler effect, polarization, back scattering etc. that may not be possible by visible and infrared sensors. The sensors operating in the microwave region are broadly classified as active and passive sensors.

1) **Passive sensor** records natural radiation at a particular frequency or range of frequency. The passive microwave sensor records the intensity of the microwave radiation ranging between a frequency range of 5 to 100 GHz emanating from the surface of earth within the antenna's field of view. The passive sensors that measure the emitted energy are the microwave radiometers. The signal recorded through the antenna is represented as an equivalent temperature, in terms of a black body source which would generate

equal amount of energy within the bandwidth of the system. Therefore, the microwave energy recorded by a passive sensor is quite low as compared to optical wavelengths since the wavelengths are so long and therefore the field of view of the antenna is kept large to record sufficient energy. Most passive microwave sensors are therefore characterized by low spatial resolution. The important applications of passive microwave remote sensing include areas such as hydrology, oceanography and meteorology. In Meteorology, passive microwave sensors measure the water and ozone contents in the atmosphere. Soil moisture based studies measure surface soil emissions influenced by moisture content within soil medium. Oceanographers utilize passive microwave sensors to monitor ocean currents and waves, measurement of sea surface levels, surface wind currents as well as oil slicks.

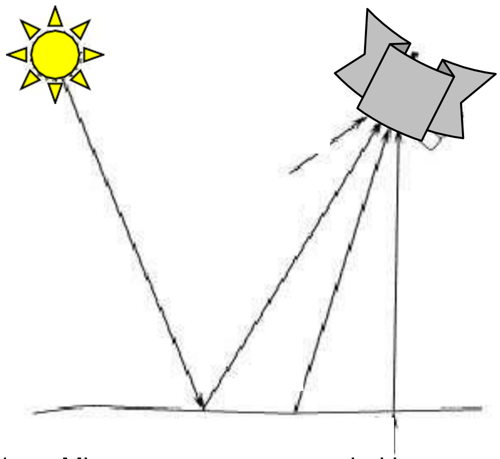


Fig. 11 Microwave energy recorded by a passive sensor

Figure 11 illustrates the working principle of passive microwave sensors which records the energy emitted by the atmosphere (A), reflected from the terrain features (B), emitted from the surface features (C), or transmitted from the subsurface (D).

2) **An active remote sensor** emits their own electromagnetic energy in the microwave region toward the surface feature which after interaction with the target produces a backscatter of energy, which is finally recorded by the active sensor's receiver (Fig. 12). Active microwave sensors are further categorized into imaging and non-imaging category. The most common form of imaging active microwave sensors is RADAR which is a acronym for Radio Detection and Ranging. Altimeters and scatter meters come under non-imaging microwave sensors category. The most widely used active remote sensing

systems is the RADAR, which transmits long wavelength microwave radiations from 3 cm to 25 cm and records the reflected energy from the target feature in the form of backscatter; LIDAR, an acronym for Light Detection And Ranging is based on the emission and transmission of relatively short wavelength laser waves through the atmosphere and then recording the backscatter radiation; SONAR, (Sound Navigation And Ranging) is based on the emission and transmission of sound waves through water medium and then recording the backscatter radiation from bottom of the water medium.

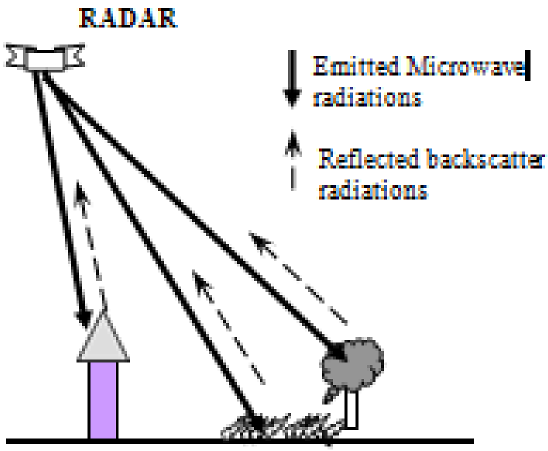



Fig. 12. Active microwave sensor.

Radar, which is basically a ranging device (Fig. 13) is composed of a transmitter, a receiver, an antenna, and an electronics system to generate and process the recorded data.

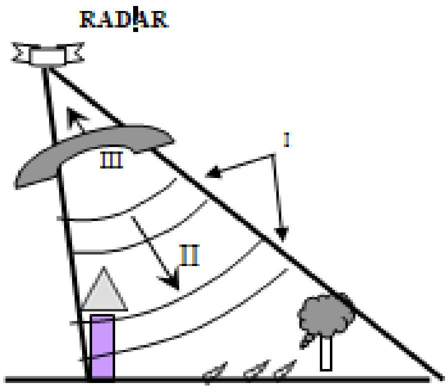



Fig. 13. Principle of the operation of the Radar sensor.

The function of transmitter is to emit successive short pulses of microwave radiation (I) at regular intervals which are converted into a beam (II) by the antenna. The microwave radiations emitted from radar illuminates the surface features obliquely at a right angle to the direction of the platform motion. The antenna receives and records the reflected energy also called as backscattered energy from the target features illuminated by the radar beam (III). Therefore, by measuring the time delay between the emitted radiation and the backscattered radiation from target features, their distance from radar and location are calculated. The forward motion of the platform and simultaneous recording of backscattered signal generates a two- dimensional image of the surface (Fig. 14).

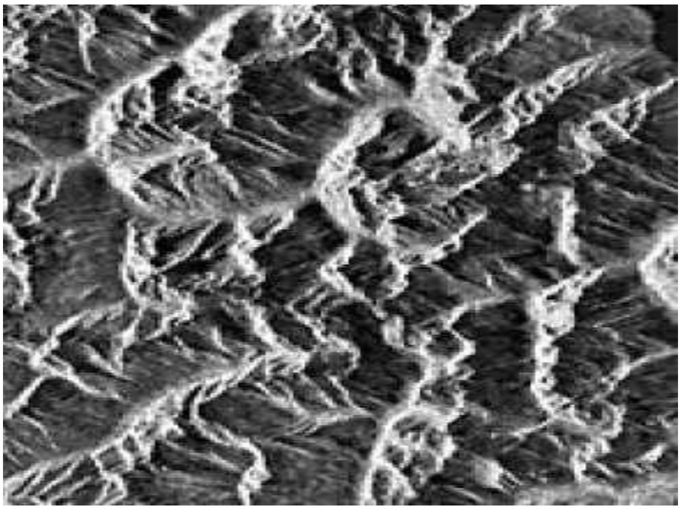


Fig. 14 ERS-2 C-band image of mountain area.

The microwave region of the spectrum (Fig. 15) is quite large, in contrast to the visible and infrared, and broad classification of several wavelength ranges or bands commonly used are mentioned below.

- **X-band:** used extensively for military reconnaissance and terrain mapping.

- **C-band:** sensor on board NASA airborne system and space borne systems including Envisat, ERS-1 and 2 and RADARSAT. Mainly used for surface soil moisture mapping.

- **S-band:** sensor board the Russian ALMAZ satellite and used for biomass modelling.

- **L-band:** sensor onboard American SEASAT and Japanese JERS-1 satellites and used for subsurface explorations.

**P-band:** sensor onboard NASA airborne research systems used for archeological explorations.

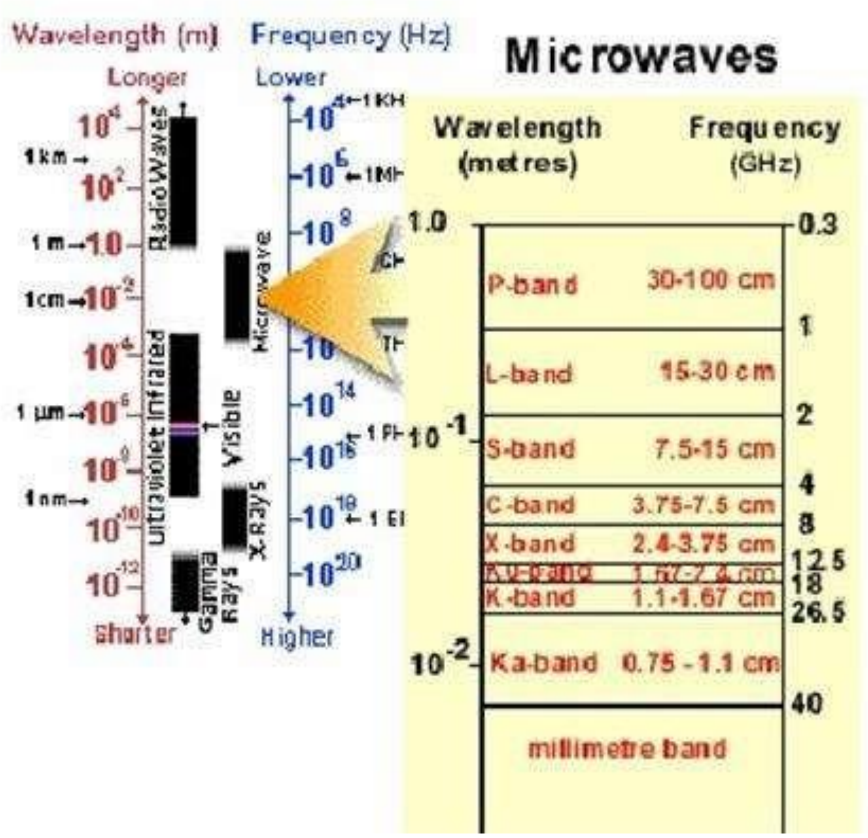



Fig. 15 The microwave region of the electromagnetic spectrum; source: Fundamentals of Remote Sensing by CCRS, Canada.

### 4.4.3 Thermal sensors

All objects having temperature above absolute zero (0 Kelvin) starts emitting electromagnetic energy in wavelength range between 3 m to 100 m. All objects selectively absorb short wavelength solar energy and radiate thermal infrared energy. In a thermal image the tone of an object is a function of its surface temperature and its emissivity i.e. all objects emit infrared radiation and the amount of emitted radiation is a function of surface temperature. Hot objects appear in lighter tone and cooler objects appear darker in an infrared image. In other words, the energy recorded by the radiometer is proportional to the product of the absolute physical temperature (T) and emissivity (î), where 'T' is referred to as brightness temperature. As all natural surface features emits radiations so as to keep thermal equilibrium which are measured by radiometer and is represented in terms of a black body.

The concept of a perfect black body relates to an ideal material that completely absorbs all incident radiation, converting it to internal energy that gives rise to a characteristic temperature profile. The radiant temperature of any object depends on two major factors i.e. kinetic temperature and emissivity. Infrared sensors detect remote objects by recording the emitted infrared energy as a continuous tone image on thermal sensitive photographic film.

Emissivity is the ratio of radiance spectrum of a non perfect emitter over that of a perfect emitter (black body) at the same temperature and is a measure of the ability of a material to radiate and to absorb the incident radiation. Radiant energy striking the surface of a material is partly reflected, absorbed and partly transmitted through the material. A black body material absorbs all radiant energy striking it therefore absorptivity equals to 1. Spectral curves in figure 16 implicit the underlying principle of thermal infrared remote sensing indicating relative intensities of radiation (radiances) as a function of wavelength for materials with different intrinsic temperatures.

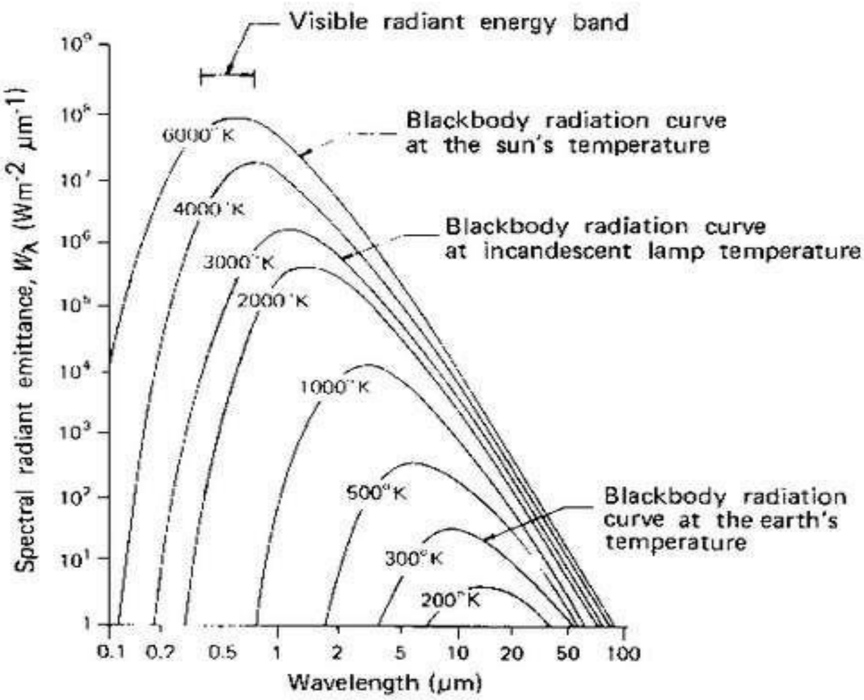
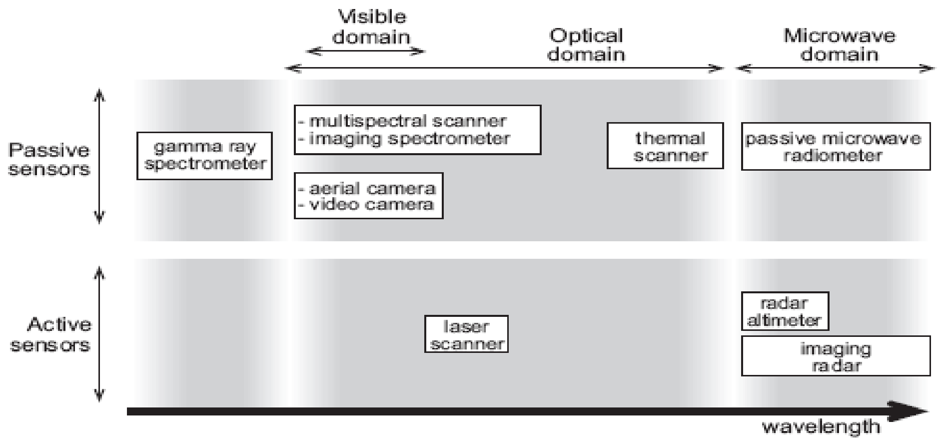



Fig. 16 Spectral curves showing relative intensities of radiation (radiances) as a function of wavelength different materials having varying temperature.

As illustrated in the above figure, all the curves have similar shapes, and higher intensity of emittance for hotter radiating object. Also, the peaks of the curves shift symmetrically towards left with the increase in kinetic temperature of the radiating object as per the Wien's Displacement Law. To be more precise, curves in the figure are representative of blackbodies at different temperatures. Natural materials are referred as gray bodies with temperatures above those of perfect blackbodies. There are objects emitting radiations even at longer wavelengths (i.e. right portion of the curves and beyond) extending into the microwave region. The emitted radiations are generally quite low in intensity and also not much attenuated by the atmosphere. The temperatures measured by these instruments are brightness temperatures (Tb) also referred to as radio-brightness and is characterised by the product of its emissivity and its physical temperature (in Kelvin).

Applications of thermal infrared remote sensing can be broadly classified into two categories; one in which surface temperature is governed by man made sources of heat and other which is governed by solar radiation. In the former case, the technique has been used from airborne platforms for determining heat losses from buildings and other engineering structures. In the latter case, thermal infrared remote sensing has been used for identifying crop types, surface soil moisture, monitoring forest fires, military operations as well as identification of crop species for detecting crop diseases.




**Overview of sensors**

**(Source: Kerle, Jamssen and Huurneman; Principles of Remote Sensing)**

## 4.5 Satellite Characteristics: Swaths and Orbits

The path followed by a satellite is referred to as its orbit. Satellites are launched into the desired orbits based on the onboard sensor capabilities as well as the objectives of the launch mission. During the early 1960s, satellites were launched primarily to monitor the Earth and its environment and sensors were designed mainly to acquire data for meteorological purposes. However, with the launch of first US based Landsat satellite series in July 1972, the era of earth resources satellites started with primary objective of mapping the surface features. Currently, more than a dozen orbiting satellites provides variety of data types that plays a significant role in enhancing the knowledge of the Earth's atmosphere, oceans, glaciers and land.

As discussed in the earlier section, remote sensing sensors can be installed on a variety of platforms to acquire data of target features. Although images from ground-based and aircraft platforms may widely be used, satellite based sensors provide images with unique characteristics which make them particularly useful for remote sensing of the Earth's surface.

Selection of satellite orbit takes into account the altitude (their height above the Earth's surface) and sensor orientation as well as its movement relative to the Earth. Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have geostationary orbits (Fig. 17a). These geostationary satellites, at altitudes of approximately 36,000 kilometres, revolve at speeds which match the rotation of the Earth so they seem stationary, with respect to specific portion of the Earth's surface. This allows the satellites to observe and collect information continuously over specific areas. Weather and communications satellites commonly have geostationary type of orbits. Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth.

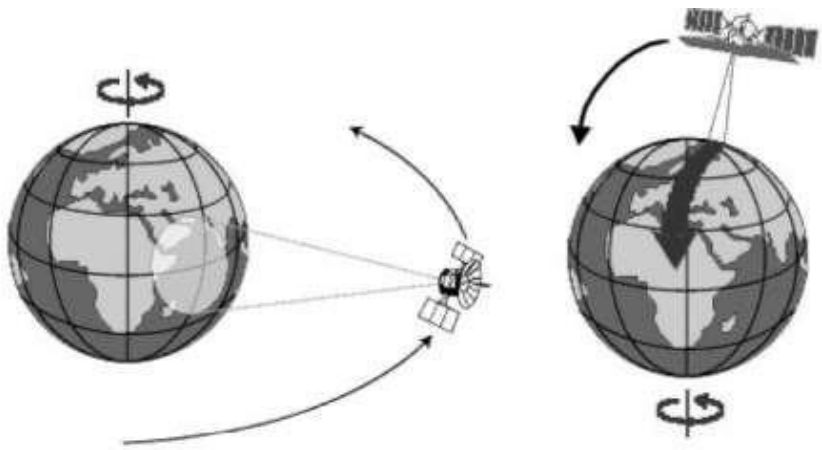


Fig. 17 (a) Geostationary Satellite (b) Polar orbiting satellite

Many remote sensing platforms are designed to follow north-south orbit which, in conjunction with the Earth's west-east rotation, allows them to cover most of the Earth's surface over a certain period of time. These are near-polar orbits, having inclination of the orbit relative to a line running between the North and South poles and are also termed as sun-synchronous or polar orbiting satellites (Fig. 17b) such that they cover each area of the world at roughly the same local time each day and referred as the local sun time. Sun-synchronous satellites are launched at 700 to 800 km altitudes. At any location, the position of the sun in the sky will be coherent to the satellite over passes thereby ensuring consistent illumination or sunlight conditions while acquiring images in a specific season over successive years.

A typical sun synchronous satellite completes 14 orbits a day, and each successive orbit is shifted over the Earth's surface by around 2875 km at the equator. Also the satellite's path is shifted in longitude by 1.17deg (approximately 130.54 km) everyday towards west, at the equator "from platforms and sensors", as shown in Fig.18.

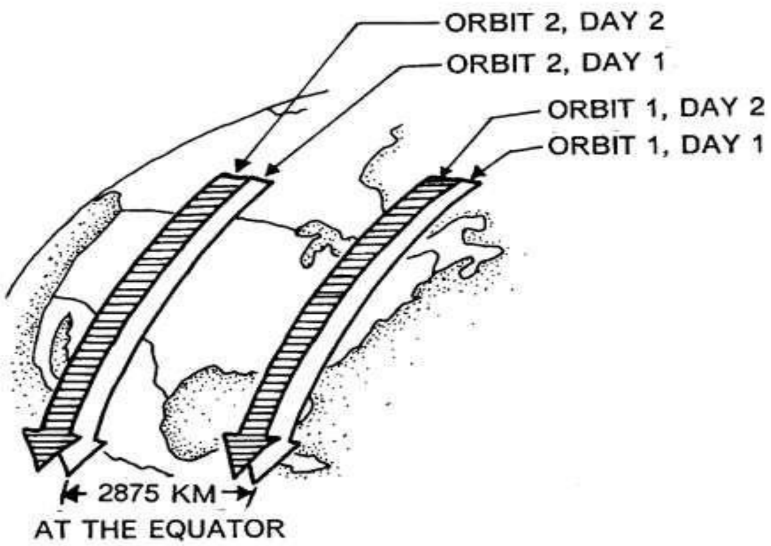



Fig. 18 Orbital shift of a typical sun- synchronous satellite

Landsat satellites and IRS satellites are typical examples of sun-synchronous, near-polar satellites. Fig.19 shows the orbits of the Landsat satellites (1, 2 and 3) in each successive pass and on successive days. Repeat cycle of the satellite was 18days and each day 14 orbits were completed.

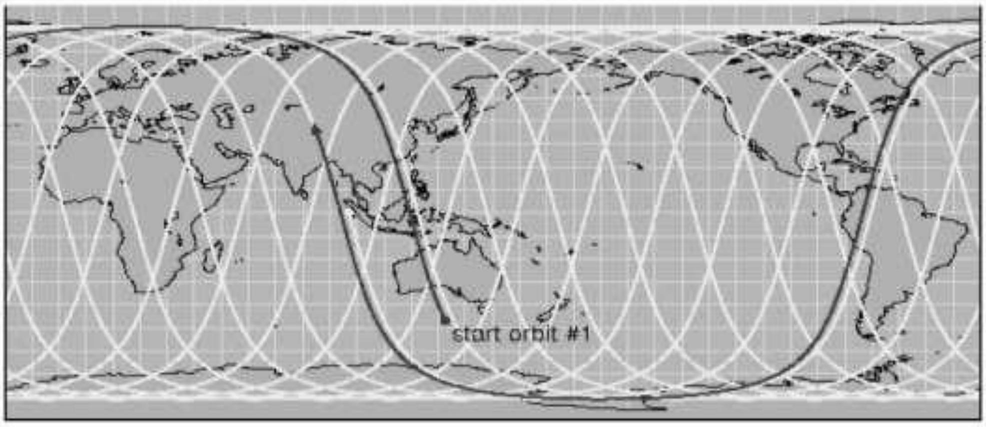



Fig. 19 Orbit of sun synchronous satellite.

The satellite while revolving around the earth scans a certain portion of the land area and the width of the area scanned during a single pass is called as the swath (Fig. 20). Swath widths for space borne sensors generally vary between tens and hundreds of kilometres wide. For example, swath width of the IRS-1C LISS-3sensor is 141 km in the visible bands and 148 km in the shortwave infrared band.

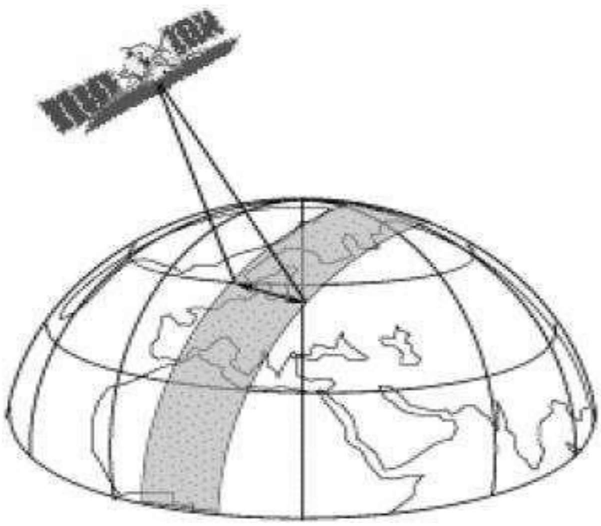


Fig. 20 Swath traced by polar orbiting satellite; source: Canada centre for remote sensing.

## 4.6 Weather and Communication Satellites

Any communication that makes the use of manmade satellite in its propagation path is referred to as satellite communication and plays a dominant role towards advancement in technology for the betterment of mankind. There are numerous artificial satellites in operation employed for traditional point-to-point communications, mobile applications, and the TV broadcasting and radio programs. Satellite communications uses high frequency signals such as Ultra High Frequency (UHF), ranging from 300 MHz to 3 GHz and Super High Frequency (SHF), ranging from 3 GHz to 30 GHz.

Satellites that are primarily used to monitor the weather and climate of the Earth are referred to as weather satellites. These satellites can be polar orbiting, scanning the entire globe in successive passes, or geostationary, stationed over the same spot over the equator. There are several geostationary meteorological satellites in operation such as GOES-12, GOES-13 and GOES-15 of United States, Elektro-L 1 Russia's new-generation weather satellite that operates at 76°E over the Indian Ocean, Japanese MTSAT-2 located over the mid Pacific at 145°E and the Himawari 8 at 140°E, European Meteosat-8 (3.5°W) and Meteosat-9 (0°) over the Atlantic Ocean and Meteosat-6 (63°E) and Meteosat-7 (57.5°E) over the Indian Ocean, India's INSAT series and Chinese Fengyun geostationary satellites.

The INSAT series of satellites carries Very High Resolution Radiometer (VHRR) for providing data for generating cloud motion vectors, cloud temperature, water vapour content, utilised in the modelling and forecasting the rainfall, movement of thunder storms and cyclones. These satellites also carry Data Relay Transponders (DRT) to facilitate reception and dissemination of meteorological data from in-situ instruments located across inaccessible areas. ISRO has also designed and developed ground based observation systems such as, Automatic Weather Station (AWS), Agro-meteorological (AGROMET) Tower and Doppler Weather Radar (DWR) as well as Vertical Atmospheric Observations System such as GPS Sonde and Boundary Layer LIDAR (BLL) so as to augment the space based observations and validating the events directly associated with various natural phenomenon.

## 4.7. Summary

**Ground-based platforms**: ground, vehicles, ladders and/or buildings:- up to 50 m

**Airborne platforms:** airplanes, helicopters, high-altitude aircrafts, balloons:- up to 50 km

**Space borne platforms:** rockets, satellites, shuttle:- from about 100 km to 36000 km

- Space shuttle: 250 to 300 km
- Space station: 300 to 400 km
- Low-level satellites: 700 to 1500 km

- High-level satellites: about 36000 km

Images shown on weather forecast news are the products acquired from geostationary satellites because of the broad coverage of the weather and cloud patterns on continental scales. These images are useful in determining the movement of weather patterns in temporal scale. The repeat coverage capability of geostationary satellites assists in collecting several images on daily basis to monitor wind and cloud patterns more closely.

## Self Assessment Exercise

1. What advantages do sensors carried on board satellites have over those carried on aircraft and building top? Are there any disadvantages also that you can think of for space borne platforms?
2. Can "remote sensing" employ anything other than electromagnetic radiation?

**Reference:**

Refer web link; http://www.britannica.com/EBchecked/topic/524891/satellite-communication and http://en.wikipedia.org/wiki/Communications_satellite for brief history and details on orbits of satellite communications.

# Unit 5: Image interpretation

**Unit Structure**



## 5.0. Learning objectives

After studying this unit you will be able to explain:

- To understand the elements of photograph/ image interpretation
- To understand the basic principle of digital image processing of remotely sensed data.
- To understand the information directly or indirectly.
- The techniques are useful in image acquisition, image corrections (radiometric, geometric), image enhancement, image transformation, image classification and accuracy assessment.
- Finally, learners will also come to know about the application of techniques of digital image processing.

## 5.1. Image Interpretation

Although most individuals have had substantial experience in interpreting "conventional" photographs / images in their daily lives, the interpretation of aerial photographs / satellite imagery often departs from every day image interpretation in three different respects: (1) the portrayal of features from an overhead often unfamiliar perspective; (2) the frequent use of wavelengths outside the visible portion of the electromagnetic spectrum: and (3) the depiction of the earth's surface at unfamiliar scales and resolutions. While these factors may be insignificant to the experienced image interpreter they can represent a substantial challenge to the novice image analyst. A systematic study of aerial photograph / satellite imagery usually involves several basic characteristics of features shown on a photograph / an image. The exact characteristics useful for any specific task and the manner in which they are considered depend on the field of application. However, most applications consider the following basic characteristics or variations of them: shape, size, pattern, tone (or hue), texture, shadows, site, and association.

## 5.2. Image Interpretation Strategies

As earlier mentioned, the image interpretation is not a simple task if knowledge, skills and experiences are not matching as there are a variety of features present on an image or aerial photograph. Also, the level of difficulty is associated with the kind of information, i.e. it is direct or derived. For example, delineating the path of a river course appearing on the surface is very easy compare to identify and delineate a historical river valley. Therefore, the rational thinking, imagination power along with subject and collateral knowledge is a necessity for a better image understanding. Sometimes, the information is available in pieces that need to be join together to know the complete information about an object or phenomenon from space imageries or aerial photographs. For example, identification of a particular crop type from imagery without knowing its seasonal period and duration might misinterpret the outcome. Therefore, it is necessary for an interpreter to know all these concepts before beginning the interpretation task and implement part of the strategies while interpretation.

The following is an example view in tabular form about the land cover appearances in various colors depending on the band combinations used in a satellite image.

Table 1. Land cover classes in appearing in colors in different band combination (SWAC, 2016)

| | **True Color**<br><br>**Red: Band 3**<br>**Green: Band 2**<br>**Blue: Band 1** | **False Color**<br><br>**Red: Band 4**<br>**Green: Band 3**<br>**Blue: Band 2** | **SWIR (GeoCover)**<br>**Red: Band 7**<br>**Green: Band 4**<br>**Blue: Band 2** |
|---|---|---|---|
| **Trees and bushes** | Olive Green | Red | Shades of green |
| **Crops** | Medium to light green | Pink to red | Shades of green |
| **Wetland Vegetation** | Dark green to black | Dark red | Shades of green |
| **Water** | Shades of blue and green | Shades of blue | Black to dark blue |
| **Urban areas** | White to light blue | Blue to gray | Lavender |
| **Bare soil** | White to light gray | Blue to gray | Magenta, Lavender, or pale pink |

## 5.3. Techniques of image interpretation

The technique of image interpretation basically involves space images and/or aerial photographs and collateral materials. The selection of input images or photographs depends entirely on the user side, largely based on the season, month or even dates and the resolution when other factors are taken into account. The collateral material or ancillary data contains existing information of an area, process, type of facility or object, that an interpreter may use as assisting resources during the interpretation process. The ancillary information present in the form of text, tables, maps, graphs or even image metadata such as spatial and radiometric resolution, date of acquisition etc. provide better definition of the scope, objectives and problems of the given task. Examples are socio-economic data, forest boundary, tree species diversity, land use map or weather reports. The collateral materials can be divided into two broad category, interpretation keys and field verification.

## 5.4. Image Interpretation Keys

Different interpretation classes can be described according to the interpretation elements. After affirming about the features present on the ground, interpretation keys can be constructed based on which object interpretation can be done (Tempfli et al., 2009). Thus, the process of image interpretation is tuned with these keys that basically sum up the complex information stored in the image form. Therefore, the keys are useful in two ways, first it act as a training tool and second, it provide a reference guide for the interpreter to correctly identify the information, even for unknown objects, in a planned and steady manner. A key is generally consist of two parts: (a) A collection of annotated or captioned images or stereograms rendering the object to be identified and (b) a graphic or word description, possible including sketches or diagrams representing the image recognition characteristics of the object of interest (Lillesand et al., 2008; Campbell and Wynne, 2011). Depending upon the way in which the features are organized, two types of keys are generally recognized:

i) Selective keys and ii) Elimination keys

i) **Selective keys**

These are basically many example images and/or aerial photographs with the supporting texts and are arranged in such a way that an interpreter simply selects that example that most closely corresponds to the object they are trying to identify, e.g. agriculture, forest, industries, lakes etc.

**ii) Elimination Keys**

The elimination keys are arranged in such a way that the interpreter follows a precise step-wise process from broad to the particular that leads to the elimination of all items except the one(s) that the interpreter is trying to identify. The elimination key is the most commonly used key type because it can provide more affirmative solutions for an example object in an image than a selective key. But, if the interpreter is not familiar or is uncertain in making choice between the two or more image objects, then it may result in a wrong selection of the right object.

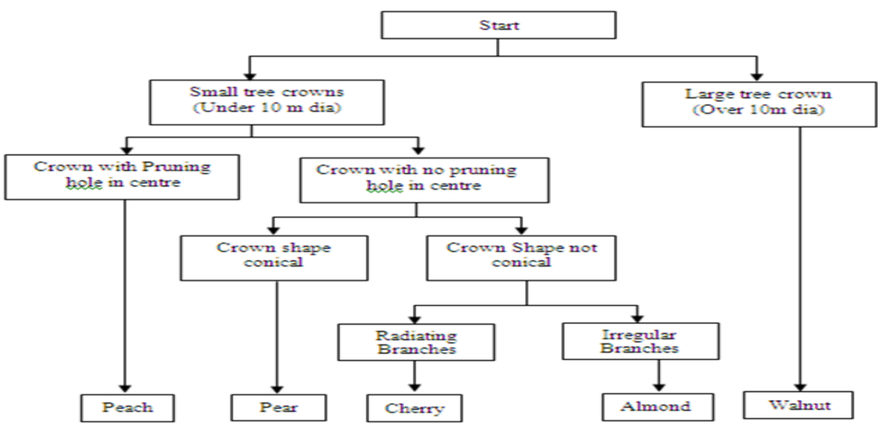
The selection of the type of key depend on the number of objects to be identified and the variability within each feature class within the selected key, for example, variation in texture in an open area.

**Field verification**

Ground verification is a type of collateral material since it is normally conducted to assist the interpreter in interpreting, classifying and analyzing the image information. Basically, ground verification help the interpreter in knowing the study area or feature class. This kind of confirmation is done before interpreting the information in order to develop a visual perception in a human vision system to match it how an object of interest appear in the field. Further ground truthing can be done after the interpretation is done to assess the accuracy of information interpreted. It is important for an investigator to chalk out a proper plan before going to ground like season, time to be spent, extent of study area, quantity of information to be collected, method of data collection.

The amount and type of field work required for a given project generally dependent upon the - type of analysis involved; image quality including scale, resolution and information to be interpreted; accuracy requirements for both classification and boundary delineation; experience of the interpreter and the knowledge of the sensor, area, and subject; terrain conditions, and the accessibility of the study area; personnel availability and access to ancillary material; and cost considerations (Estes, 2016).

**An example of Dichotomous key**



There are mainly two types of image interpretation:

A) Visual Image interpretation

B) Digital Image interpretation

## 5.5. Visual Image Interpretation

The electro-magnetic radiations interact with a wide range of target features lying on the Earth's surface. Different spatial objects have different reflecting behaviour in different wavelength (spectral) regions. These behaviors are being recorded by sensors that are sensitive towards information retrieval in those particular spectral regions and are finally reproduced digitally in image or pixel form. A digital image is like a container wherein the pixels like squared boxes are arranged in rows and columns. These pixels have an assigned numeric values, called 'digital number' (DN), which relates to the amount of reflectivity or emittance received by the sensors indexed in numeric form. Depending on the number of sensors used, visualization of the sensor-derived information is being done preferably in a colored form, in between the ranges of three primary colors of the human vision - Red, Green and Blue (RGB). The human vision system communicating between eye and brain after visual observation is capable of and constantly doing interpretation; drawing conclusions by spontaneous recognition due to object's knowledge; or, by logical inferences due to orderly build reasoning process; or, sometimes by field observation. Thus, the human vision system is well trained in 'object understanding'. However, seeing the i) complexity in reflective behaviour of objects, ii) overlapping regions and iii) human eye's spectral limitations, a necessity was felt to evolve a formal interpretation technique to recognize the objects in an image obtained through remote sensing. In this context, it is noticeable that our eye-brain system is also trained over a period of time in interpreting the objects in any thematic or specialized area in a space.

Visual Image Interpretation has many applications. The technique is important in creating maps of interest as point, lines and polygon (area) with their labeling. On an image of an urban area available in a hardcopy form, we can create a map by delineating the features by overlaying a transparency sheet on it and tracing the features of interest such as post-offices, temples, churches, historical monuments, lakes, inhabitated clusters and the transit road and rail networks connecting to them.

This may be useful in finding the shortest distance to minimize the transit time so as to reach the target location such as a post-office in a most economical way. Alternatively, a digital map of the same can be created in the case where the image is available in digital form in a computer by direct 'digitization' on-screen using the same interpretation technique.

## 5.6. Fundamentals of Visual Image Interpretation

The object or phenomenon recognition develops as the experience grows by visually inspecting a number of aerial photographs, space-borne images of different resolutions with ancillary information such as field inventoried maps, reports etc. Further, the state of complexity about information - direct or derived, also outlays the growing of image understanding. However, what so ever in manner the understanding can't be fully developed if the interpreter does not utilizes the brain's imagination and analytical power to its full potential. In this continuation, it is also important to mention here that the interpreter's skills can be application specific depending on the number and duration of times the interpretation in a field of application(s).

**Interpretation Elements**

The interpretation of image or aerial photograph is different from conventional ones in three different ways where the former is : i) taken from overhead and present a panoramic view ii) captures the features in multi-wavelength spectrum, apart from visible spectrum and iii) image and present the features at different scales and resolutions (Campbell and Wynne, 2011). The characteristics of feature identification is specific for the particular field of application in which they are applied. However, the basic elements considered for image interpretation are tone, texture, shape, size, pattern, association, shadow, aspect etc. These elements are used together, often, in combination.

**Tone**

Tone is considered as a basic element for all the image interpretation tasks. The tone is referred as relative brightness which is influenced by intensity (total brightness) and angle of illumination. The brightness is actually a result of exposure of distribution and amount of light in a given wavelength spectrum falling on an object. It is important to mention here that the degree of brightness is directly related to amount of energy reflected or emitted. The light or the absence of light relating lightness or darkness can lead to formation of a grey-scale image where tonal variation could be from black to white. Human eye is capable of viewing 40-50 tones. The tone changes when we enhance an image or when we visualize the features in different bands. In day-to-day life the tone is informally referred as 'color' which can be arranged from shortest wavelength to longest in the order of V (violet), I (indigo), B (Blue), G (green), Y (yellow), O (orange) and R (red) or VIBGYOR for memory aid. It is also important to mention here that the tonal variation is analytically more noticeable when features are recorded and produced by sensors digitally than conventionally printed on hard surfaces of paper or plastics. For example, a 8-bit colored image displayed in a combination of three primary colors (RGB) can have a total size of 256 possible combination of digital numbers (Lillesand et al., 2008). Alternatively, the RGB components of a color can be described by intensity (I), hue (H) and saturation (S). system which are basically the total brightness, dominant or average wavelength of light and purity of a color, respectively. Sometimes, the RGB to IHS transformation can lead to tonal or color enhancement for better interpretation of a colored or colored infrared (CIR) imageries or aerial photographs.

**Texture**

Texture is the frequency of tonal change on an image or aerial photograph which determines how smooth or rough the feature's surface is when visualized. The texture can be coarse or fine, smooth or rough, even or uneven etc. When an irregular surface is illuminated from an oblique angle, a pattern of highlighted and shadowed areas are created that give a textural appearance of feature's surface (Campbell and Wynne, 2011). The texture is strongly related to the spatial resolution of the image. As the scale of the image is reduced, the texture of any object or area of the image becomes progressively finer and ultimately disappear. It is easy for an image interpreter to discern between objects of similar tone based on their textural differences such as metallic and non-metallic roads.

**Shape**

The shape is a general form, configuration or outline of individual objects. In case of stereoscopic images the objects's height also defines its shape. The shape is an important sign for the interpreter. For example, sprinkler's irrigated fields when seen in an image looks circular in shape. Similarly, road, canal or river appears in a linear shape.

**Size**

The size of object in an image is important indication for an interpreter for feature discrimination and estimation of its approximate size. The relative size of an object when compared to its neighbors provides the interpreter a spontaneous impression about its scale and resolution. In case where the interpreter has a pre-knowledge about an object visually, it is not very difficult for him to identify unfamiliar neighboring objects and estimate its approximate size. For example, flourishing cropland area can be easily identifiable when a canal is passing nearby that serves the water for irrigation purpose. The size act also as a precious interpretation assistance where the dimensions are in direct relation with the object's identification or serve as a definite criteria to identify the object, for example, residential blocks and commercial complexes can easily be identified based on their size characteristics if other factors are also taken into consideration.

**Pattern**

The pattern refers to the spatial arrangement of individual objects in an image or aerial photograph into visibly distinct repetitive forms. This kind of spatial orderly repeat for both natural and man-made objects helps the interpreter in recognizing them. For example, an orchard where trees are present in a form that is distinctly arranged at certain spatial intervals can be easily discriminated with that of the forest tree stands.

Association

The association refers to the occurrence of certain features in relation to other or more specifically the relationship between other recognizable objects or features in the neighbourhood to the object in which the interpreter is interested. For example, the water can be associated with inhabited or irrigated area. Similarly, the mining activities can be associated with transportation routes. It is important to note here that the association does not necessarily involve size or pattern.

**Shadow**

The shadow is important for interpreters in two opposing respects: i) the shape or outline of a shadow affords an impression of the profile view of objects (which help in interpretation) and ii) objects within shadow reflect little light and are difficult to be differentiated on an image (which raises difficulty in interpretation) (Lillesand et al., 2008). For example, shadow cast by various tree species or cultural features (bridges, towers) can help in their identification and area estimation. But, the shadow of a tall building may hinders the delineation of the object on which the building's shadow is falling. For an investigator working in the field of forestry, it would be of much importance for him/her to know which side is sunlit and which side is sun-shadowed of a hilly region on an image in order to know the spatial distribution of dominant tree species on both side.

**Aspect**

The aspect or aspect ratio is the ratio of width of shape to its height or it is the estimation of how long the object is compared to its width. When the width is larger than its height, the shape of the object is 'landscape' rather than 'portrait'. The other advantage of aspect of a feature is that the continuously long thin features can be easily discernible even when they are narrower than the spatial resolution of the image, for example roads, streams etc.

## 5.7. Digital image interpretation

“A single portrait is enough to carve the whole story”

A digital image is like a gray colored two-dimensional matrix made up of finite set of squared cells arranged in rows and columns. These cells in digital world, called as 'picture elements or pixels', have some assigned numerical value called as digital number (DN) which, in remote sensing, relates to brightness of the cell. A row of pixels is called as a scan line.

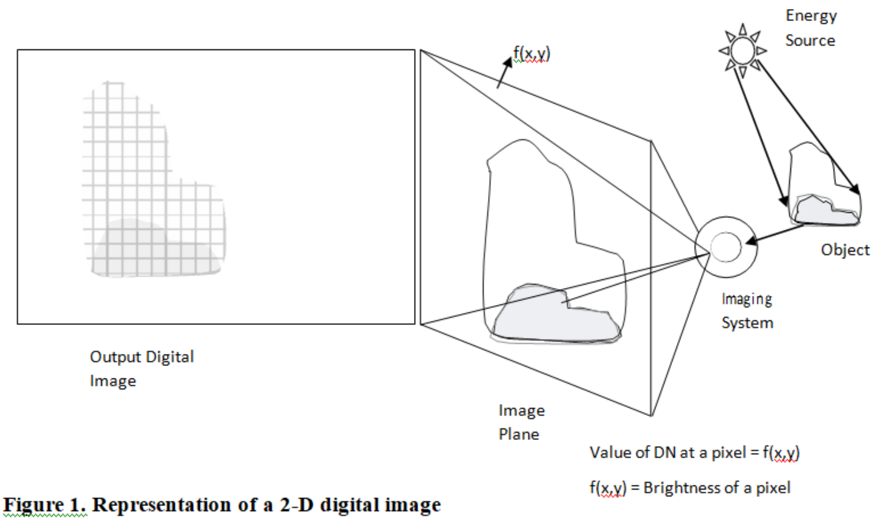



**Figure 1. Representation of a 2-D digital image**

The development in digital image processing has been evolved since the inception of digital computers and the two goes in parallel. Digital image processing methods were introduced in early 1920s. In 1921, Bartlane cable picture transmission system was used to transmit digitized newspaper images over submarine cable lines between London and New York. The images were coded and sent by telegraph at the transmitter end and decoded into images at the receiver using telegraph printers. The images were initially coded with 5 gray levels, but this number was increased to 15 in 1929 thereby enhancing the quality of the reproduced images (BCPTS, 2016).

The availability of digital computers was powerful enough to perform meaningful image processing tasks appeared in early 1960s. The use of such computers and algorithms for improving the quality of images of the moon taken by Ranger 7 probe started at Jet Propulsion Laboratory (JPL), NASA USA in 1964. In JPL, the image processing tasks involved was to correct various types of image distortion inherent in the on-board television camera (Gonzalez and Woods, 2002). Around 1970, the photographs captured using photographic imaging techniques were transferred to computers for the purpose of automated computer analysis using raster digitization methods (Konecny, 2003). The 1970s saw a surge in space missions and computing technology. The overwhelming increase in scientific interest due to growing need felt by scientists working in medicine and planetary sciences for remote observations of objects and events has led to the multi-dimensional and multifold development of digital image processing techniques. The invention of computerized tomography (CT) for medical diagnosis and the release of satellite images of Earth and extra-planetary features taken by Landsat missions for earth observation in early 1970s were landmark incidents that featured the later development of digital image processing techniques. The multispectrum imaging characteristics of Landsat sensors binds the developers to evolve the image processing techniques for visual image interpretation and digital analysis of information gained in the form of multispectral satellite images in a meaningful way.

It will not be inappropriate to say that this century is the digital century where we are surrounded with digital products and technologies and the multimedia information processing is at the core. The advancement in digital image processing, thus, also coupled with these products and technologies.

The digital image processing is a very vast field. Here, we will try to explain the basic concepts of different processing techniques applied to digital images for different applications without much dwelling into mathematical description of imaging and processing.

## 5.8. Components of Digital Image

Any image processing task includes few essential components. For example, a sensing step will require

i) a physical device that will be sensitive towards absorbing reflected/emitted energy from the source object and ii) a digitizer that will basically convert the energy absorbed by the physical sensors, for example in an electrical output form (electrical volt), into a digital form (bits or bytes). These components have been given in the following figure 2.

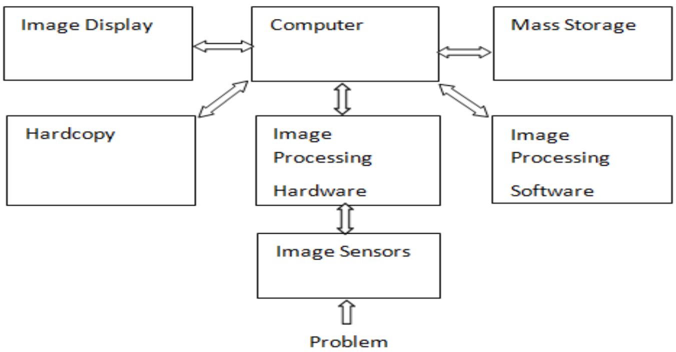



Figure 2. Essential components of a typical image processing system

The area of remote sensing what we experience today is evolved over a long period of time from aerial photography where images were use to record as photographs or photograph-like images. A photographic image is an analog picture or image in the form of physical record comprising pieces of paper or film with chemical coatings on it that represent a record of pattern of the image. In analog images the brightness's within an image is analogous or proportional to the brightness's within a scene. The problem lies with the analog pictures is that the user faces difficulties in storage, transmission, searching and analysis. Contrary to analog images, the digital images are arrays of pixels, each with a discrete digital number and are also discernable when analysed visually. The advantages of having digital images are they can be easily handled, stored, transmitted, retrieved, exchanged from one format to other and statistically manipulated which is not possible in case of analog images. Although our ability increases to display, examine, and analyse the modern remotely sensed digital image data but these data are also subject to corruption, damage to disk drives, magnetic fields, and deterioration of the physical media. In remote sensing, a digital image acquired through different sensors is represented in the form of a matrix consisting of pixels arranged in rows and columns. Each pixel has a unique location and are indexed according to their radiometric resolution, for example, pixels of a 8-bit image is indexed between 0-255. A subset of a multispectral Landsat 8 image is shown below which is also utilized for different purposes in later sections.

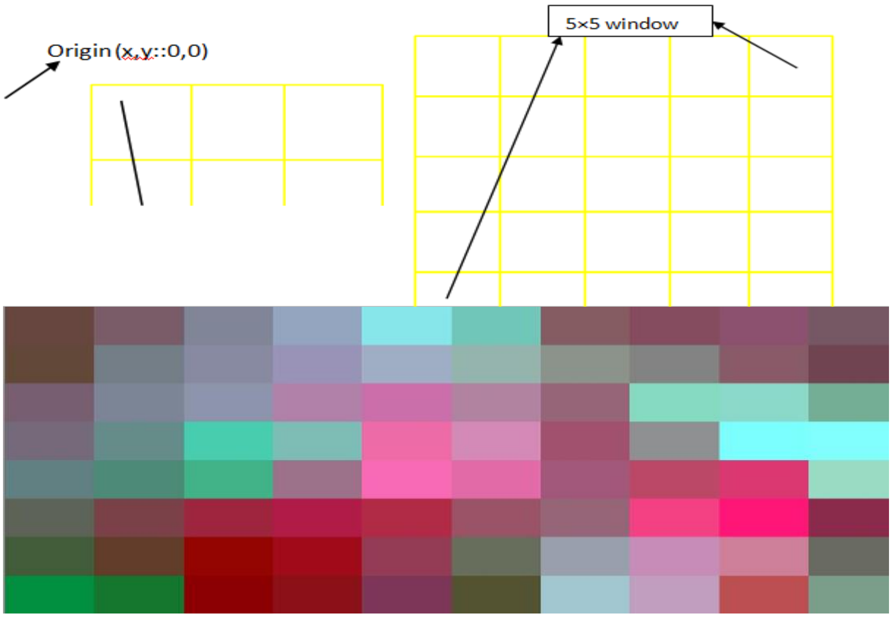



Figure 3. Pixels (8×10) of a part of the Landsat 8 satellite image (Image.tif)

The associated and/or additional information such as metadata of the image is stored either in a separate file or placed in the data file itself as a header (table 1). The image file contains only pixel values (table 2).

Table 1. Metadata Information of the Satellite Image as presented in Image.tif

| | | |
|---|---|---|
| **File Name** | Image.tif | |
| **Number of Bands** | 3 | |
| **Projection** | UTM, WGS84,Zone 43N | |
| **Format** | Unsigned 8-bit | |
| **Data Type** | Continuous | |
| **Pixel resolution** | 30m | |
| **Image Width** | 10 Pixel | |
| **Image Height** | 8 Pixel | |
| **Image Extent(Meters)** | Upper Left X | 657045 |
| | Upper Left Y | 3367335 |
| | Lower Right X | 657345 |
| | Lower Right Y | 3367095 |

Table 2. Pixel (spatial resolution 30m) data of the part of satellite image (Image.tif) as appeared in 3 bands (Band 1: Near Infra-Red, Band 2: Red and Band 3: Green)

(X: X-coordinate; Y: Y-coordinate; and DN: Digital Number or Pixel Value)

| X | Y | DN (Band 1) | DN (Band 2) | DN (Band 3) | X | Y | DN (Band 1) | DN (Band 2) | DN (Band 3) |
|---|---|---|---|---|---|---|---|---|---|
| 657060 | 3367320 | 84 | 39 | 43 | 657060 | 3367200 | 79 | 71 | 88 |
| 657090 | 3367320 | 98 | 52 | 71 | 657090 | 3367200 | 64 | 77 | 82 |
| 657120 | 3367320 | 105 | 74 | 104 | 657120 | 3367200 | 54 | 99 | 93 |
| 657150 | 3367320 | 121 | 92 | 130 | 657150 | 3367200 | 128 | 63 | 94 |
| 657180 | 3367320 | 111 | 128 | 160 | 657180 | 3367200 | 203 | 59 | 123 |
| 657210 | 3367320 | 91 | 110 | 126 | 657210 | 3367200 | 185 | 59 | 114 |
| 657240 | 3367320 | 109 | 51 | 66 | 657240 | 3367200 | 133 | 49 | 82 |
| 657270 | 3367320 | 109 | 42 | 64 | 657270 | 3367200 | 154 | 40 | 71 |
| 657300 | 3367320 | 115 | 45 | 75 | 657300 | 3367200 | 179 | 31 | 77 |
| 657330 | 3367320 | 97 | 49 | 69 | 657330 | 3367200 | 125 | 122 | 133 |
| 657060 | 3367290 | 80 | 40 | 39 | 657060 | 3367170 | 76 | 55 | 59 |
| 657090 | 3367290 | 95 | 70 | 92 | 657090 | 3367170 | 100 | 37 | 49 |
| 657120 | 3367290 | 111 | 77 | 109 | 657120 | 3367170 | 129 | 21 | 42 |
| 657150 | 3367290 | 125 | 82 | 125 | 657150 | 3367170 | 145 | 15 | 49 |
| 657180 | 3367290 | 130 | 97 | 134 | 657180 | 3367170 | 146 | 24 | 48 |
| 657210 | 3367290 | 123 | 100 | 119 | 657210 | 3367170 | 126 | 46 | 70 |
| 657240 | 3367290 | 115 | 82 | 94 | 657240 | 3367170 | 123 | 57 | 82 |
| 657270 | 3367290 | 107 | 73 | 89 | 657270 | 3367170 | 200 | 36 | 90 |
| 657300 | 3367290 | 112 | 50 | 70 | 657300 | 3367170 | 255 | 12 | 81 |
| 657330 | 3367290 | 93 | 38 | 56 | 657330 | 3367170 | 114 | 24 | 52 |
| 657060 | 3367260 | 98 | 53 | 76 | 657060 | 3367140 | 55 | 52 | 40 |
| 657090 | 67260 | 102 | 74 | 102 | 657090 | 3367140 | 80 | 34 | 29 |
| 657120 | 67260 | 115 | 83 | 117 | 657120 | 3367140 | 121 | 3 | 1 |
| 657150 | 67260 | 145 | 72 | 116 | 657150 | 3367140 | 132 | 6 | 17 |
| 657180 | 67260 | 166 | 62 | 116 | 657180 | 3367140 | 121 | 33 | 58 |
| 657210 | 67260 | 145 | 73 | 110 | 657210 | 3367140 | 85 | 61 | 63 |
| 657240 | 67260 | 123 | 56 | 82 | 657240 | 3367140 | 125 | 89 | 118 |
| 657270 | 67260 | 108 | 122 | 132 | 657270 | 3367140 | 164 | 78 | 126 |
| 657300 | 67260 | 114 | 121 | 137 | 657300 | 3367140 | 169 | 71 | 106 |
| 657330 | 67260 | 94 | 97 | 102 | 657330 | 3367140 | 86 | 59 | 67 |
| 657060 | 67230 | 95 | 59 | 83 | 657060 | 3367110 | 0 | 80 | 43 |
| 657090 | 67230 | 84 | 78 | 94 | 657090 | 3367110 | 17 | 66 | 31 |
| 657120 | 3367230 | 59 | 114 | 119 | 657120 | 3367110 | 114 | 0 | 0 |
| 657150 | 3367230 | 103 | 105 | 124 | 657150 | 3367110 | 115 | 9 | 16 |
| 657180 | 3367230 | 194 | 60 | 114 | 657180 | 3367110 | 103 | 30 | 59 |
| 657210 | 3367230 | 173 | 77 | 124 | 657210 | 3367110 | 68 | 46 | 33 |
| 657240 | 3367230 | 132 | 45 | 75 | 657240 | 3367110 | 134 | 111 | 142 |
| 657270 | 3367230 | 117 | 80 | 99 | 657270 | 3367110 | 158 | 88 | 131 |
| 657300 | 3367230 | 101 | 163 | 183 | 657300 | 3367110 | 153 | 44 | 55 |
| 657330 | 3367230 | 106 | 255 | 255 | 657330 | 3367110 | 101 | 88 | 94 |

## 5.9. Digital Image Processing

The digital image processing is a big domain. The tools and technology for data acquisition is different for different applications. Here, in the forthcoming sections we will be describing only major processing stages of digital images that are commonly used in the field of remote sensing.

### 5.9.1. Image Acquisition

The reflected energy acquisition from the Earth's surface is measured by imaging sensors that has a capability to digitize the signal collected by the sensor in its Video and Digital camera. The sensors are mounted on an aircraft or space craft platforms. In earlier days, the conventional camera and analog- to-digital converters were there to acquire an image. A digital image can be also being produced from papers using either a CCD camera or a scanner. It is important to mention here that in remote sensing an imaging system is a complex system where reflection or scattering of energy from the Earth's surface, followed by transmission through the atmosphere to sensors, and the data transmission from sensor to ground station on the Earth's surface where after an initial pre-processing such as volts to DN conversion, removing of noises, re-sampling and others, the data is ready in an image format to be utilized for different purposes such as land use/land cover study, disaster monitoring, environmental pollution study etc. It is well known that the data are recorded in optical as well as microwave spectral regions through both active and passive sensing and hence are delivered in to distributed spectral bands (visible, near infra-red, short wave infra-red, microwave) at certain spatial and radiometric resolution. Generally, the digital images are of four kind: a) Binary, b) Grayscale [0 to 255; black to white], c) True color or RGB [ 0 to 255 ] (such as 24-bit color images), and d) Indexed. Further, data acquired and delivered in raster and vector format with additional information in a metadata form.

The digital images obtained from multispectral sensors are arranged in different spectral bands and are represented in a matrix form (figure 4).

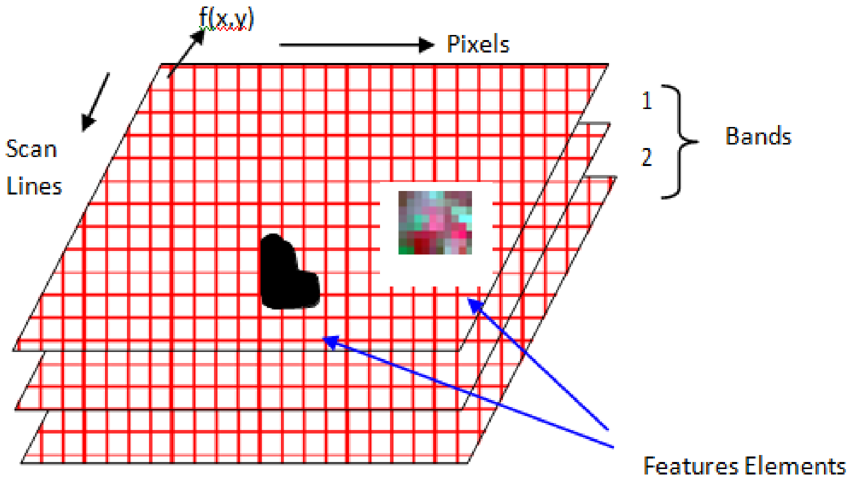



Figure 4. Structure of a Multispectral Image and feature elements

The digital data are for storing purpose are organized in the following three formats. An image, for example, consisting of three bands of same resolution can be visualized as three superimposed images with corresponding pixels in one band registering exactly to those in the other bands. The data formats are:

**Band Interleaved by Pixel (BIP)**

This is one of the initial formats for digital data. In this, the data are organized in sequence values for line 1, pixel 1, band 1; then for line 1, pixel 1, band 2; then finally for line 1, pixel 1, band 3. Next are the three bands for line 1, pixel 2, and so on. In this way, the pixel values (of pixel 1) for all three bands are written followed by the values for the next pixels (pixel 2, pixel 3 and so on) are represented. This arrangement is advantageous for many analyses in which the pixel value (DN) vector is queried or required to calculate another quantity. The disadvantage with this image format is that it becomes bulky while displaying.

**Band Interleaved by Line (BIL)**

The BIL treat each line of the data as a separate unit. In sequence, the data are arranged as line 1 for band 1, line 1 for band 2, line 1 for band 3, line 2 for band 1, line 2 for band 2, line 2 for band 3 and so on. In this way, each line is represented in all three bands before the next line is encountered. A common variation in the BIL format is to group lines in sets of 3 or 7, for example, rather than to consider each single line as the unit.

**Band Sequential (BSQ)**

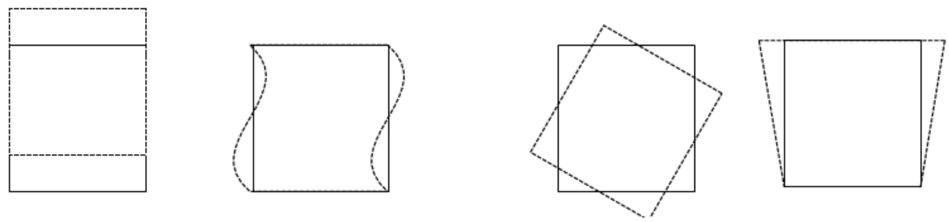
In BSQ, all the data for band 1 are written in sequence, followed by all data for band 2, and so on. In this, each band is treated as a separate unit. This is a most commonly applied image format since it presents the data which closely matches the data structure used for display and analysis.

## 5.10. Image Pre-processing

Image Pre-processing is a process to enhance the image in order to make it suitable for further processing. It includes mainly radiometric and geometric corrections.

### 5.10.1 Geometric Corrections

The geometric distortions in the remotely sensed images is inherent in nature and is depend on the manner in which they are acquired. It is to be noted that the Earth's geometry is three-dimensional and spherical in shape and therefore, transformations of remotely sensed image becomes necessary to map the curved Earth's surface to a two-dimensional plane. The geometric distortions in the images occurs due to several reasons which can be broadly classified into two categories: systematic or predictable errors and nonsystematic or random errors. The source of systematic or internal errors are: geometric distortion in the image due to terrain effects (elevation differences); cross-scan geometric distortion due to skew in ground swath at the time of scanning (by the time ground swath takes place the ground track changes due to movement of space-/air-craft); along scan geometric distortion due to changing mirror scan rate at the time of scan; panoramic distortion - the ground area imaged is proportional to the tangent of the scan angle rather than to the angle itself, and since data are sampled at regular intervals, this produces along scan distortion, particularly where instantaneous field of view (IFOV) is larger causing imaged ground area at the extremities of the scan larger laterally than the region sensed at nadir giving a compression of the image data towards its edges; along-track scale distortion is caused when platform speed changes resulting in the change in the ground track covered by successive mirror scan; the simultaneous satellite scanning towards west-east with Earth rotation in North-South results in a shift of ground swath causing along-track distortion. The platform instability while scanning results in nonsystematic or external errors. This is caused by: platform attitude (roll, yaw and pitch) changes during forward motion and this leads to image rotation and image displacement along- track and across track while scanning (figure 5a-5c); change in the remote sensing platform altitude causes the change in scale at constant angular IFOV and field of view (figure 5d). The above mentioned geometric distortions can be rectified using the methods given below.



(a) Pitch (b) Roll (c) Yaw (d) Altitude

Figure 5. Effect of platform attitude errors

All the remote sensing application requires plan metrically correct versions of remotely captured images so that they will match to other imagery and to maps and will provide the basis for accurate measurements of distance and area. There are two techniques that can be used to correct the various types of geometric distortions present in digital image data: one is orbital geometry modelling and the other one, rather used in many image processing, is the transformation based on ground control points (GCPs) (Sunar and Özkan, 2000). The GCPs are identified spectrally distinct areas as small as a few pixels denoted as image coordinates. The examples are road intersections, distinctive water bodies, edges of land-cover parcels, stream junctions, and other similar features. To interrelate the geometrically correct (map) coordinates and the distorted image coordinates, a coordinate transformation is performed by applying a least-squares regression analysis to the set of GCPs and determining the coefficients of the transformation matrix for linear or nonlinear transformations. It is to be noted here that as the number of GCPs is increased, registration error decreases. After calculating the transformation coefficients, various resampling methods such as nearest neighbour, bilinear or cubic convolution can be used to determine the pixel values to fill into the corrected output image file from the original distorted image file.

#### 5.10.1.1. Georegistration and Georeferencing

The geometric registration or georegistration involves identifying several image coordinates - row and column, or GCPs in the distorted image and link them to their true positions in a target map or ground coordinates such as latitude-longitude using transformation function (parameters) that basically relates the coordinates of two systems. The true ground coordinates are typically measured from a target map, either in paper or digital format. The target map could be a topographic or any other map that has been transformed to the wanted map projection system before. This is called as image-to-map registration. Geometric registration may also be performed by registering one (or more) images to another image, instead of to geographic coordinates. This is called image-to-image registration and is often done prior to performing various image transformation procedures, which involve comparing images from different sensors or dates. One more important concept with respect to geometry of satellite image is rectification. Rectification is the process by which the geometry of an image area is made planimetric (Haralick, 1973). The accuracy of the registration at each GCP after registration is measured in terms of the location error which is the root mean square error (RMSE) - the standard deviation of the difference between actual positions of GCPs and their new calculated positions (i.e., after registration). These differences between measured and transformed GCPs coordinates are known as residual error or simply residuals. Usually RMSE is reported in units of image pixels for both north– south and east–west directions. If analysts wish to assess the overall accuracy of the registration, some of the GCPs should be withheld from the registration procedure and then used to evaluate its success. There is another term called geo-coding which is geo-referencing with subsequent re-sampling and includes the two step process: i) each new raster pixel is projected using transformation function onto the original image and ii) a digital number for the new pixel is determined and stored.

### 5.10.1.2. Transformation

Image transformation is an integral of geo-referencing and involves two steps: i) selection of suitable transformation method and ii) determination of the transformation parameters. The polynomial transformation is a general type of transformation that involves 1st, 2nd and nth order of transformation. The 1st order polynomial transformation relates map coordinates (x,y) with image coordinates (m,n) in the following manner:

$$x = a+bm+cn \quad (1)$$

$$y = d+em+fn \quad (2)$$

The six transformation parameters (a to f) in the above two equations (1st order polynomial) is determined by a required number of GCPs (three) using a least squares adjustments for overall best fit of image and map. For the 2nd and 3rd order polynomial a minimum number of GCP is six and ten, respectively. An error of transformation is calculated and overall transformation accuracy is determined as variances or RMSE in both x- and y-direction and in terms of an overall RMSE. It is important to mention here that RMSE conveys an overall accuracy but does not indicate which part of the image is accurately transformed and which are not. It is also important to note that RMSE is valid only for the area bounded by GCPs and therefore, its selection should be well distributed and includes the locations near the edges of the image.

### 5.10.1.3. Re-sampling

Image re-sampling is a process of interpolation to bring an image into registration with another image or a plan metrically correct map. Re-sampling scales, rotates, translates, and performs related manipulations as necessary to bring the geometry of an uncorrected image to match a particular reference image of desired properties.

The computationally efficient and preferred re-sampling approach is a nearest-neighbor in which each “corrected” pixel is assigned the value from the nearest “uncorrected” pixel. The advantages of this approach are its ability to preserve the original values of the unaltered image.

A relatively more complex re-sampling approach is bilinear interpolation where a value is calculated for each output pixel based on a weighted average of the four nearest input pixels. While output value calculation, a nearer pixel value is given a greater influence than a more distant pixels. Because each output value is based on several input values, the output image will not have the unnaturally blocky appearance compare to some nearest-neighbor images. The image therefore has a more “natural” look. However, there are important changes. First, because bilinear interpolation creates new pixel values, the brightness values in the input image are lost. The analyst may find that the range of brightness values in the output image differs from those in the input image. Such changes to digital brightness values may be significant in later processing steps. Second, because the resampling is conducted by averaging over areas (i.e., blocks of pixels), it decreases spatial resolution by a kind of “smearing” caused by averaging small features with adjacent background pixels.

Another relatively complex re-sampling method is cubic convolution. Cubic convolution uses a weighted average of values within a neighborhood that extends about two pixels in each direction, usually encompassing 16 adjacent pixels. Typically, the images produced by cubic convolution re-sampling are much more attractive than those of other procedures, but the data are altered more than are those of nearest-neighbor or bilinear interpolation, the computations are more intensive, and the minimum number of GCPs is larger.

### 5.10.2. Radiometric corrections

It include correcting for sensor irregularities and unwanted sensor or atmospheric noise causing visible errors in the raw data and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor. The radiometric problems in the data are mainly of three kinds: Periodic Line Dropouts, Line stripping and Random noise or spike corrections.

#### 5.10.2.1. Periodic Line Dropouts

In this, one of the detectors of the sensor either gives wrong data or stop functioning. For example, Landsat-7 Enhanced Thematic Mapper (ETM) has 16 detectors per band (channel) except thermal channel. In this, every sixth scan line has a string of zeros which plots as a black line on the image. The first step in the radiometric correction or restoration process is to measure the average DN value per scan line for the entire scene. The average DN value for each scan line is then compared with this scene average. Any scan line deviating from the average by more than a designated threshold value is identified as defective. In the next step, the defective lines are replaced. In this, for each pixel in a defective line, an average DN is calculated using DNs for the corresponding pixel on the preceding and succeeding scan lines. The average DN is substituted for the defective pixel. The resulting image is a major improvement, although every sixth scan line consists of artificial data. This restoration process is equally effective for random line dropouts that do not follow a systematic pattern.

#### 5.10.2.2. Line stripping

It is possible that with time the response of some detectors of a band may shift to higher or lower levels. As a result of which every scan line recorded by that detector is brighter or darker than the other lines. This defect is known as periodic line striping. This can be understood by an example in which for example, if every second line (detector number 2) has this defect, i.e. 'second-line striping' where every second line of that detector has a brightness offset like the second line can have digital value twice that of the other detectors (lines), causing every second scan line to be twice as bright as the scene average.

For this problem, one of the radiometric correction or restoration method is to plot equal number of histograms for the DNs recorded by each detector (for e.g. 16 histograms for 16 detectors). A comparison of these histograms with a histogram for the entire scene can be made. Then, for each detector the mean and standard deviation are adjusted to match values for the entire scene. Alternatively, the DNs of detector number 2 can be altered by using any arithmetic operator by a single factor to produce the corrected values from which the restored image is plotted.

In another restoration method, a histogram of DNs for each of the 16 detectors if first plotted. Then deviations in mean or median values for the histograms are used to recognize and determine corrections for detector differences.

#### 5.10.2.3. Random noise or spike corrections

The line dropouts and line striping are the form of nonrandom noise in the image that may appear. Random noise occurs in situations where individual pixels with DNs are much higher or lower than the surrounding pixels. In the image these pixels produce bright and dark spots that spoil the image quality. Therefore, the random noise requires more distinguished restoration method. These spots can be removed by digital filters such as moving average filter.

## 5.11. Image Enhancement

The purpose of image enhancement is to prepare the image more interpretable for a particular application and/or feature extraction. The image enhancement techniques can be classified in many ways. In contrast enhancement or global enhancement, the raw data is transformed by using the statistics computed over the entire image. The examples of contrast enhancement techniques are linear contrast stretch, histogram equalized stretch and piece-wise contrast stretch. On the other hand, spatial or local enhancement considers the local conditions only and these can vary considerably over an image. The examples of spatial enhancement techniques are image smoothing and sharpening filters.

### 5.11.1. Contrast Enhancement

Contrast enhancement involves changing the original values so that more of the available range is used, thereby increasing the contrast between targets and their backgrounds. The contrast enhancements, thus, utilizes image histogram to be stretched over the entire grey range. A histogram is a graphical representation of the amount of DN values distributed over an entire image, for example the amount (frequency) of DN value 10 (x-axis) is 10000 pixels (y-axis) in an image. For a 8-bit image, the DN ranges in between 0 to 255 (or black to white). Commonly, the histogram is statistically represented as mean, standard deviation, minimum and maximum (range). A narrow histogram, thus, having small standard deviation, shows a low contrast image where all the DNs are nearby with a fewer grey values.

#### 5.11.1.1. Linear Contrast Stretch

In a 8-bit image, a DN value in the low end of the original histogram is assigned to extreme black (0), and a value at the high end is assigned to extreme white (255). The remaining pixel values are distributed (interpolated) linearly between these extremes. One drawback of the linear stretch, is that it assigns as many display levels to the rarely occurring DN values as it does to the frequently occurring values. However, linear contrast stretch, putting (min, max) at (0,255) in most cases still produces a rather dull image. Even though all gray shades of the display are utilized, the bulk of the pixels are displayed in mid gray. This is caused by the more or less normal distribution, within the minimum and maximum values in the tail of the distribution. For this reason it is common to cut off the tails of the distribution at the lower and upper range (usually be defining the size of the tails by their percentage from the total).

#### 5.11.1.2. Histogram Equalization Stretch

It is a non-linear transformation of image pixels where the original histogram is being readjusted to create a uniform pixel density along the horizontal grey value (DN) axis.

This involves two steps: i) it computes the histograms of the original image and the cumulative frequency density percentage and ii) computation of transformation function based on which the contrast manipulation takes place in the output scene. Thus, in this method, both the shape and the extent of the histogram is taken into consideration. The underlying principle is based upon the assumption that each histogram class in the displayed image must contain an approximately equal number of pixel values, so that the histogram of these displayed values are uniform throughout the classes, and certain adjacent grey values can be group. Due to this reason, the number of grey levels in the enhanced image is less than the number of grey levels in the original image.

#### 5.11.1.3 Piece-wise Linear Stretch

This method is similar to the linear contrast stretch, but the linear interpolation of the output values is applied between user defined DN values. This method is useful to enhance only a certain land cover type, for example water. The data values for this feature are in the range of 5 to 18, and in order to be able to discriminate as much as possible, it is wise to use all available gray levels for this feature only. In this way detailed differences within the feature of interest appear, where as the remaining features are assigned to a single gray tone.

## 5.12. Spatial Filtering

In spatial filtering operation the image is divided into its constituent spatial frequencies - number of changes in brightness value per unit distance for any particular part of an image, and selectively altering certain spatial frequencies to emphasize some image features. Thus, spatial filters are designed to highlight or suppress specific features in an image based on their spatial frequency. Spatial frequency is related to the concept of image texture. A 'rough' textured areas of an image, where the tonal changes are dramatic over a small area, have high spatial frequencies, while "smooth" areas with few changes in tone over several pixels, have low spatial frequencies.

The filtering procedure involves 'moving window' concept of a few pixels in (kernel) size like 3x3 or 5x5 (figure 3) over each pixel in the image, applying a mathematical calculation (or convolution) using the pixel values under that window by assigning a weight to each pixel in the window, and replacing the central pixel with the new value.

The window is moved along in both the row and column dimensions one pixel at a time and the calculation is repeated until the entire image has been filtered and a "new" image has been generated. By varying the calculation performed and the weightings of the individual pixels in the filter window, filters can be designed to enhance or suppress different types of features. It is to be noted here that in a moving window concept for the pixels along the border of the image to be in act as a centre pixel, the border pixels are duplicated temporarily during convolution process.

### 5.12.1 Low-Pass or Low-Frequency Filter

The low-pass filters block the high spatial frequency details, thereby allowing appearing only those pixels where there are small or fewer tonal variation over several pixels, i.e. pixels having low spatial frequencies. In this way, the low-frequency filter evaluates a particular input pixel brightness value and the pixels surrounding the input pixel, and outputs a new brightness value which is the mean of this convolution. Thus, the low-pass filters using an averaging option 'smoothen' the image. For example, by applying averaging filter for the kernel pixels given in table 3, we get the gain as 0.11. The other view of the smoothing operation is that it blur the image, mainly at the edges of the objects. The size of the kernel also affect the degree of smoothing. The larger the size of the moving window is, the more blurred will be the output image. Therefore, contrast stretching is necessary after a filtering operation to utilize the full dynamic range of gray values.

Table 3. Kernel filter pixel values

| | | |
|---|---|---|
| 2 | 2 | 2 |
| 2 | 2 | 2 |
| 2 | 2 | 2 |

To minimize the high degree of blurring in the image, it is important that a larger pixel value be assigned to the centre pixel. For example, if we replace the centre pixel value (2) with 4 by multiplying it with two, then the gain for the resulting kernel would be 0.05.

### 5.12.2 High-Pass or High-Frequency Filter

A simple high pass filter works by subtracting a low pass filtered image (pixels by pixel) from the unprocessed original image. The high-pass filters block the low spatial frequency details, thereby allowing to appear only those pixels where there are large or more tonal variation over a few pixels distance only, i.e. pixels having high spatial frequencies, thereby emphasizing edges. In this way, the high-frequency filter evaluates a particular input pixel brightness value and its adjacent pixels, and outputs a new brightness value which is the mean of this convolution. Often, the difference between the centre pixel value and its neighboring pixel values results in edge detection. Thus, high centre pixel value than its corresponding neighbors is more suitable for the result. Alternatively, the edging result can also be enhanced by converting the neighboring pixel values to negative (table 4). The gain for the resulting kernel would be 0.25. The output high-pass filtered image can be used as an aid (another band) during the classification of images. Some of the known high-pass filters are Laplacian edge enhancement filter, Sobel edge detection filters etc.

Table 4. Kernel filter pixel values for edge enhancement

| | | |
|---|---|---|
| -2 | -2 | -2 |
| -2 | -20 | -2 |
| -2 | -2 | -2 |

Laplacian Edge Enhancement filter

The Laplacian filter calculate the difference between the DN value of the central pixel and the average of the DN values of four adjacent pixels located horizontally and vertically. The sum of all elements within the mask is zero (table 5b).

Table 5. Modified Laplacian filtering operation

a. Input Image

| | | |
|---|---|---|
| a1 | a2 | a3 |
| $a_4$ | $x$ | $a_5$ |
| $a_6$ | $a_7$ | $a_8$ |

b. Laplacian filter

| | | |
|---|---|---|
| 0 | -1 | 0 |
| -1 | 4 | -1 |
| 0 | -1 | 0 |

c. Output Image

| | | |
|---|---|---|
| $a_1$ | $-a_2$ | $a_3$ |
| $-a_4$ | $y$ | $-a_5$ |
| $a_6$ | $-a_7$ | $a_8$ |

The above in equation form is written as:

$$y = (x-a2) + (x-a7) + (x-a4) + (x-a5) \qquad (4)$$

Sobel Edge Enhancement filter

The Sobel filter computes the gradient (slope) horizontally and vertically. In this, two high-frequency filters are being calculated in two different directions. In the vertical filter, the kernel values are basically rotated 900 to the horizontal kernel values (table 6).

Table 6. Sobel filtering operation

| | | |
|---|---|---|
| 1 | 0 | -1 |
| 2 | 0 | -2 |
| 1 | 0 | -1 |

a. Horizontal Kernel (kx)

| | | |
|---|---|---|
| 1 | 2 | 1 |
| 0 | 0 | 0 |
| -1 | -2 | -1 |

b. Vertical Kernel (ky)

The output images are:

x = the resulting image after applying kx to the input image pixel values in the window y = the resulting image after applying ky to the input image pixel values in the window

The resultant x and y images (pixel values) are then squared and then square root of their sum is being calculated to produce a final image (z). (5)

## 5.13. Image Transformation

Essentially, image transformation involves the generation of a 'new image' from two or more sources. The source could be a single image involving two or more spectral bands. The resulting image could be produced after using multitemporal-multispectral image data of the same area. The operation may involve simple arithmetic operations to a more complex statistical calculations.

### 5.13.1 Spectral Image Rationing or Image division

Image division is one of the most commonly applied image transformation technique which reveal the fine variation in spectral responses (DN value) of the planetary features observed in different image bands. A fair example of ratioing is observed in determining the presence and health of the vegetation by utilizing the DNs of near-infra red (NIR) (0.7-1.3 μm) and red (R) (0.6-0.7 μm) bands as the fact is in the former one reflectance from vegetation is highest and lowest in the 0.5-0.7 μm range of visible spectrum in the case of later one. Mathematically, the ratio function in general form can be given as:

$$\mathrm{ORV}_{i,j} = \frac{\mathrm{DN}_{i,j,a}}{\mathrm{DN}_{i,j,b}}$$

where, ORV = output ratio value for the pixel at row i and column j; DNi,j,a and DNi,j,b = pixel (reflectance) value at the same location in band a and band b, respectively.

**Normalized Difference Vegetation Index**

Different features on the earth's surface has different spectral reflectance behavior and this concept is well utilized in the case of Normalized Difference Vegetation Index (NDVI). NDVI is an example of more complex band ratioing concept where sums of and differences between two spectral bands is used in the form of an index. As stated above, in this NIR and R bands are being used as two distinct spectral region for monitoring vegetation health. Apart from NDVI, there are other two simple indices. These indices are given below in equation form:

It is to be noted here that the computations in the above three equations are being done in each corresponding pixels for against their values (DNs). Here, in case of NDVI, the difference is basically 'normalized' by dividing by the sum of the two DN values (of two bands). An example case of the NDVI for figure 3 (image.tif) is computed from DN values as given in table 2 for each pixel for the entire image and the output NDVI values as computed is given in table 7. It is evident from the table 7 is that after computation the raw NDVI value ranges from -1 to +1. The NDVI range is symmetrical around zero (NIR = R).

Table 7. NDVI values of the above depicted satellite image (Image.tif) ranging from -1 to +1

| | | NDVI | | | NDVI | NIR- | | NDVI |
|---|---|---|---|---|---|---|---|---|
| 45 | 123 | 0.37 | -14 | 230 | -0.06 | 122 | 170 | 0.72 |
| 46 | 150 | 0.31 | -7 | 235 | -0.03 | 80 | 172 | 0.47 |
| 31 | 179 | 0.17 | -3 | 191 | -0.02 | 66 | 180 | 0.37 |
| 29 | 213 | 0.14 | 36 | 154 | 0.23 | 164 | 236 | 0.69 |
| -17 | 239 | -0.07 | 6 | 162 | 0.04 | 243 | 267 | 0.91 |
| -19 | 201 | -0.09 | -55 | 173 | -0.32 | 90 | 138 | 0.65 |
| 58 | 160 | 0.36 | -2 | 208 | -0.01 | 3 | 107 | 0.03 |
| 67 | 151 | 0.44 | 134 | 254 | 0.53 | 46 | 114 | 0.40 |
| 70 | 160 | 0.44 | 696 | 250 | 0.38 | 118 | 124 | 0.95 |
| 48 | 146 | 0.33 | 87 | 177 | 0.49 | 126 | 138 | 0.91 |
| 40 | 120 | 0.33 | 37 | 197 | 0.19 | 88 | 154 | 0.57 |
| 25 | 165 | 0.15 | -62 | 264 | -0.23 | 24 | 146 | 0.16 |
| 34 | 188 | 0.18 | -149 | 361 | -0.41 | 36 | 214 | 0.17 |
| 43 | 207 | 0.21 | 8 | 150 | 0.05 | 86 | 242 | 0.36 |
| 33 | 227 | 0.15 | -13 | 141 | -0.09 | 98 | 240 | 0.41 |
| 23 | 223 | 0.10 | -45 | 153 | -0.29 | 27 | 145 | 0.19 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 33 | 197 | 0.17 | 65 | 191 | 0.34 | -80 | 80 | -1.00 |
| 34 | 180 | 0.19 | 144 | 262 | 0.55 | -49 | 83 | -0.59 |
| 62 | 162 | 0.38 | 126 | 244 | 0.52 | 114 | 114 | 1.00 |
| 55 | 131 | 0.42 | 84 | 182 | 0.46 | 106 | 124 | 0.85 |
| 45 | 151 | 0.30 | 114 | 194 | 0.59 | 73 | 133 | 0.55 |
| 28 | 176 | 0.16 | 148 | 210 | 0.70 | 22 | 114 | 0.19 |
| 32 | 198 | 0.16 | 3 | 247 | 0.01 | 23 | 245 | 0.09 |
| 73 | 217 | 0.34 | 21 | 131 | 0.16 | 70 | 246 | 0.28 |
| 104 | 228 | 0.46 | 63 | 137 | 0.46 | 109 | 197 | 0.55 |
| 72 | 218 | 0.33 | 108 | 150 | 0.72 | 13 | 189 | 0.07 |
| 67 | 179 | 0.37 | 130 | 160 | 0.81 | | | |

## 5.14. Principal Component Analysis (PCA) or Transformation (PCT)

The principal components analysis is a non-parametric, orthogonal linear transformation technique that help in compressing the dimensionality. For example, it reduces the number of bands (in case of remote sensing multispectral image bands) in the data in to fewer bands, also called 'components'. Normally, the multispectral image data is usually strongly correlated from one band to the other. For example, the visible bands (band 2 and band 3) in the image.tif shows a positive correlation (figure 6a) and a negative correlation between NIR and visible bands (figure 6b). This can be largely due to spectral reflectance characteristics (here, pixel value or DN) and the greenness present in the environment.

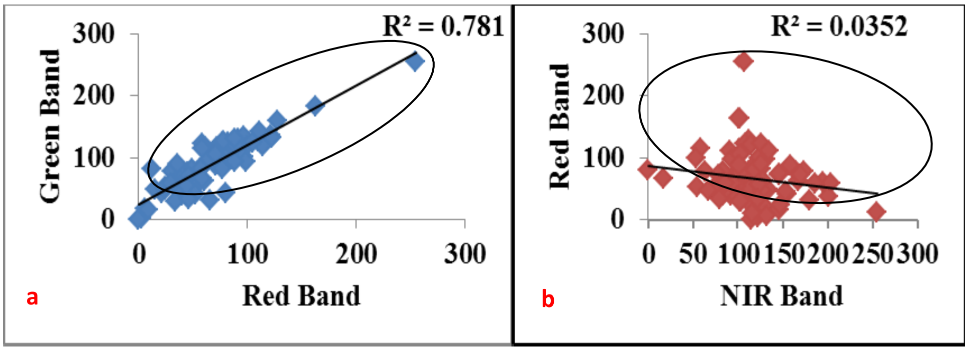



Figure 6. Correlation between one band to the other of Image.tif: a) Positive and b) Negative

The trend lines denote the axis along which the values are plotted. The correlation (scatter) plot will depicts redundancy in information when the pixels values of each band are plotted with the other bands of Landsat 8. Applying PCA reduces this redundancy and thus, also compact the data to be investigated. PCA through transformation creates new images from the uncorrelated values of different images using a linear transformation of correlated variables that correspond to a rotation (of axis of the spectral space) and translation of the original coordinate system (or pixel values). After rotation, the length and the direction of the widest transect of the scattered ellipse is calculated. The transect corresponding to the resulting longest or major axis of the spectral space or ellipse that contains the new pixel value, is called the first principal component (PC1). Geometrically, PC1 points in the direction with the largest variance. PC2 being orthogonal or perpendicular to PC1, points to the second largest variance. For a n-dimensional space (spectral bands), the same pattern is repeated. The direction (of variation) of the PC1 is called as the first eigenvector, and the variance (or proportionally the length of the axis of variation) is called as the first eigenvalue. Algebraically, the basis of eigenvector and eigenvalue is the data's variance-covariance matrix and correlation matrix. The method also called as eigen vector decomposition (EVD) or spectral decomposition, thus, decomposes the variance-covariance matrix and correlation matrix of the raw data into matrices of eigenvector and eigenvalue. The eigenvectors act as weighting coefficients. The transformation basically maximize the

amount of information or variance present in the original data, say eleven bands of Landsat 8, into the fewer number of new components, say three, of which over 90 percent of the information present in the original eleven bands. The advantage is that PCA operates on all bands together and thus, it reduces the difficulty of selecting appropriate bands associated with the band ratioing concept. The major difference between this and other transformation technique is that the new components are ordered in terms of the decreasing amount of variance (or eigenvalues) explained. Therefore, the later components describe the minor variations or sometimes noise only. In this way, interpretation and analysis of data present in the new components is simpler and more efficient. Another benefit of PCA is that it permits the identification of a set of coefficients that concentrates maximum information in a resulting single component. The singular value decomposition (SVD) method is a preferred matrix decomposition algorithm used in PCA for its numerical accuracy. One of the main difference is that EVD works on the variance-covariance matrix and correlation matrix while SVD operates on the raw data matrix.

A result after applying the SVD based PCA on the 3-band image (Image.tif) is given below.

| PCA Result (SVD) | PC1 | PC2 | PC3 |
|---|---|---|---|
| Standard deviation | 168.2622 | 47.69272 | 9.04753 |
| Proportion of Variance | 0.9232 | 0.07417 | 0.00267 |
| Cumulative Proportion | 0.9232 | 0.99733 | 1.00000 |
| Rotation (n x k) = (3 x3 ) | | | |
| | **-0.7096016** | **-0.6835029** | **0.1711416** |

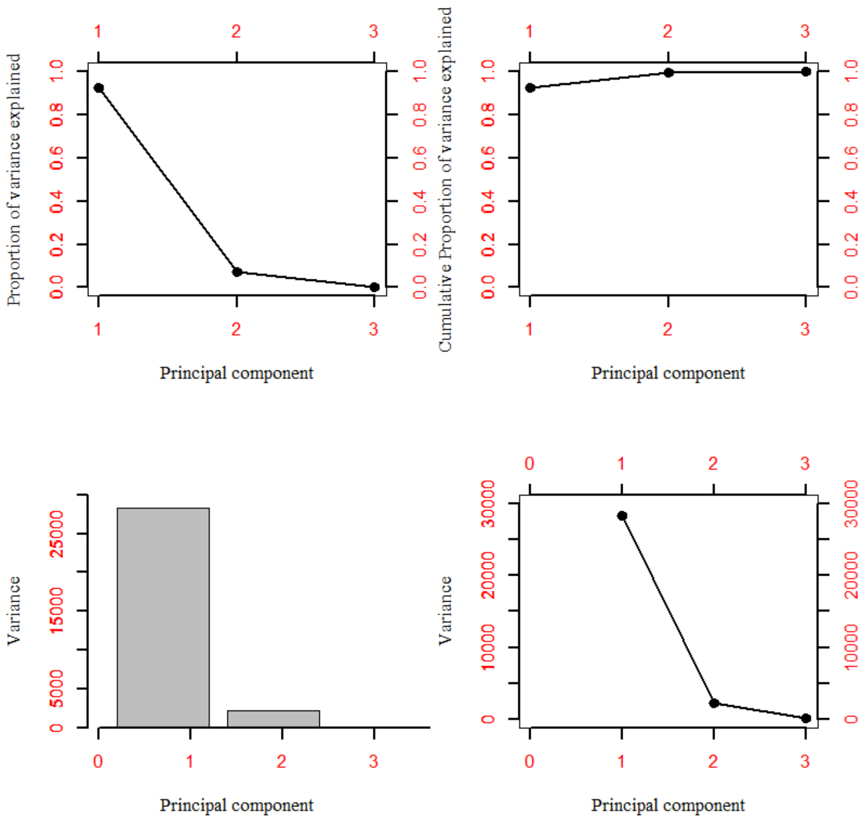



Figure 7. Graphical display of results obtained after applying SVD based PCA in a 3-band satellite image (Image.tif).

As indicated above, the result of applying SVD based PCA yield the PC1 containing over 92% of the information (variance) present in the original three bands followed by PC2 and PC3, respectively, in a decreasing manner. Thus, the interpreter retains over 92% of the original information in a much more concise form and avoids the replicated and redundant information. This not only reduced the bulkiness of the data to be analyzed but also reduces the time and cost to be exhausted for the analysis. Another important point of note regarding PCA is that since each resulting component is a linear combination of the original bands, the interpreter should know the technique to interpret the meaning of new components.

PCA is useful in a wide range of applications including data exploration and visualization of underlying patterns within correlated data sets, de correlation, detection of outliers, data compression, feature reduction, enhancement of visual interpretability, improvement of statistical discrimination of clusters, ecological ordination etc.

## 5.15. Image Classification

In remote sensing, the information hidden in multispectral image pixels or band pixels can be understood in a variety of ways and image classification is one of those ways. In classification, the bands are sometimes also called as features, the band pixel value as feature vector and the graph or plot showing the feature vector as feature space. Image classification is basically about classifying the 'pattern' of rectangular matrix of n-by-n pixels in to classes such as land use/land cover (LU/LC) classes. The pattern in a multispectral classification will use pixel value or DN. The pixel based classification groups the similar pixels into classes. This can be performed by simply comparing pixels values to one another or training the samples of pixels of known identity and then classifying the pattern based on the training samples. The resulting classes are clusters or regions in a map form, each of which is identified by a unique color or symbol. In this way, spectral or pixel-based classification, which is more common, use the pixel information stored in different bands of an image. Whereas the spatial classification use the spatial relationship of the pixels with its neighboring pixels which may involve proximity, size, shape, directionality, texture etc. It is important to mention here that there is no single 'right' approach for image classification, but it depends on the objective of the classification, nature of the data to be classified and available resources. A classification can be divided into four phases: training phase where number of classes are defined, analysis of training statistics, assignment where every pixel is included in any of the defined classes, and map output and assessment that may include map, table etc. It is also essential to perform geometric and radiometric calibration before classification. The image classification technique can be broadly categorized in to two: supervised and unsupervised.

### 5.15.1. Supervised Classification

In this, the user ´supervises´ the classification method that uses algorithms employing the pixel value for constructing the particular numerical relationship for each class like water, agriculture land, built- up area, forest etc. In this classification, the first phase is 'training phase' in which user 'trains' or guide the classification algorithm by assigning a selected number of representative pixels (or training pixels) from a homogeneous area to a particular class they belong to. For this, the user should be familiar with image interpretation technique or should have at least a prior knowledge through which (s) he identifies the pixel(s) of a particular LU/LC class. The training samples, also called as seeds or area of interest (AOI) or regions of interest (ROI) help in estimating the statistical parameters of the particular classifier used. These parameters are the properties of probability model (of classifier). These parameters are sometimes called as 'signature' for the particular class for which they have been created. The second phase is called as 'classification phase' in which each and every pixel of the entire image is divided into the assigned classes based on the class-specific signature. After classification, the pixel is classified in to the class it most probably matches using the chosen classifier algorithm. The third and final one is 'output phase' in which the result output is transferred in a thematic map or tabulated or digital data (ASCII, DAT, SHAPE etc.) form. Depending upon the requirement or end-use purpose, the result is either directly used or passed to the other systems as an input.

There are a number of statistical methods used as a supervised classifiers, each one having merits and demerits. The commonly applied methods are: maximum likelihood classifier (MLC) or estimation (MLE), minimum distance method, parallelepiped method, Bayesian's method, decision tree classification, fuzzy classification, and artificial neural network (ANN) method. The principles and working algorithms of all these classifiers are now out of the scope of this work and can be referred to any standard text books on remote sensing. However, seeing the wide use of MLC in classification, a description about the algorithm is given below.

Maximum Likelihood Classifier (MLC) or estimation (MLE)

MLC is a supervised statistical approach and is based on two principles:

i. MLC considers both the variances and covariance's of the class signatures when assigning each pixel to one of the LU/LC classes represented in the signature file.

ii. It is assumed that the pixel in each feature class sample (AOI) in multidimensional space are normally or equally distributed or is Gaussian (i.e. probability of occurrence is equal) which convey that a class can be described by mean vector and variance-covariance matrix.

Given the above two characteristics for each cell value, the probability using the Bayes' theorem is estimated for each class to determine the membership of the pixels to the class. Then, each pixel is classified to the class to which it has the highest probability of being a member.

The Bayes' classification is performed according to

$$x \in \omega i, \text{ if } p(\omega i|x) > p(\omega j|x) \text{ for all } j \neq I \qquad (10)$$

where, ωi represent the spectral classes (e.g. water, agriculture, forest etc.), i = 1,..n.x is the pixel vector or DN or brightness value of the pixel in a multispectral space.

The probability p(ωj|x) denotes the likelihood of a pixel vector x belongs to class ωi. According to the Bayes' theorem, therefore, the pixel at x belongs to spectral class ωi if p(ωj|x) is largest for that spectral class. The probability is computed using the normal probability density function (PDF) to classify an unidentified pixel vector x by computing the probability of the x belonging to each class and then assigning the pixel to the class for which it has maximum probability. The normal PDF is calculated as:

$$y = f(x \mid \bar{x}, \sigma) = \frac{1}{\sigma\sqrt{2pi}} e^{\frac{-(x - \bar{x})^2}{2\sigma^2}} \qquad (11)$$

where, x = mean of DN values of each feature class in the training dataset;

σ = standard deviation of DN values of each feature class in the training dataset

x = A single pixel of whole image dataset of one band

The result obtained after applying supervised approach on the satellite image (figure 8a) using MLC method is shown in figure 8c.

### 5.15.2. Unsupervised Classification

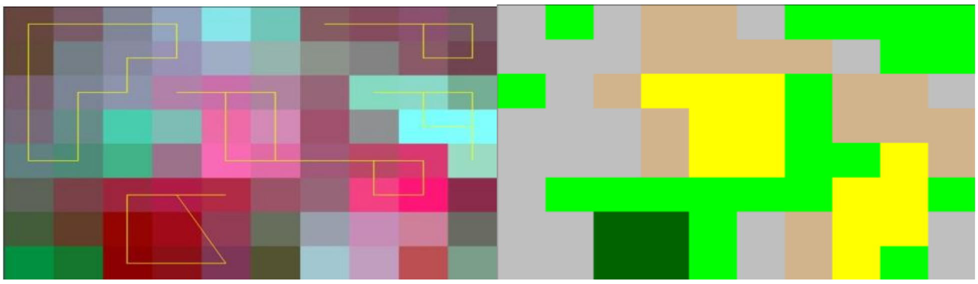
The unsupervised classifiers, unlike the supervised classifiers, do not uses training of images. Rather, it identifies the agglomeration or clustering of image pixels based upon similarity measures. The commonly applied measure is distance measure which often include Euclidean distance. The classifier segment the whole image randomly in to n number of classes which is assigned by the user. Here, the major role of human lies in the later half of the process once the initial classification step is over. The result obtained after initial classification are examined for corrective measures. The interpreter verifies the output classes by overlaying the map over image or through ground truthing report. In case of any required changes in the map, modification is done either by reclassification by merging or splitting of classes or by direct alteration of the boundary of the class clusters in to the appropriate classes. Once the corrective measures are done, a final unsupervised classified map is produced which is free or minimal from errors. Like in supervised classification, here also different classifiers are used for partitioning the pixels, for example, k-means, c-means, hierarchical clustering etc. Seeing the wide use of k-means algorithm in unsupervised classification, a description about the same is given below.

k-means

The k-means is a numerical, unsupervised and non-deterministic method. The k-means treats each observation in the input data as an object having a location in the space. It is also advantageous to implement k-means since it uses the actual observations of the objects (rather than the larger set of dissimilarity measures), and not just their proximities unlike the hierarchical clustering based approaches. The objective of the k-means method is to minimise the total intra-cluster variance or the squared error function. In this algorithm, the sum of absolute differences between each point and its closest centre in Euclidian 3-D space is minimised. Each centroid is the mean of the points in that cluster. This objective can be expressed in the following equation:

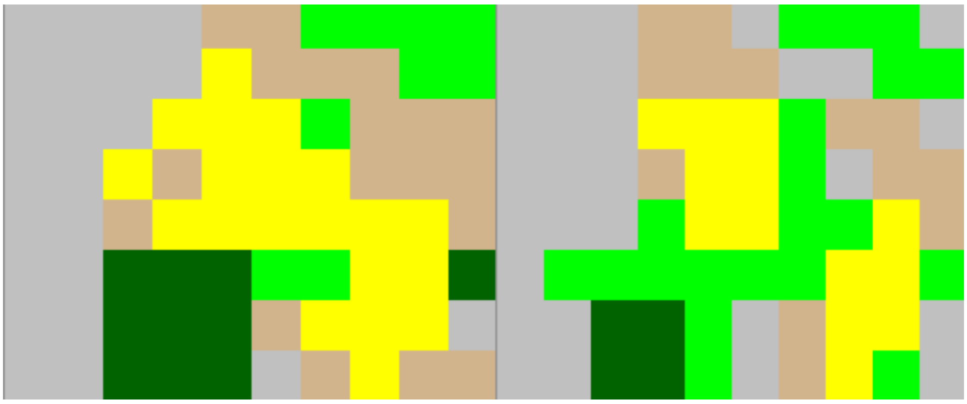
$$D = \sum_{i=1}^{k} \sum_{x_i \in C_k} \left| x_i - C_j \right|^2 \qquad \text{----------------------(12)}$$

where, there are k clusters Ck with iterations i beginning from 1 to k, D is the total intra cluster variance or the squared error function, xi is the data point (vector data) and Cj is the mean vector or cluster centre. The minimum computational complexity of the k-means algorithm is O(ndCT), where n is the number of d-dimensional pattern, d is the number of feature vectors, C is the number of assigned clusters and T is the number of iterations.



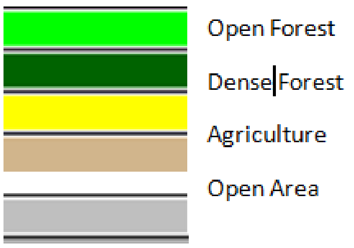
(a) Training samples (AOI) on Satellite Image (b) Hybrid Classified Map

A result obtained after applying unsupervised approach using Iterative Self-Organizing Data Analysis (ISODATA) clustering technique is shown in figure 8d.



(c) Supervised Classified Map (d) Unsupervised Classified Map

**Figure 8. (a) Training samples on Satellite image, both were used in supervised image classification procedures, and (b) to (d) Maps obtained after applying different classification scheme**




The cluster variance is above a pre-determined threshold. The ISODATA, although computationally more intensive than the k-means algorithm, does not solve for a predetermined number of clusters. It is quite more adaptive as it try hard to optimize a cluster solution.

## 5.16 Hybrid Classification

A third approach is the hybrid classification strategy which uses the unsupervised spectral class statistics to 'train' the pixels in supervised analyses. Here also, user's knowledge of image interpretation or ground truth or other reference data is used to find out the homogeneous spectral classes or clusters. In this way, this approach include methods that combine the statistics generated from supervised and unsupervised trainings incorporating both thematic and spectral meaning.

A result obtained after applying hybrid classification strategy is shown in figure 8b.

## 5.17 Applications of Digital Image Processing

Digital image processing techniques has a wide range of applications. One of the most important application of image processing techniques is examining the applicability of images before they are being utilized for the purpose, digitally correcting errors and removal of errors in the raw image, removal of error or noise before the corrected image is being utilized for the assigned purpose. The techniques of digital image processing helps in detection and extraction of information on: a) physical characteristics/processes such as mineral resources, soil, landform, quantity and quality of water bodies, flood, erosion etc., b) Biological conditions such as forests, crops, wild animals etc., c)

Cultural factors such as land use, recreational activities, cultural status (life style, health and safety, population density), man-made facilities and activities (structure, utility networks, waste disposal) etc.,

d) Ecological relationships such as eutrophication, salinization etc., e) modification in regimes such as alteration (change of habitats, change in drainage), land transformation, land alteration, resource renewal and extraction, accidents (oil spills and leaks) etc. One the results are ready, the digital image processing techniques also study the validity (and accuracy) of the results. Apart from the above mentioned applications, the techniques are also widely used in medical image processing and extra- planetary missions.

## 5.18. Conclusions

Digital image processing is a process of examining the images for the purpose of extraction of information hidden in the image form. The digital image processing can be distributed at three levels: Low level, Medium level and High level. The low level image processing includes image acquisition, image pre-processing and image classification. The medium level image processing includes compression and morphological processing of images. The high level image processing includes image reconstruction, object recognition and image representation and description. The focus of this chapter is to prepare the readers with fundamental concepts behind digital images and different processing steps and providing solutions to different problems which a user may encounter from the beginning itself or in between the processes.

Any image acquired digitally or photographically has a purpose. The images in remote sensing are acquired using sensors designed with finest technologies. In the beginning, the analyst attempts to detect and remove the noises present in the image. Then (s)he detect, identify, classify and measure the physical and cultural objects and/processes in the image. Furthermore, (s)he evaluate their patterns, and spatial relationship encountered in the image, all in a logical manner. In between the before mentioned tasks, he faces problems in the images. Sometimes, the data size is too heavy and therefore, needs compression. Sometime, there is a lot of redundancy in the data and therefore, needs the removal of repeating information. The solution to these and other problems lies in digital image processing and here an attempt have been made to unfold some of them. The solution include a wide range of image processing techniques that have been developed to aid the interpretation of remotely sensed data and to extract as much information as possible from the images. The choice of specific techniques or algorithms to use depends on the objective of individual tasks. For example, in this chapter, three statistical techniques of satellite image classification (supervised, unsupervised and mixed classification) have been examined. It has also been shown to the readers that how accuracy assessment of the resultant output should be done instead of blindly reporting the results.

Visual image interpretation is an important first step in obtaining the desired information from a remotely sensed data. The information can be readable directly from the imagery or may be in hidden form where it needs to be derived indirectly. For the purpose, the images or aerial photographs present in a digital or in a hardcopy form are visualized. Since the spectral behaviour of an object is different in different spectrum, it is very important for the interpreter to overcome this limitation for a human-vision system by visualizing the information present in the images using color composite technique. The interpretation elements are basically a set of guidelines that aid the interpreter to look the features from different viewpoints and to draw conclusions. The image interpretation involves the tone, texture, shape, size, pattern, association, shadow, aspect as basic elements. These elements are used together, often, in combination to extract the desired information and helps in overall image understanding. The collateral or ancillary information collected from different sources such as field, submitted texts or even transferred verbally through local knowledge helps in quality outcome of the interpretation task. These elements not only help in the immediate feature recognition and delineation but also in classification of the entire image into a group of feature classes as an input strategy. A good interpreter manages the quality and timely output delivery of the information from remotely sensed images and/or aerial photographs to its clients without much time attending the post-delivery error correction on client feedback. Further, the visual image interpretation ability increases with increasing experiences, the skills of the interpreter itself and the quality of the input imageries and aerial photographs.

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# Unit 6: Data Pre-processing

**Unit Structure**



## 6.0. Learning objectives

After studying this unit you will be able to explain:

- About the data type
- To understand the concept of Geo-relational and object oriented data structure in GIS.
- Corrections in data pre processing
- Enhancement in data pre processing

## 6.1. Data

Data is the most important part of the GIS system. In GIS both tabular and spatial data can be used which are collected by self or purchased from commercial data providers. Data such as toposheet, maps, satellite imageries and aerial photography are type of spatial data. These data are georeferenced with the help of latitude and longitude value, so that each pixels of maps, photographs etc. have some geographical coordinate which give them spatial location and values. These spatial data also have attribute data, which are in tabular form. Like population, agriculture production, number of urban centres, utilities services etc.

### 6.1.1. Spatial data type

There are two broad methods or format to store spatial data in GIS platform. They are:

- Raster data
- Vector data

**Raster:** Raster data are in pixel form (Fig. 2). Where entire study area is divided into regular grids of cells in particular format and sequence

i.e. row by row from top left corner. Each cell has certain value. Every location of the study area corresponds to a cell in the raster format and layer is formed by set of cells with their associated values.

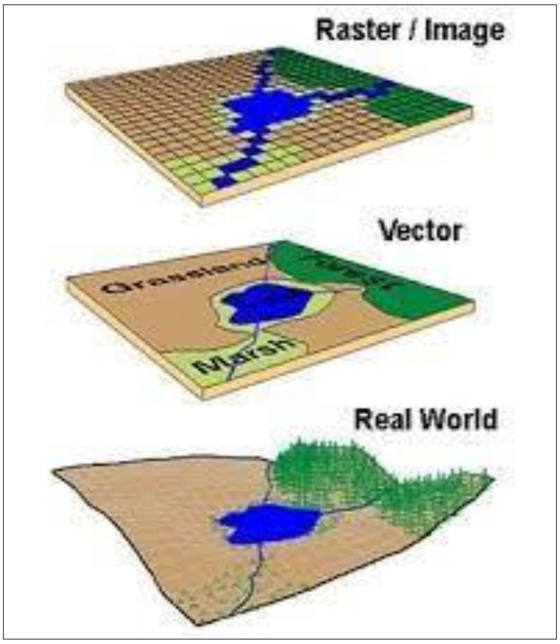



Fig. 2. [Source: Theobald, 2007.GIS Concepts and ArcGIS methods, 3rd edition]

In raster format, single cell represents a point, Sequence of neighbouring cell represent a line and collection of contiguous cells represents polygon. Size of all cells in raster format is same which determine its resolution. Cartesian matrix is produced as cells in raster format are arranged in row and column. Where, x-axis of the matrix parallel to the row of raster data and y-axis parallel to the column and there is unique row and column address of each cell.

**Voxel:** Voxel data model is additionally supported in some selected GIS software. It represents the value on a regular grid in three dimensional spaces. This is analogous to a pixel, which represents 2D image data. Voxels can be interpolated from 3D point clouds (3D pointvector data), or merged from 2D raster slices.

**Vector:** In vector data model, every feature is represented in the form of point, line and polygon (Fig. 2). For instance, wells are represented by point, rivers by line and lake represented by polygon as x and y locations. There is only one x and y location for a point, line feature is saved as array of several x and y pairs and polygon is also stored as a series of x and y location but in case of polygon starting and ending points are same.

### 6.1.2 Non-spatial or attribute data

**Users:** Without user's value of any system is negligible, because users are the one who manage the system and develop them for their utilizations. Users of GIS have vast range from a technical specialist who is responsible for the designing and maintenance of the system to the users who used it for their personal utilities. Those who used it for personal services do not care about the method of analysis; they just care about the result of analysis. GIS software is very user friendly as it allows the non-technical users to get access to GIS analytical capabilities without knowing about the detail commands of software. It consists a graphic window so that users can execute required analysis with just pressing the keys without learning the specific commands in detail.

**Methods:** Different methods like models and other tools which are necessary for different type of analysis which are in-built present in the GIS software is the key behind the success of any GIS software.

## 6.2. Functions of GIS

There are six major tasks carried out in any GIS software. They are data input, manipulation, management, query analysis and output or visualization (result).

1. **Input**

Two types of data are used in GIS. They are spatial and non-spatial data. The geographical location of any entity or feature is shown in the form of spatial data and attribute data are shown in non-spatial form which provide detailed information about spatial data. Therefore, attribute data should be logically attached with the concerned features. In GIS, there are five type of data entry system (figure 3). They are as follows:

- Keyboard entry
- Coordinate geometry
- Manual digitizing
- Scanning
- Input of existing digital files

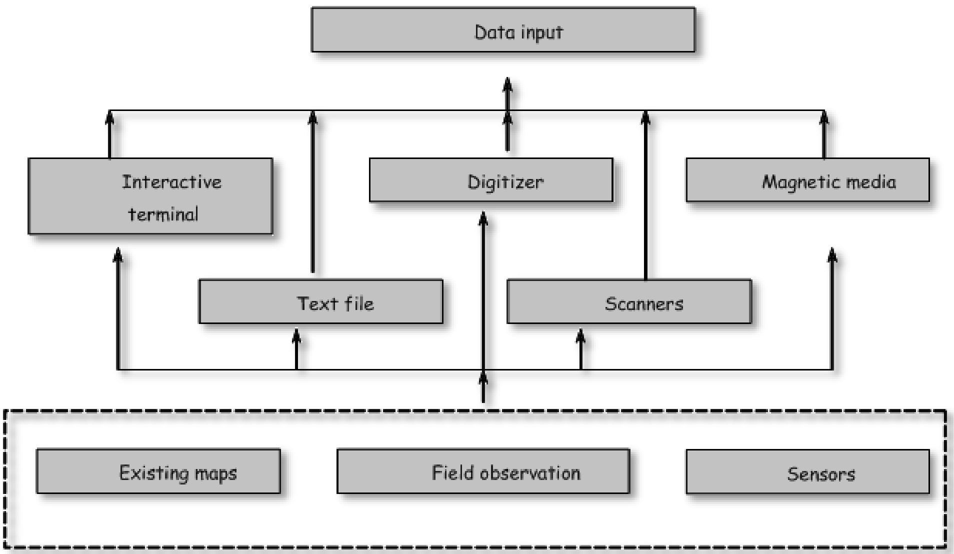



Fig. 3 [Source: Theobald, 2007.GIS Concepts and ArcGIS methods, 3rd Edn.]

## 2. Manipulation

Manipulation procedure with data is applied to all components of geographic information system. These processes are carried out on the spatial data, attribute data and also on spatial relations among objects or structure elements of objects representation.

**(A) Manipulation with Raster data:** In the process of manipulation with raster attribute data the procedure carried out are:

- Change of map projection

- Transformation of reference system
- Re-sampling of raster
- Conversion of representation
- Reclassification of raster values
- Assigning new values to raster
- Extraction of values from raster
- Creation and analysis of surfaces
- Mathematical and logical operations with raster

**(B) Manipulation of attribute data value of vector representation:** In manipulation of attribute, data of vector following process are adopted.

- Modification of topology
- Spatial splitting of vector representation
- Matching the edges of map sheets
- Change of raster cell size
- Generalization

**3. Management**

There is enough storage space in computer files to store small GIS project data. However, it is difficult to store and manage large volume of data and large number of users. So in that case, data base management system is advised to use which helps in storage, management and organize large amount of data like tables, index, query and other processes in database. In DBMS, various types of models are there, but the relational model database management system is extremely useful in case of GIS use. Data are stored conceptually as a set of tables and every table will have the attribute data, which are related to a common entity in relational database model. With the help of this model, common fields of different tables are used to link with each others. Relational database management system is very flexible in nature because of the simple architecture, so it is widely used in the GIS environment.

**4. Query**

With the help of Structured Query Language (SQL), the stored information of both spatial data and associated non-spatial attribute data can be retrieved. Query by using

SQL depends upon the type of user interface. Besides this menu derived system is also used in retrieval of data. For instance, following types of question can be queried:

- Select the districts, which have more than 10,000 populations?

**5. Analysis**

Analysis of geographic data is the most important task of GIS. The analysis process is also called as geographic or spatial analysis or geo-processing. Where to identify the patterns and trends and the future scenario the geographic properties of features are analysed. Therefore, there are various modern GIS tools for these types of analysis.

**6. Visualization**

Both spatial and tabular data can be presented in hard copy map, statistical summaries, modeling solutions and graphical representation in GIS platform. The end result in GIS is map and graphs, in which the result can be best represented. Best storing, communication and representation of geographic information is possible only through the maps and graphs, and GIS made it possible and easier. New and more innovative tools are there in GIS, which increase the art of visualization of the result or output to the users.

## 6.3. GIS Database creation

In GIS getting the spatial data is not an easy and cheap task. Most costlier and time consuming phase of GIS is data capturing. For instance, spatial data capturing constitute about 60 to 80 percent of total cost of fully operational GIS based projects, Bernhardsen (1999).

### 6.3.1 GIS data source

Spatial data are collected from mainly following two sources. They are:

i. Primary source

ii. Secondary source

**(A) Primary source:** In primary data, source spatial data is captured directly into GIS environment. For instance, capturing of data from Global positioning system (GPS) or through satellite imagery from remote sensing satellite. Attribute data is collected through surveying and also through GPS.

**(B) Secondary source:** Capturing of data from Secondary source is easier task and more common in the field of History. In this source hard copy map is converted into digital form. For conversion of hard copy map into digital form generally following two techniques are used. First one is to produce raster format data or digital data, scanning of hard copy map is carried out. In second process hard copy map is digitised, where point, line and polygon features are traced. There are also two ways to doing this. First on is directly tracing of hard copy map into digital format and second one is digitization of scanned map. Vector data is produced in these processes. Attribute data are collected by already published sources like census, district abstracts, research papers, articles and books etc.

## 6.4. Method of GIS data creation

### 6.4.1. Raster data creation

**Raster data creation through Scanning:** It is a faster method of raster data creation than other methods. An electronic detector moved across the whole map or image. Following two type of scanner are generally used.

a) **Flatbed scanner:** In this scanning system a flat scanning stage is used where map placed on this stage and in both the x and y direction the detectors moved on the stage like copy machine.

b) **Drum scanner:** Map is placed on a rotating cylindrical drum and detector moves horizontally over whole map. Movement in x direction is provided by sensor motion and movement in y direction is provided by drum rotation.

Output of the scanning is in digital form and generally black and white result comes out after scanning but color output is also possible by scanning the same document in red, green and blue filters in three time scanning.

**Raster data creation through image Processing:** Raster data is also created from digital image processing. Generally supervised classification is used for this exercise. In this processes digital number of sampling pixel is selected as training sight for each type of features like vegetation, built-up, open land, water bodies etc. In digital image processing software like ERDAS or ENVI image is classified in given number of classes based on the sample pixels or training sites using the classification algorithm (Fig. 4). This process produces raster dataset.

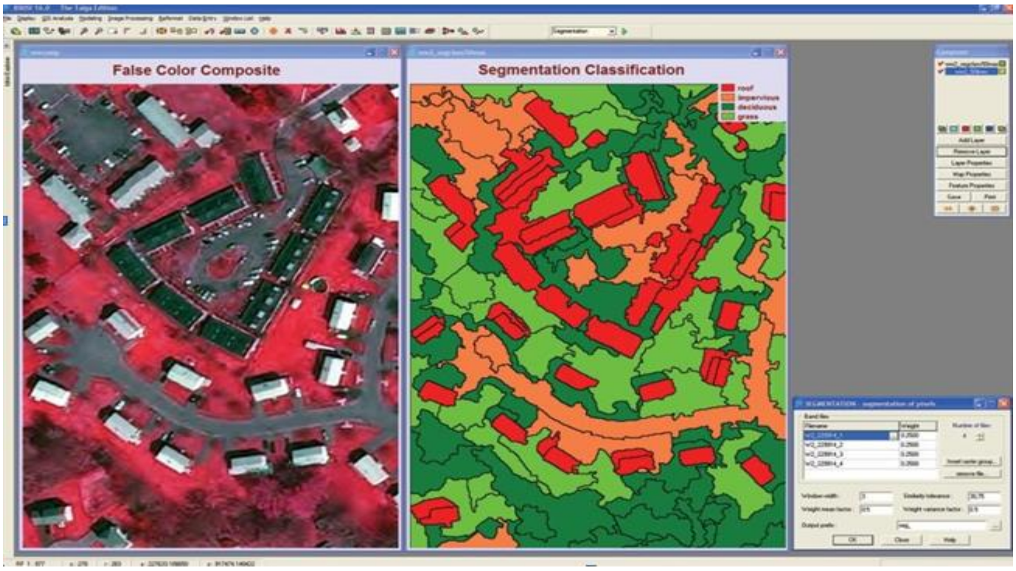



Fig. 4 [Source: www.directionsmag.com]

### 6.4.2. Vector data creation

**Manual digitization:** To convert paper-based sources of spatial data in digital form traditionally manual digitization technique is used. A digitizing table is used where paper map is attached through tape to a digitizing table (Fig. 5). Known coordinates

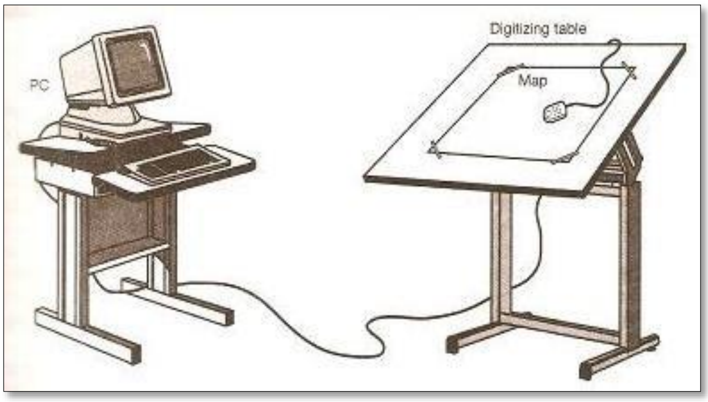



Fig. 5 [Source: www.directionsmag.com]

usually between 4-6 initial points are logged. These points are mostly intersections points of graticule lines. Identifiable locations such as street intersections or landmarks are used as points in case of absence of an overlying grid system. Mouse like hand held device called puck is used for tracing to digitize the feature ( Fig.5).

Newly acquired data is transformed from table units (the coordinates of the digitizing table) into real world units using and algorithm after all the features are traced. This algorithm uses the table coordinates of the initial points which are known and made the data equivalent to the real world and assign the coordinates to those points.

**RMS (root-mean-square) error** is produced in this process if there is adjustment problem in table units to real world coordinates. The precision of digitized data and range of error are shown by RMS error. Human error, shrinkage or physical alteration of the paper and differences in projection are the factors leads to RMS error.

**Heads up digitizing:** Head up digitizing is very popular method for digital conversion of data, because of its cost effective nature and large format scanner. It involves direct digitization over ortho-rectified image like satellite image or an aerial photograph, so it is also called as on screen digitization (figure 6).

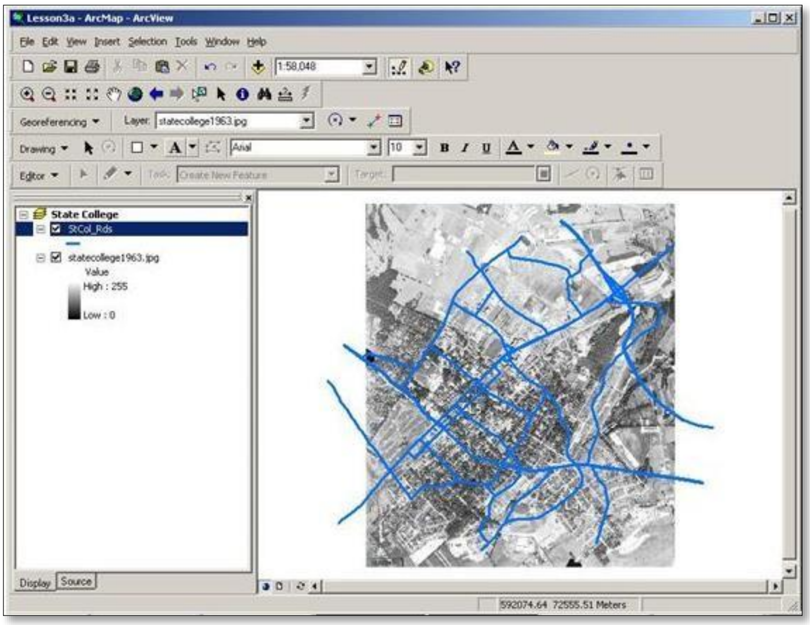



Fig. 6 [Source: www.directionsmag.com]

The interested features are directly traced from the image or photograph. In on screen digitization no transformation is needed to convert the data into needed projection. So working in this method is easier than the manual digitization process. Besides this accuracy in this method is also better as level of accuracy is derived from the initial accuracy of the digital image. To extract the data from scanned and referenced maps heads-up digitizing is also utilized.

**Photogrammetry:** To acquire accurate measurement data from aerial photograph photogrammetry is used. Data related to ground distance and direction, height of features and terrain elevation are obtained through this technique. Photogrammetric techniques determine ground distances and directions, heights of features, and terrain elevations. GIS data is produced by 3-D stereo digitizing and by producing spatially rectified aerial photograph in photogrammetry. Generally, there is 60% overlap along each flight line and about 30% overlap between flight lines. These overlapped areas are used for creating 3 D model.

It is compulsory to georeference photograph to obtain true georeferenced coordinates from a model. Ground survey or GPS is used to take control points for georeferencing. Stereo plotter is used to take measurements from overlapping pairs of photographs.

**Coordinate Geometry (COGO):** Coordinate geometry is keyboard-based technique for data entry in GIS. To store cadastral or land records this method is most commonly used. As the actual survey measurements of the property lines created by the entering method this is highly precise. Original surveyor plats records are used to enter the distances and bearing data. Vector file are build by GIS software based on these values.

**Geocoding:** It is also a keyboard-based technique like COGO. To creates x,y coordinate locations interpolated from a decodable spatial database addresses from a flat file are used in Geocoding (Fig. 7) (such as a .dbf file, MS Access database or excel spreadsheet).

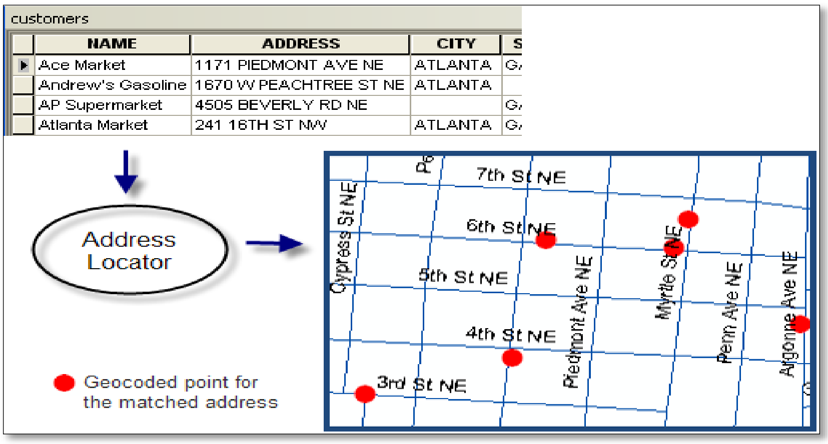



Fig. 7 [Source: www.wiley.co.uk/gis]

**Global Positioning Systems (GPS):** To collect accurate linear and point location data GPS is used. At present GPS have 28 satellites that orbit the earth, transmitting navigational signals (Fig. 8). It was originally developed in the 1970's by the Department of Defence and used for military purposes. The GPS can pinpoint the holder's location through interpolation of these signals received by a data logger.

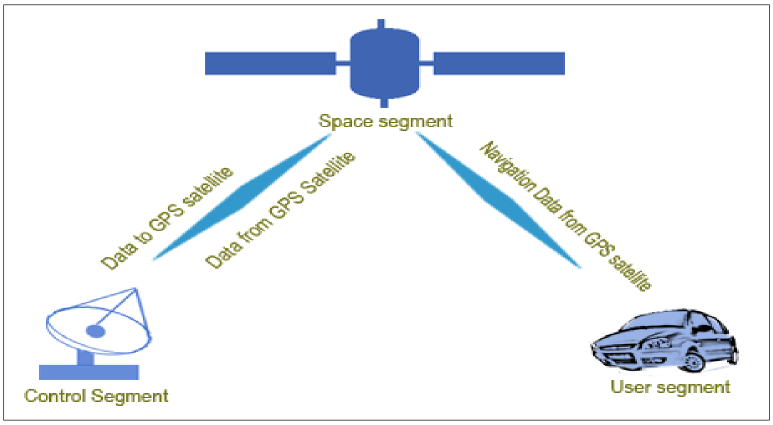



Fig. 8 [Source: www.wiley.co.uk/gis]

**Automated surveying:** Electronic data capturing instruments like theodolites, electronic distance measurement (EDM) systems, and total stations to capture spatial and attribute data are used in automated surveying (figure 9). The total station that combines the theodolite's angle-measuring capabilities with the EDM's distance calculations is the most sophisticated of these instruments. Distance and direction data from their instruments are directly downloaded by surveyors into many vector-based GIS programs. Pre-processing of data is compulsory before it can be used to make a map.

Fig. 9 [Source: www.wiley.co.uk/gis]

## 6.5. Pre processing Corrections

Remote sensing data acquired from imaging sensors mounted on a satellite or any other aerial platform may contain various kinds of distortions and deficiencies. These may include geometric distortions or radiometric distortions. Correction or removal of both of these forms of distortions is required before using the remote sensing data for image interpretation. Pre-processing of remotely sensed data is therefore carried out to rectify and to restore the image by removing such distortions and deficiencies. The pre-processing may be broadly classified as geometric corrections and radiometric corrections.

### 6.5.1. Geometric Corrections

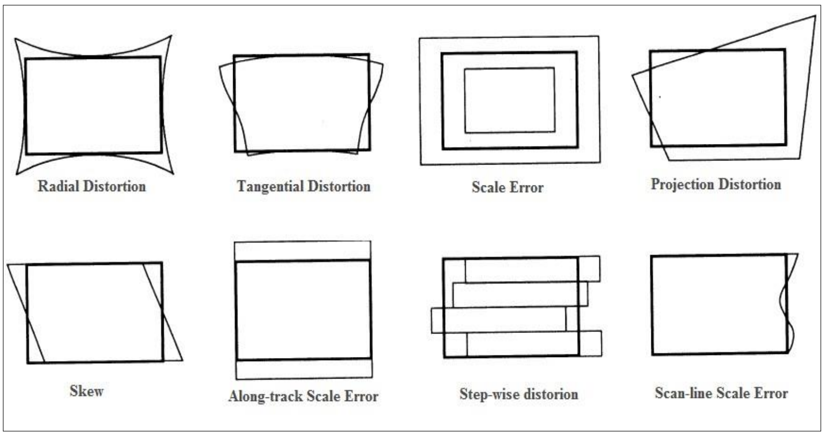
Geometric distortions may render the remote sensing data unusable for several purposes unless some preprocessing is carried out. These distortions may occur due to various reasons including motion of the sensor platform, relief displacement, curvature of the earth, rotation of the earth, atmospheric refraction and non- linearities in the sweep of a sensor's IFOV (instantaneous field of view). Some of these distortions may be systematic which may be predictable. On the other hand, some of these errors are random or non-systematic in nature.

Systematic distortions are also known as internal distortions, which may be due to the geometry of the sensors. Systematic errors or distortions may be easily determined and removed by applying suitable corrections based on relationships that are mathematically derived through modeling the sources of errors. Whereas, non-systematic distortions (external distortions) may be due to attitude of the sensor (including roll, pitch and yaw) or due to changes in altitude of the scanners. Correction to these errors can be applied using the knowledge of platform ephemeris; ground control points (GCPs) etc.

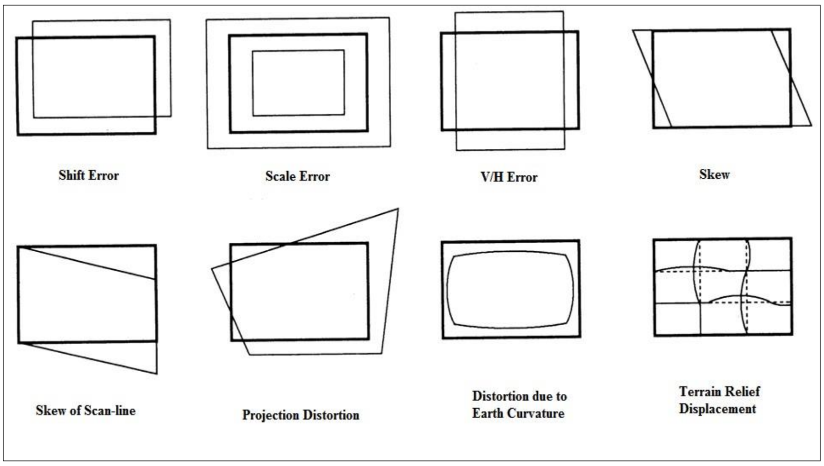
Preprocessing of the raw data obtained from satellites is usually required for eliminating different kinds of distortions in the data. This is carried out to precisely match the position of individual pixels in the remote sensing image with their corresponding locations on the surface of earth. The purposes of geometric corrections applied on remote sensing include:

- Transformation of an image corresponding to a map projection
- Identification of points of interest on the image and on map
- Preparation of mosaics of images corresponding to their geographical positions
- Overlay analysis of various images acquired at different time or by different sensors

- Incorporation of remote sensing data into Geographic Information System (GIS)




**Various Types of Internal Distortions (*Source: Bhatta, 2008*)**




**Various Types of External Distortions (*Source: Bhatta, 2008*)**

#### 6.5.1.1 Systematic Distortions

Various types of systematic distortions are introduced in the remote sensing data due to various factors including scan skew, variation in platform velocity, earth rotation, variation in mirror scan velocity, panoramic, perspective and aspect ratio. A brief description these factors is given in the following paragraphs.

**Scan Skew:** Scan skew in the image is produced if the ground swath is slightly skewed with respect to the ground track i.e. it is not normal to the ground track. It generally happens due to the forward motion of the platform during the time taken by each mirror sweep. As the satellite makes a move along a fixed orbital path, the Earth below it moves/rotates on its axis from west to east. Geometry of the satellite image is thus skewed due to the relative position of the fixed path of the satellite with that of the rotation of the earth about its axis. Thus, the area covered by each optical sweep of the image sensor is slightly towards the west of its previous sweep, resulting in the skew in the image. The correction to skew distortion involves offsetting each successive scanline slightly towards the west.

**Platform Velocity:** The variation in the velocity of the platform results in the variation of the ground track coverage in successive mirror scans. This produces along-track scale distortion in the scanned data.

**Earth Rotation:** The scanning of the ground track by a sensor takes a significant time period during which the Earth also rotates by a significant amount. This causes a shift of the ground swath being scanned and thus resulting in a long-scan kind of distortion.

**Mirror-Scan Velocity Variance:** The rate of mirror scanning also varies usually across a given scan due to variation in the mirror scan velocity. This also results in along-scan type of geometric distortions in the remote sensing data.

**Panoramic Distortion:** The ground area imaged by a sensor is not proportional to the scan angle rather it is proportional to the tangent of the scan angle. It also introduces along-scan distortions.

**Perspective:** Scanned data is also subjected to long-scan distortions if the images are used to represent the projection of a point on the earth, on a plane that is tangent to the surface of the earth, with all the projection lines being normal.

**Aspect Ratio:** Some of the sensors, e.g. Landsat MSS, produce images containing non-square pixels. It may result in due the difference between the instantaneous field of view and the spacing between pixels along each scan line. The oversampling in the cross-track direction, leads to the creation of pixels that are not square. Knowing the correct spacing between scan lines and that between pixels along a scan line, the aspect ratio of pixels may be corrected.

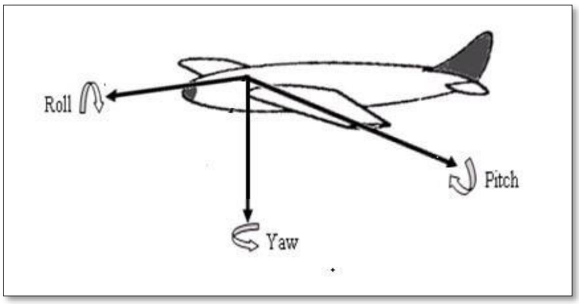
For the given ephemeris of a satellite and geometry of the sensors, geometric distortions may be computed and accordingly correction to the scanned data may be applied. Thus, geometric or systematic distortions may be corrected using a derived mathematical model.

### 6.5.1.2. Non-systematic Distortions

These are external geometric errors, which are usually caused by various spatial and temporal variations in different phenomena. These may include random movements of the platform at the time of scanning. Non-systematic distortions are usually introduced due to:

(i) Altitude changes and

(ii) Attitude changes (roll, pitch, and yaw).




Correction to these kinds of distortions includes use of various mathematical models as well as the use of ground control points (GCP). Position of about Ground control points may be collected from topographic maps or other sources e.g. global positioning system (GPS).

The method of correcting the digital images using GCPs is termed as “Image-to-ground geocorrection” or “Image-to-map rectification”. Another technique known as “image-to-image correction” is also commonly used. It involves fitting of the coordinate system of one digital image to that of a second image of the same area.

**Coordinate Transformation**

The technique of coordinate transformation is useful in carrying out geometric corrections with the help of ground control points. In this process, rearrangement of pixels in the raw image is carried out over a new grid system. Selection of suitable transformation formula as well as suitable ground control points is important in carrying out coordinate transformation.

**Transformation Equation**

The formula used for coordinate transformation depends upon nature of geometric distortions. Use of polynomial equation is common in computing the rectified pixel coordinates. A first order transformation may correct scale, skew, and rotation in an image. Second order transformation or higher nonlinear transformations may be used to correct nonlinear distortions including the distortions caused by curvature of the earth as well as camera lens distortion. In general, a third order polynomial is considered to provide sufficient corrections for various existing remote sensing systems including LANDSAT. Various forms of polynomials used in geometric corrections include the following:

Linear Polynomial (First Order):

$$x = a_0 + a_1X + a_2Y$$
$$y = b_0 + b_1X + b_2Y$$

Quadratic Polynomial (Second Order):

$$x = a_0 + a_1X + a_2Y + a_3XY + a_4X^2 + a_5Y^2$$
$$y = b_0 + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2$$

Cubic Polynomial (Third Order):

$$x = a_0 + a_1X + a_2Y + a_3XY + a_4X^2 + a_5Y^2 + a_6X^2Y + a_7XY^2 + a_8X^3 + a_9Y^3$$
$$y = b_0 + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2 + b_6X^2Y + b_7XY^2 + b_8X^3 + b_9Y^3$$

A three dimensional (3-D) generalized form of polynomials may be expressed as:

$$x = \sum_{i=0}^{m}\sum_{j=0}^{n}\sum_{k=0}^{p} a_{ijk}X^iY^jZ^k \qquad y = \sum_{i=0}^{m}\sum_{j=0}^{n}\sum_{k=0}^{p} b_{ijk}X^iY^jZ^k$$

Where, $a$ and $b$ are model parameters; $X$, $Y$, $Z$ are the cartographic / terrain coordinates; and $m$, $n$, and $p$ are integer values (generally between 0 and 3). The sum of $m$, $n$, and $p$ – generally being equal to 3 – represents the order of polynomial equation.

### Selection of GCPs

Number of ground control points and selection of their location play crucial role in the accuracy of geometric correction. Number of GCPs required for this purpose depends upon the type of formula / polynomial used for geometric correction. Total number of GCPs should be more than the number of unknown parameters in the polynomial equation used. The minimum number of GCPs required for geometric correction using a polynomial is given by the following formula.

$$n_{min} = \frac{(t+1)(t+2)}{2}$$

Where, $n_{min}$ is the minimum number of GCPs required, and t is the order of polynomial used in geometric correction. However, more number of GCPs may be selected depending upon the topography of the area, accuracy required in geometric correction and type of formula used. Selection of GCP for geometric corrections should be such that they are almost equally spaced over the entire image including the corner areas.

**Re-sampling**

Re-sampling is carried out after the process of transformation is completed. It is a process that involves matching coordinates of image pixels to their corresponding position on the surface of earth and creates a new image on a pixel-by-pixel basis. Often, a mismatch occurs between the grid of pixels in the source image and that in the reference image. Therefore, pixels are re-sampled so that new data file values can be computed for the output file. Various methods commonly used for re-sampling include nearest neighborhood, bilinear and cubic interpolations.

Nearest neighborhood, Re-sampling is one of the fastest methods of re-sampling. It is also sometimes termed as zero-order interpolation. In this approach, the value of each new pixel in the re-sampled image is assigned based upon the value of pixel nearest to it. The advantage of this system is that no calculation is required to determine the output pixel value, once its location has been calculated. Whereas, other methods tend to determine the pixel value based upon averaging of values of surrounding pixels. Nearest neighborhood, method is easy to use, for this purpose, as compared to other interpolation methods. However, the output images obtained through this method have a rough appearance as compared to the original image. Further, there may be instances of loss of data values and duplication of values of some pixels. The loss in data may lead to break in appearance of various linear features such as roads, railways, canals, streams.

Bilinear Re-sampling is also known as first-order re-sampling method in which, values of four pixels surrounding the pixel of interest are used to determine its values. Bilinear re-sampling produces smoother images as compared to that obtained through nearest neighborhood method. However, this is a slow process as extra computation efforts are to be applied in this method. Moreover, the original data of the image is altered in the output image and contrast is also reduced.

In Cubic (Second-order) Re-sampling method, a $4 \times 4$-pixel neighborhood is used for computation of pixel values in the re-sampled image. With the use of this method, the smoothening effect as produced by bilinear re-sampling may be avoided. However, even more computational efforts are required in this method. Further, this method renders overshoot of pixel values on either side of sharp edges.

### 6.5.2. Radiometric Corrections

Remote Sensing data may contain noise contributed by several factors including the intervening atmosphere, sun-sensor geometry or that contributed by sensor itself. Radiometric correction (also referred to as “pre-processing” or “restoration”) is applied to modify DN (digital number) values in order to eliminate or minimize the effect of noise. Radiometric corrections are generally required to remove the noise within an image (to take care of speckle or striping in data); between adjacent or overlapping images (for the purpose of mosaicking); between bands (for various multispectral techniques); or between images of different dates (temporal data) and sensors (multispectral data). Radiometric corrections may be classified into the following types:

i. De-stripping
ii. Elimination of missing scan line
iii. Removal of random noise
iv. Sun angle and topographic correction
v. Atmospheric correction

#### (i) De-stripping

Multi-spectral scanners sweeping multiple scanlines simultaneously often generate data that may contain systematic stripping or banding. This problem used to be common in the early Landsat multispectral scanners data due to variations and drift in the response over time of the six MSS detectors. While the six detectors used for each band used to be properly calibrated and matched prior to the launch of the satellite, after sometime, the radiometric response of one or more may tend to drift. Such a drift results in relatively higher or lower values along every sixth line in the remote sensing data. The overall effect was thus a stripped appearance of images. Strips are therefore a pattern of lines with consistently high or low DN values. The process of removing these strips is called as de-stripping.

There are several methods developed for de-stripping. One of the common methods is used to compile a set of histograms for the image. It includes construction of histograms, one for each detector of the problem band. Thus, for a given band of multispectral data, one histogram needs to be constructed for 1st, 7th, 13th, , scan lines. A second histogram is generated for 2nd, 8th, 14th ………… scan lines. Values of means and standard deviations for each of the six histograms are computed. Histograms are then compared using the mean and standard deviation values to identify the problem detectors.

Correction for radiometric distortions amongst the detectors can then be applied by considering one of the sensors as a standard one, and modifying the brightness of all pixels recorded by each of the other sensors. Values are modified in such a way that their mean brightness and standard deviations are in accordance with those of the standard sensor. The following equation may be used to determine the new brightness value.

$$DN_{new} = \frac{\sigma_d}{\sigma_i} DN_{old} + m_d - \frac{\sigma_d}{\sigma_i} m_i$$

Where,

$DN_{new}$ = new DN value or the new brightness value

$DN_{old}$ = old DN value or the old brightness value

$\sigma_d$ = reference value of standard deviation

$m_d$ = reference value of mean

$\sigma_i$ = standard deviation of the detector under consideration

$m_i$ = mean of the detector under consideration

It may be noted that if one sensor is not considered as the reference, an independent reference value of mean brightness and standard deviation, may be used in computation of new DN values.

### (ii) Elimination of Missing Scan Lines

Another problem associated with the line-oriented noise is “Line Dropout”, which happens if a detector stops functioning either temporarily or due to its complete failure. It results in the missing of a complete line or a partial line or erroneous data along a scan line causing a horizontal streak in the remote sensing image. Line dropout may be rectified by replacing defective DN values with the average of values for pixels occurring in lines adjacent to the missing line. Following expression may be used for computing new DN values.

$$DN_{i,j} = \frac{(DN_{i,j-1} + DN_{i,j+1})}{2}$$

Where, DNi,j is the value for erroneous pixel located in ith column and jth line. Alternatively, DN values in the preceding line may simply be used as the DN values for the erroneous pixels, that is, simply repeating the preceding line. This logic is commonly used in case of two consecutive lines missing in the remote sensing data. In this case, the first line may be recovered by repeating the previous line. Similarly, the second missing line may be retrieved by repeating the subsequent line. In case, there are three consecutive lines missing in an image, the first and third missing lines may be replaced by repeating the preceding and subsequent lines respectively, as carried out in the case of two missing lines. While the second missing line is replaced by averaging the DN values of recovered first and third lines.

### (iii) Removal of Random Noise

The problem of random noise in digital data is characterized as non- systematic variations in gray levels from pixel to pixel. It is also called as bit errors. These errors can be identified by their significant differences in DN value from that of the adjacent pixels in the affected band. Each pixel in an image is compared with its neighboring pixels. If the DN value of a pixel and that of the surrounding pixels differs by the magnitude that is more than a user specific threshold level, the pixel is considered to contain noise. The inconsistent DN values of such pixels may be corrected by substituting an average DN value of neighboring pixels. Moving windows of $3 \times 3$ or $5 \times 5$ pixels are commonly used for this purpose.

| | | |
|---|---|---|
| $DN_1$ | $DN_2$ | $DN_3$ |
| $DN_4$ | $DN_5$ | $DN_6$ |
| $DN_7$ | $DN_8$ | $DN_9$ |

A 3 X 3-pixel neighborhood

A 3 X 3-pixel neighborhood window as shown in the Figure may be used for determining the noise. For example, in order to determine whether the pixel with value DN5 contain any noise, average DN values are computed as shown below.

$$DN_{average\text{-}I} = (DN_1 + DN_3 + DN_7 + DN_9)\ /4$$

$$DN_{average\text{-}II} = (DN_2 + DN_4 + DN_6 + DN_8)\ /4$$

The difference of these two average DN values is compared with a threshold value, which may be computed as:

$$\textbf{Threshold} = (DN_{average\text{-}I} - DN_{average\text{-}II}) \times \textbf{weight}$$

Weight depends upon the choice of analyst – lower the value of weight, the greater the number of pixels in the image considered to contain noise. If any of the differences, that is, $(DN_5 - DN_{average\text{-}I})$ or $(DN_5 - DN_{average\text{-}II})$ is more than the threshold value, the pixels is considered to contain noise. In such cases, the value DN5 is replaced by DNaverage-II in order to remove the noise from the pixel.

**(iv) Sun Angle and Topographic Correction**

The brightness of pixels in the remote sensing data is also affected by the sun angle at the time of observation as well as by the distance between the earth and the sun. Both of these parameters change with the change in time over a period of a year. Therefore, the brightness values of corresponding pixels in two remote sensing images acquired at different time may vary due to variation in sun angle and earth-sun distance.

The correction involves normalization of the image data acquired at different time or in different seasons under different solar angles. Correction in brightness values is applied considering the sun being at the zenith on the given date of data sensing. It includes, dividing each pixel value in an image by the sine of the angle of solar elevation at the time and location of data acquisition. Alternatively, sun's angle from the zenith (90° –the solar elevation angle) may also be used to apply the correction for sun elevation. In this case, the pixel value is divided by the cosine of the sun's angle from the zenith.

Another correction i.e. for the earth-sun distance is also applied to limit the effects of seasonal changes in the earth-sun distance. The irradiance from the sun is inversely proportional to the square of the earth-sun distance, which, in general, is expressed in terms of astronomical units – one unit being equivalent to the mean distance between the earth and the sun i.e. approximately 149.6 × 106 kilometers.

The combined effect of solar zenith angle and the earth-sun distance, on the incident irradiance on earth's surface, i.e. the normalized solar radiance (E) may be computed as given below:

$$E = \frac{E_0 \cos\theta_0}{d^2}$$

Where, E0 is solar irradiance at mean earth-sun distance, d is the earth-sun distance (expressed as astronomical units) and θ0 is sun's angle from the zenith. It may be noted that the information on the sun's solar angle, earth- sun distance for a given imagery is part of the auxiliary data, which is normally provided with the remote sensing data.

**(v) Atmospheric Corrections**

Solar radiation, during its transmission to the earth's surface, is absorbed or scattered by the atmosphere. Moreover, the reflected or emitted radiation from the surface of earth is also absorbed or scattered by the atmosphere before it reaches the sensors mounted on the satellite or any other aerial platform. A sensor therefore, in addition to the direct reflected or emitted radiation from the target, also receives the scattered radiation from a target as well as the radiation scattered by the atmosphere, which is known as path radiance.

The atmosphere thus affects the radiance measured at any point in an image in two forms of opposite nature. At one hand, the energy illuminating a ground object is attenuated. Whereas, on the other hand, it acts as a reflector, thereby augmenting scattered path radiance detected by the sensor. The combined signal observed at any given pixel location can be written as follows:

$$L = \frac{\rho E T}{\pi} + L_p$$

Where,

$L$ = total spectral radiance recorded by the sensor

$\rho$ = reflectance of the target

$E$ = irradiance on the target

$T$ = atmospheric transmission

$L_p$ = path radiance

The effect of atmosphere upon the remote sensing data is generally not considered as an error in data, because they are part of the signal received by the sensors. However, for some specific analysis such as scene matching or change detection, it is often required to remove atmospheric effects. Several algorithms have been developed over the past few decades to correct the atmospheric effects. One of the common methods includes use of radiative transfer equation. Use of ground truth data is also commonly made for removing atmospheric effects on remote sensing data.

## 6.6. Image Enhancement

Image enhancement means to improve the visibility of any portion or feature of the image suppressing the information in other portions or features. Information extraction techniques help to get the statistical information about any specific feature or portion of the image. Now a day Image enhancement is applied in the field of medical imaging, analysis of satellite image etc. The satellite image having insufficient information (details) or having a lots of extra information which is unwanted. It may reduce the noise level by using the enhancement technique and eliminate by using some filtering techniques. Even filtering techniques are a part of image enhancement techniques. These techniques are discussed in detail and illustrated in this module.

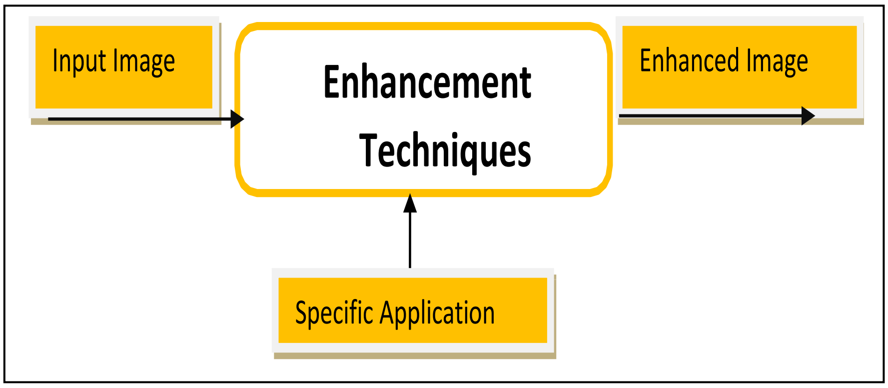



Fig (10): Process of image enhancement Source: self

For example, you can remove noise, sharpen or brighten an image and improve perceptual aspects, such as image quality, intelligibility or visual appearance and make it easier to identify key features. The enhancement techniques change the original digital number (DN) values permanently. Therefore those images cannot be used for many digital analysis e.g, image classification. These techniques are applied either to single-band image or separately to the individual bands of a multi-band image set.

### 6.6.1. Image Reduction and Magnification

**Image Reduction:** Image Reduction techniques allow the analyst to obtain a regional perspective of the remotely sensed data. The computer screen cannot display the entire image on the screen unless reduce the visual representation of the image. It is commonly known as zoom out.

| | | | | | |
|---|---|---|---|---|---|
| 0 | 1 | 4 | 2 | 5 | 3 |
| 2 | 4 | 2 | 1 | 2 | 2 |
| 5 | 8 | 8 | 6 | 5 | 3 |
| 4 | 9 | 8 | 5 | 5 | 5 |
| 7 | 8 | 3 | 5 | 4 | 5 |
| 5 | 6 | 7 | 5 | 4 | 6 |

Original image

| | | |
|---|---|---|
| 0 | 4 | 5 |
| 5 | 8 | 6 |
| 7 | 3 | 4 |

Reduced image

Fig (11): Logic of a simple 2x integer reduction. Source: Self

Fig (11) shows the hypothetical example of 2x image reduction achieved by sampling every other row and column of the original data. Result shows that the new image consisting of only quarter (25%) of the original data.

**Image Magnification:**

Image magnification is very useful techniques when the analysis is trying to obtain the detail information about the spectral reflectance or emitance characteristics of a relatively small geographic area of interest and it is also used to match the display scale of another image. It is commonly known as zoom out.

| | | | |
|---|---|---|---|
| 0 | 2 | 5 | 2 |
| 3 | 4 | 1 | 1 |
| | 5 | 8 | 6 |
| 4 | 9 | 8 | 5 |

Original image

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0 | 2 | 2 | 5 | 5 |
| 0 | 0 | 2 | 2 | 5 | 5 |
| 3 | 3 | 4 | 4 | 1 | 1 |
| 3 | 3 | 4 | 4 | 1 | 1 |
| 7 | 7 | 5 | 5 | 8 | 8 |
| 7 | 7 | 5 | 5 | 8 | 8 |

Magnified image

Fig (3): logic of a simple 2x integer magnification. Source: Self

Fig (3) shows the hypothetical example of 2x image magnification achieved by replacing every row and column in the original image. The new image will consist of four times as many pixels as the original scene. Row and column deletion is the simplest form of image magnification. To magnify an image by an integer factor m squared, each pixel in the original image is replaced by an m×m block of pixels all of the original pixel values.

## 6.7. Methods of Enhancement

- Spatial Domain enhancement techniques
- Frequency Domain enhancement techniques

(1) **Spatial domain enhancement techniques** modify the grey scale or intensity value of image and it is based on direct manipulation of pixels in an image. Spatial domain process are denoted by the expression

$$g(x, y) = T[f(x, y)]$$

Where,

f(x, y) is input image.

g(x, y) is processed image.

f is the intensity value at the pixel located by x and y.

T is define the operator on f over some neighborhood region of x and y.

Intensity value at the pixel located by x and y after processed does not depend on the intensity value at pixel located by x and y which are there in the neighborhood of x and y alone. It is also depend on the intensity which are there in the neighborhood of the x and y point. The value of a pixel with coordinates (x, y) in the enhanced image is the result of performing some operation on the pixels in the neighborhood of (x, y) in the input image, f. In frequency domain methods, the image is first transferred into frequency domain. It means that, Fourier Transform of the image is computed first. Fourier analysis is a mathematical technique is used to separate the satellite image into its various spatial frequency component. Frequency domain filtering operations is shown in Fig (4).

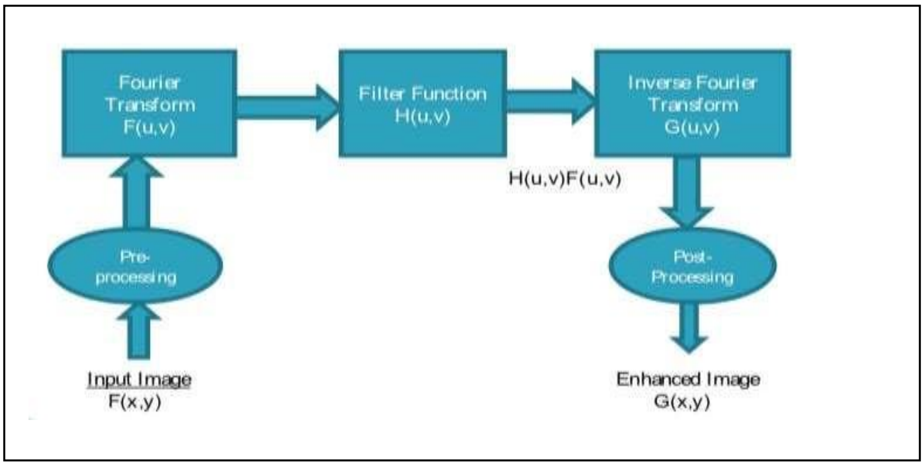



Fig (4): Filtering operation in frequency domain

Source: http://www.slideshare.net/diwakerpant/frequency-domain-image-enhancement-techniques.

### 6.7.1. Contrast Enhancement

Remote sensing images have played an important role in many fields such as meteorology, agriculture, geology, education, etc. Contrast enhancement techniques are required for better visual perception and colour reproduction. The range of brightness values present on image is referred to as contrast. Contrast enhancement techniques have been widely used in many applications of image processing where the subjective quality of images is important for human interpretation. A common problem in remote sensing is that the range of reflectance values collected by a sensor may not match the capabilities of the colour display monitor. In digital image processing the contrast enhancement for satellite image in the field of remote sensing a lot of work has been done to get better the quality of image such as histogram equalization, multi-histogram equalization and pixel dependent contrast preserving. Contrast generally refers to the difference in luminance or grey level values in an image and is an important characteristic. It can be defined as the ratio of the maximum intensity to the minimum intensity over an image.

**Contrast Ratio = BV max / BV min**

Where,

BV max is the maximum brightness value.
BV min is the minimum brightness value.
In this module we will talk about contrast enhancement. Linear and non-linear transformation functions such as image negatives, logarithmic transformations, power-law transformations, and piecewise linear transformations will be discussed. Histogram process and histogram of four basic grey-level characteristics will be introduced.

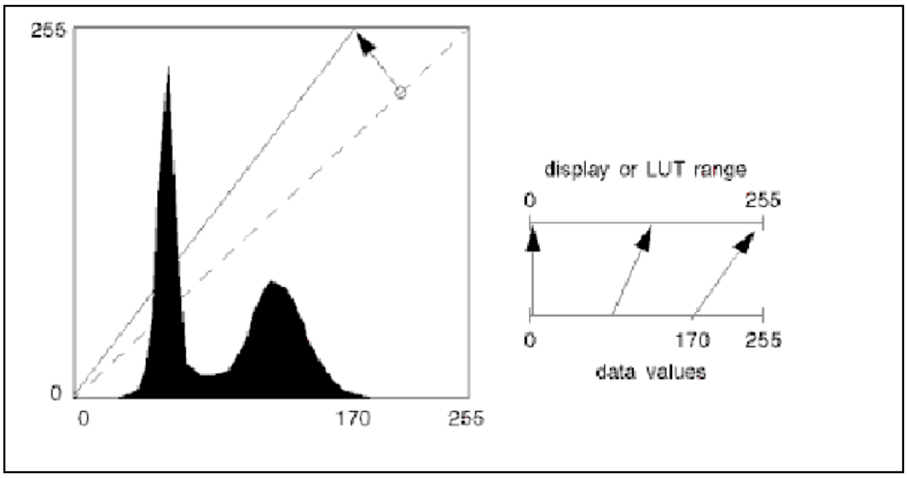



Fig (5): Image Histogram

Source:
https://hexagongeospatial.fluidtopics.net/book#!book;uri=a0316196704acf3e68dc2909785a5f77;breadcrumb=1959db97f38d1f1c5b119813d9287f6a-60efbd0962e05deb5a71261633febc8d

The key to understand contrast enhancements is to the concept of an image histogram. A histogram is a graphical representation of satellite data.

#### 6.7.1.1. Linear Contrast Enhancement

Linear Contrast linearly expands the original digital values of the remotely sensed data into a new distribution. It is also referred to as a contrast stretching. These types of enhancements are best applied to remotely sensed images with Gaussian or near-Gaussian histograms, meaning, all the brightness values fall within a narrow range of the histogram and only one mode is apparent. There are four methods of linear contrast enhancement.

- Minimum-Maximum Linear Contrast Stretch
- Piecewise Linear Contrast Stretch
- Saturation stretch

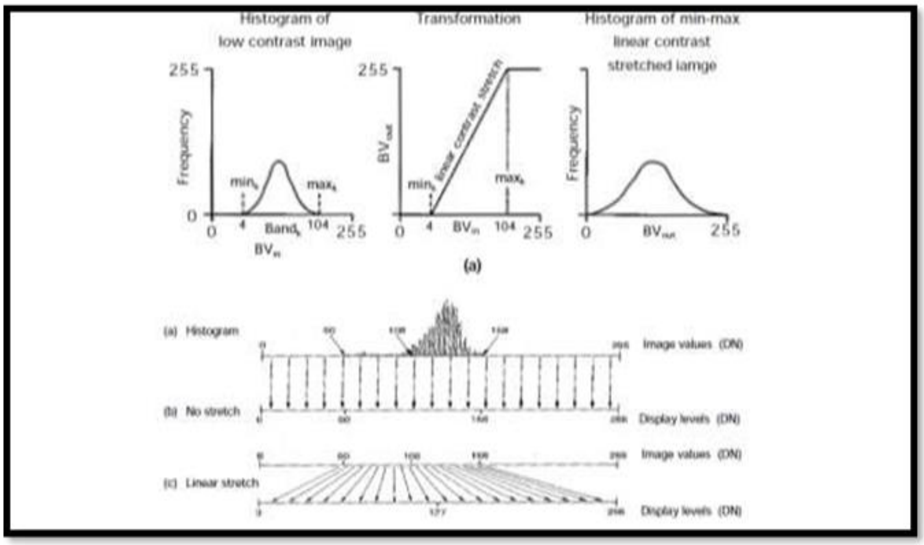



Fig (6): Linear Contrast Stretch
**source: Lilles and Kiefer, 1993**

Fig(6) Shows the graphical representation of linear contrast stretch.

**Minimum-Maximum Linear Contrast Stretch:** In this technique the original minimum and maximum values of the data are assigned to a newly specified set of values that utilize the full range of available brightness values of the display unit. To perform linear contrast enhancement, the analyst examines the satellite image statistics and determines the minimum and maximum brightness values in band k, maxk and mink respectively.

$$\mathbf{BVout = [(BVin - mink / maxk - mink)]\ quantk}$$

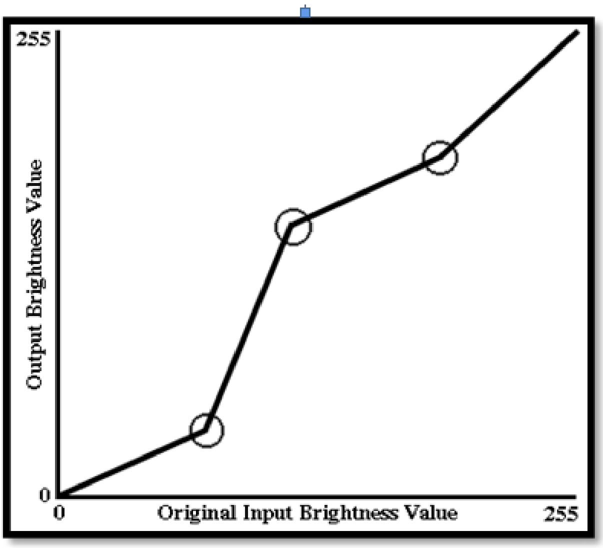
Where, BVout is the orignal input brightness values and quantk is the maximun value of range of brightness.

**Piecewise Linear Contrast Stretch:** It involves the identification of a number of linear enhancement steps that expands the brightness ranges in the modes of the histogram. The piecewise linear contrast stretch is similar to the minimum- maximum linear contrast stretch except this method use a specified minimum and maximum values that lie in a certain percentage of pixels from the mean of the histogram. In the piecewise stretch, a series of small min-max stretches are set up within a single histogram. It is very powerful enhancement techniques.

A piecewise linear contrast stretch normally follows two rules:

1) Data values are continuous there can be no break in the values between high, middle, and low range.

2) Data values specified can go only in an upward, increasing direction, as shown in Fig (7).




Fig(7): Logic of a piecewise linear contrast stretch:Source: http://www.r-s-c-c.org/node/244

In the piecewise linear contrast stretch, several breakpoints are defined that increase or decrease the contrast of the image for a given range of values. The minimum and maximum values are stretched to the values of 0 and 255 at a constant level of intensity.

**Saturation Linear Contrast Stretch:** The saturation contrast stretch is also referred as percentage linear contrast stretch or tail trim. It is similar to the minimum-maximum linear contrast stretch except this method uses specified minimum and maximum values that lie in a certain percentage of pixels. Sometimes these tails of the histogram is enhanced more prominently. This is the main of this method. In this method the information content of the pixels that saturate at 0 and 255 is lost; however, the remainder part of histogram is more enhanced compared to minimum to maximum linear stretch.

### 6.7.1.2. Non-Linear Contrast Enhancement:

Nonlinear contrast enhancement often involves histogram equalizations through the use of an algorithm. In the nonlinear contrast enhancement techniques the each value in the input image can have several values in the output image, so that objects in the original image lose their corrective relative brightness value. Usually, nonlinear enhancements bring out the contrast in one range while decreasing the contrast in other ranges.

There are three types of nonlinear enhancement techniques

- Histogram Equalizations
- Adaptive Histogram Equalization
- Homomorphic Filter

**(1) Histogram equalization** is another non-linear contrast enhancement technique. It is one of the most useful method for the nonlinear contrast enhancement. It usually increases the global contrast of satellite images. It create an output version of satellite image which maximizes the contrast of the data by applying a nonlinear contrast stretch that redistributes pixel values so that there are approximately the same number of pixels with each value within a range. When the histogram values of satellite image is equalized, all pixel values of the image are redistributed. Histogram equalization can also separate pixels into distinct groups if there are few output values over a wide range. It is not necessary that contrast will always be increase in this. There may be some cases were histogram equalization can be worse. In this case the contrast is decreased or it doesn't force the distribution "flat" which means the number of pixel in each intensity levels distributed equally.

The total number of pixels is divided by the number of bins, equaling the number of pixels per bin, as shown in the following equation:

$$A = \frac{T}{N}$$

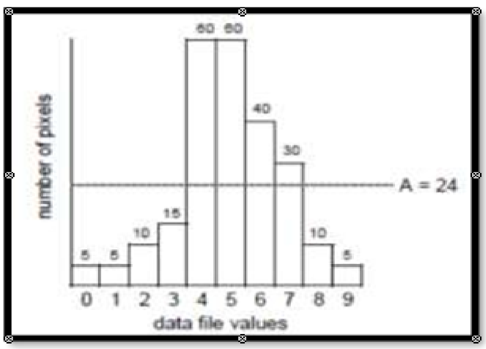
Where,

N= number of bins (If there are many bins or many pixels with the same valueor values, some bins may be empty).

T= total number of pixels in the image.

A= equalized number of pixels per bin.

**Histogram Equalization Example**: In this example, 10 bins are rescaled to the range 0 to 9, because the input values ranged from 0 to 9, so that the equalized histogram can be compared to the original. The output histogram of this equalized image is shown in fig 8(b). In the output, histogram is not exactly flat, since the pixels can rarely be grouped together into bins with an equal number of pixels.



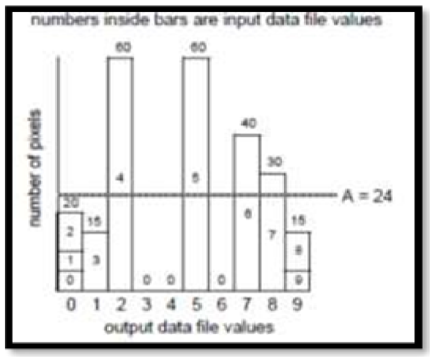




Fig (8a): Histogram Equalization Fig (8b) Equalized Histogram

Source: ERDAS, (2014). ERDAS field guide)

There are 240 pixels represented by this histogram. To equalize this histogram to 10 bins, 240 pixels / 10 bins = 24 pixels per bin = A Following equation is used to assign pixels to bins:

$$B_i = \mathrm{int}\left[\frac{\left(\sum_{k=1}^{i-1} H_k\right) + \frac{H_i}{2}}{A}\right]$$

Source: ERDAS, (2014). ERDAS field guide

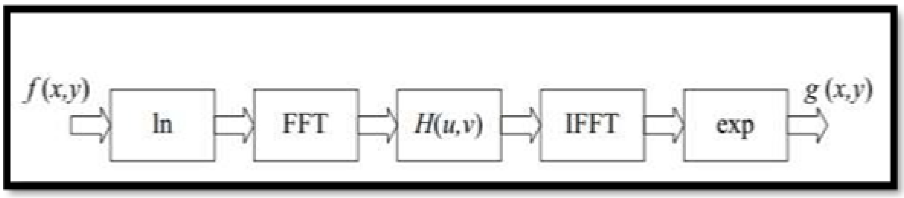
Where, A = equalized number of pixels per bin. Hi = number of values with the value i. Hk = number of pixel per bin.

k = a particular bin number. int = integer function.

Bi= bin number for pixels with value i.

There is also one important thing to be note here that during histogram equalization the overall shape of the histogram changes, where as in histogram stretching the overall shape of histogram remains same.

**Adaptive Histogram Equalization:** In Adaptive histogram equalization the satellite image divide into several rectangular domains, compute an equalizing histogram and modify levels. This method enhances the contrast of images by transforming the values in the intensity image. Contrast is increased at the most populated range of brightness values of the histogram. It automatically reduces the contrast in very light or dark parts of the image associated with the tails of a normally distributed histogram. According to this method, we partition the given image into blocks of suitable size and equalize the histogram of each sub block. In order to eliminate artificial boundaries created by the process, the intensities are interpolated across the block regions using bicubic interpolating functions (Al-amri, S. S., Kalyankar, N. V., & Khamitkar, S. D. (2010)




Source:
http://debian.fmi.unisofia.bg/~blizzard/download/Image%20Processing/6.Image%20Enhancement%203.pdf

**Homomorphic filters:** For homomorphic filter to be effective it needs to affect the low- and high- frequency components of the Fourier transform in different way.

**Filters:** There are two types of enhancement techniques called spatial domain and frequency domain techniques which are categorized again for smoothing and sharpening the images. We considered the filtering in frequency domain using FFT, use of the terms frequency domain and frequency components is really no different from the terms time domain and time components, which we would use to express the domain and values of f(x) if x where a time variable attenuated to some degree.

**Lowpass filter (smoothing):** A low-pass filter is a filter that passes low- frequency signals and attenuates signals with frequencies higher than the cut-off frequency. The actual amount of attenuation for each frequency varies depending on specific filter design. Smoothing is fundamentally a low pass operation in the frequency domain . There are several standard forms of low pass filters are Ideal, Butterworth and Gaussian low pass filter.

**Highpass filters (sharpening):** A high-pass filter is a filter that passes high frequencies well, but attenuates frequencies lower than the cut-off frequency. Sharpening is fundamentally a high pass operation in the frequency domain. There are several standard forms of high pass filters such as Ideal, Butterworth and Gaussian high pass filter. All high pass filter (Hhp) is often represented by its relationship to the low pass filter (Hlp).

$$Hhp = 1 - Hl$$

**Indices:** Band rationing of satellite image is the arithmetic operation that is most widely applied to images in the application of remote sensing such as geological, forestry and agriculture. In these enhancement techniques the DN value of one band is divided by that of any other band in the sensor array. Creating ratio images is done using the following general formula:

$$\mathbf{BV_{i,\,j,\,r} = (BV_{\,i,\,j,\,k} / BV_{\,I\,,j,\,l}}$$

Where,

$BV_{i\,,j,\,r}$ = output ratio values for pixel at row i, column j.

$BV_{i\,,j,\,k}$ and $B\,V_{i\,,j,l}$ are the brightness values at the same location in bands k andl respectively.

- If $BV_{i,j,k}$ and $BV_{i\;,j,l}$ both values are similar, resulting proportion is a number close to 1.
- If the numerator number is low and denominator high, the quotient approaches zero.
- If this is reversed (high numerator; low denominator) the number is well above 1.

The Ratio of their reflectance between the two bands should always be very similar. Three band ratio images can be combined as colour composites which highlight certain features in distinctive colours. Commonly used ratios/indices are as follow

**Vegetation Index = DNNIR / DNR**

Where, $DN_{NIR}$ = Brightness value of pixel in NIR band

$DN_R$ = Brightness value of pixel in R band

**Normalized Difference Vegetation Index (NDVI):** In the NDVI, the difference between the near-infrared and red (or visible) reflectance is divided by their sum. The NDVI has a range limited to a value from -1 to 1. Data from vegetated areas will yield positive values for the NDVI due. NDVI is calculated as follows:

**NDVI = (NIR - RED) / (NIR + RED)**

**Normalized Difference Snow Index (NDSI):** Normalized difference of two bands (one in the visible and one in the near-infrared or short-wave infrared parts of the spectrum) is used to map snow. Values of NDSI greater than 0.4 indicate the presence of snow.

$$NDSI = \frac{(Green - NIR)}{(Green + NIR)}$$

The NDSI was originally developed for use with Land sat TM/ETM+ bands 2 and 5 or MODIS bands 4 and 6. However, it will work with any multispectral sensor with a green band between 0.5-0.6 µm and a NIR band between 0.76-0.96 µm.

**Reference:** Riggs, G., D. Hall, and V. Salomonson. "A Snow Index for the Land sat Thematic Mapper and Moderate Resolution Imaging Spectrometer." Geoscience and Remote Sensing Symposium, IGARSS '94, Volume 4: Surface and Atmospheric Remote Sensing: Technologies, Data Analysis, and Interpretation (1994), pp. 1942-1944.

**Normalized Difference Built-up Index (NDBI):** This index highlights urban areas where there is typically a higher reflectance in the shortwave- infrared (SWIR) region, compared to the near-infrared (NIR) region. Applications include watershed runoff predictions and land-use planning.

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

The NDBI was originally developed for use with Landsat TM bands 5 and 4. However, it will work with any multispectral sensor with a SWIR band between 1.55-1.75 µm and a NIR band between 0.76-0.9 µm.

**Reference:** Zha, Y., J. Gao, and S. Ni. "Use of Normalized Difference Built-Up Index in Automatically Mapping Urban Areas from TM Imagery." International Journal of Remote Sensing 24, no. 3 (2003): 583-594.

## Summary

So at present time Geographical Information System (GIS) is the most powerful, most applicable and useful system for every type of planning, management, development and decision making projects. Ground level reality with the help of spatial data can be obtained from various sources and managed in GIS platform. Data integration from various sources is possible in GIS. Like integration of remote sensing data and image and data of land record and agriculture and economic census data could be carried out with the help of GIS. So at present time it will be more appropriate to use GIS application in all types of planning and developmental activities and also in day to day life.

During the time the image is being scanned, the satellite follows a specific path that is subject to minor variations at the same time that the earth is moving underneath. There may also be variation in the velocity of the platform as well as in the rate of scanning by the sensor. As a result, various kinds of systematic and random distortions may be introduced in remote sensing data. Geometric corrections are therefore required to take care of different kinds of distortions occurring in the data. In addition, remote sensing images are typically captured at a great distance from the earth's surface. Therefore, electromagnetic energy has to pass through a large distance in the atmosphere before it reaches the sensor. Depending upon the atmospheric conditions (such as particulate matter, moisture content and turbulence), the incoming energy may be significantly modified. Therefore, suitable corrections need to be applied to take care of these effects upon the remote sensing data.

**Frequently Asked Questions**

Q1. What is GIS?

Q2. How many components are there in GIS?

Q3. Write about format of GIS data type?

Q4. Write a short note on function of GIS?

Q5. Give a short note on different method of GIS data creation?

Q6. What are various objectives of geometric corrections applied on remote sensing data?

Q7. Differentiate between systematic and non-systematic distortions occurring in remote sensing data?

Q8. Distinguish between nearest neighborhood resampling and bilinear resampling methods?

Q9. Describe the process used for elimination of three number consecutive missing lines in remote sensing data?

Q10. What do you understand by noise in remote sensing data? How it can be removed?

**Multiple Choice Questions-**

1. Which of the following causes a systematic distortion

(a) Rotation of earth

(b) Attitude changes

(c) Roll of the platform

(d) None of these

Ans: a

2. Non-systematic distortions in the image may be corrected by

(a) Image to ground geo-correction

(b) Image to map rectification

(c) Image to image correction

(d) All of these

Ans: d

3. The process of offsetting each successive scanline in an image towards the West is carried out to correct

(a) Skew distortion

(b) Panoramic distortion

(c) Both (a) and (b)

(d) None of these

Ans: a

4. Which of the following is not an internal distortion

(a) Radial distortion

(b) Skew

(c) Projection distortion

(d) Terrain Relief Displacement

Ans: d

5. Distortions in remote sensing data associated with the platform of the sensor is due to

(a) Roll

(b) Pitch

(c) Yaw

(d) All of these

Ans: d

6. Along-scan kind of distortions in remote sensing images are introduced due to

(a) Earth rotation

(b) Mirror-scan Velocity variation

(c) Perspective

(d) All of these

Ans: d

7. The response of one of the detectors in a multispectral scanner of a satellite has deviated from its calibrated one. This will result in

(a) Stripping in image

(b) Missing line image

(c) both (a) and (b)

(d) None of these

Ans: a

8. In a third order polynomial used in geometric correction of an image using GCPs, then the minimum number of GCPs required is

(a) 3

(b) 5

(c) 10

(d) 20

Ans: c

9. The size of pixel neighborhood used in second order resampling is

(a) $3 \times 3$

(b) $4 \times 4$

(c) $5 \times 5$

(d) None of these

Ans: b

10. Given the following statements, choose the correct option

Statement I: The spectral radiance recorded by a sensor depends upon the irradiance on the target as well as reflectance of the target.

Statement II: The brightness value of pixels is independent of the sun angle at the time of observation.

(a) Both the statements are true

(b) Both the statements are false

(c) Statement I is true but Statement II is false

(d) Statement I is false but Statement II is true

Ans: c

11. What is full form of GIS

a) Geographical information system

b) Geographical information science

c) Geographic innovative science

d) Geographical international science

12. Which of the following is not component of GIS

(a) Hardware

(b) Software

(c) User

(d) GPS

13. Conversion of hardcopy map into pixel form image is called as

a) Rasterization

b) Vectorization

c) Image processing

d) Clipping

14. Process of conversion of pixel image into point, line and polygon format is called as

a) Rasterization

b) Vectorization

c) Image processing

d) Clipping

15. What is full form of COGO

a) Coordinate geometry

b) Clipping geometry

c) Coordinate geography

d) Coordinate Geo-referencing

**Suggested Readings**

1. Maguire, D. J. (1991). An overview and definition of GIS. Geographical Information Systems: Principles and applications, 1, 9-20.

2. Jackson, M. J., & Woodsford, P. A. (1991). GIS data capture hardware and software. Geographical Information Systems: Principles and Applications, 1, 239-249.

3. Lange, A. F., & Gilbert, C. (1999). Using GPS for GIS data capture. Geographical Information System, PA Longley, MF Goodchild, DJ Maguire, and DW Rhind (Eds.), 2nd Edn. John Wiley & Sons, New York, 467-79.

4. David DiBiase, Understanding Geographic Data.

5. www.wiley.com/gis

6. Bhatta, B. (2008). Remote sensing and GIS. Oxford University Press, USA. ISBN: 019569239X, 9780195692396.

7. Jensen, John R. (2015), Introductiory to Digital Image Processing : A Remote Sensing Perspective, 4th Edn., Pearson Education. ISBN: 013405816X, 978-0134058160.

8. Lillesand Thomas, Keifer Ralph W. and Chipman Jonathan (2015). Remote sensing and Image Interpretation, 7th Edn. John Wiley & Sons, New York. ISBN : 978-1-118-34328-9.

9. Liu, J. G., & Mason, P. J. (2013). Essential image processing and GIS for remote sensing. John Wiley & Sons. ISBN: 978-0-470-51031-5.

10. Reddy, Anji M. (2012), Textbook of remote sensing and geographical information systems, 4th Edn., B S Publications. ISBN: 9381075972, 978-9381075975.

# Unit 7: Basics of GIS and GPS

**Unit Structure**



## 7.0. Learning objectives

After studying this unit you will be able to explain:

- Know the concept and definition of GIS and GPS
- Know the major components of GIS and GPS systems and their functions
- Appreciate the power of GIS and GPS tools in scientific studies and making life easier
- Know various applications of GIS and GPS
- Know indigenous and globally developed GIS and GPS

## 7.1. Introduction

Geographical Information System (GIS) is a modern and efficient tool for handling spatial data. It is an integrated computer-based system of geography and information tied together. The applications of GIS are immense pertaining to almost all disciplines. Global Positioning System (GPS) further enhances the capability of GIS by providing real time positional data along with several applications. In this module working of GIS and GPS is briefly explained along with their areas of applications.

## 7.2. Geographical Information System (GIS)

GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially-referenced data for solving complex planning and management problems. It is an integrated system that is designed to work with spatial and attribute data. In other words, a GIS is both a system with specific capabilities for spatially-referenced data, as well as a set of operations for working with non-spatial data.

## 7.3. Components of GIS

GIS integrates five key components: hardware, software, data, people, and methods.

**Hardware:** Hardware is the computer system on which a GIS operates and the GIS software runs. The computer forms the backbone of the GIS hardware; besides this it needs input and output devices. Scanner and or digitizer board are the most common input devices whereas printers and plotters are output devices for a GIS hardware setup.

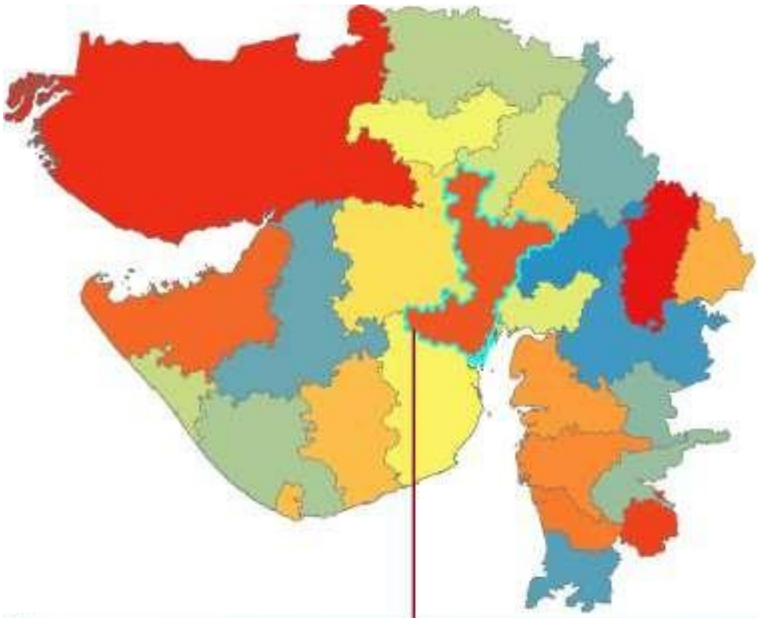
**Software:** GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are

- Data input and verification
- Data storage and database management
- Data transformation
- Data output and presentation
- Interaction with the user

Data: The most important component of GIS is the data. GIS has two types of data-

- **Spatial data -** Spatial data refers to all types of data objects or elements that are present in a geographical space. It enables the global finding and location of individuals or devices anywhere in the world. Spatial data is also known as geospatial or geographic data.

- **Attribute data -**Attribute data is information appended in tabular format with respect to the spatial features. Attribute data provides characteristics about spatial data.



| FID | Shape * | OBJECTID | DISTRICT | STATE | DIST_CENSU | Area |
|---|---|---|---|---|---|---|
| 0 | Polygon | 3 | Ahmadabad | GJ | 2407 | 7712.663568 |
| 1 | Polygon | 17 | Amreli | GJ | 2413 | 7621.29371 |
| 2 | Polygon | 19 | Anand | GJ | 2415 | 2806.433531 |
| 3 | Polygon | 44 | Banas Kantha | GJ | 2402 | 10247.553593 |

Fig. 1: Spatial data and its attribute data in GIS

**People:** GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. The people who use GIS can be broadly classified into two classes. The GIS operator, whose work is to vectorise the map objects and GIS engineer/user who uses this vectorised data to perform query, analysis for problem solving.

**Method:** Above all a successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization. There are various techniques used for map creation and further usage for any project.

## 7.4. Formats of GIS Data

In GIS, the spatial data can be represented in two formats: Vector format and Raster format which are described below:

### 7.4.1 Vector Format

In vector format, any real feature on earth is represented either as Point, Line or Polygon. In vector models, objects are created by connecting points with straight line (or arcs) and area is defined by sets of lines. Information about points, lines and polygons is encoded and stored as a collection of x, y coordinate. Location of a point feature such as tubewell can be described by a single x, y coordinate. Linear feature such as river can be stored as a collection of point coordinates. Polygon feature, such as river catchment can be stored as a closed loop of coordinates.

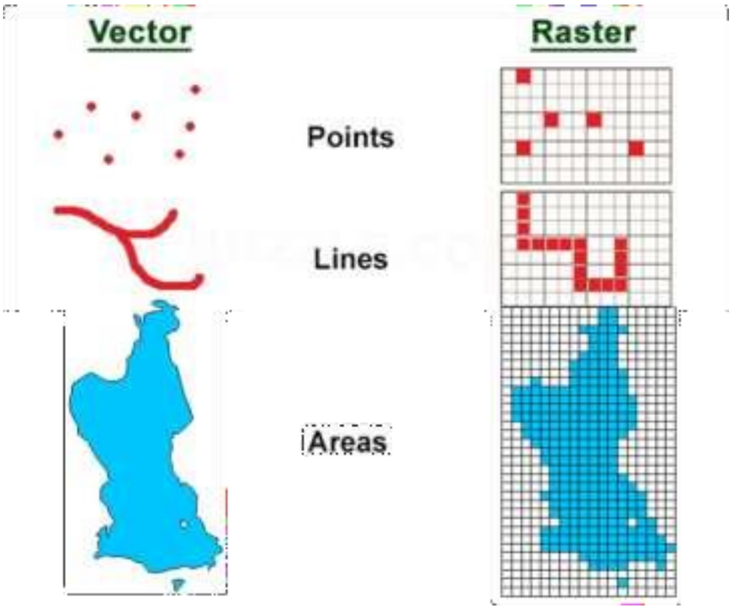



Fig. 2: Representation of data in GIS (Vector and Raster format)

### 7.4. 2. Raster Format

Raster data represents all information in square pixel (PIXEL = Picture Element) form which is the smallest unit of whole raster representation. In raster format, study area is divided into a regular grid of cells in which each cell contains single value. Continuous data type, such as elevation, vegetation etc. are represented using raster model.

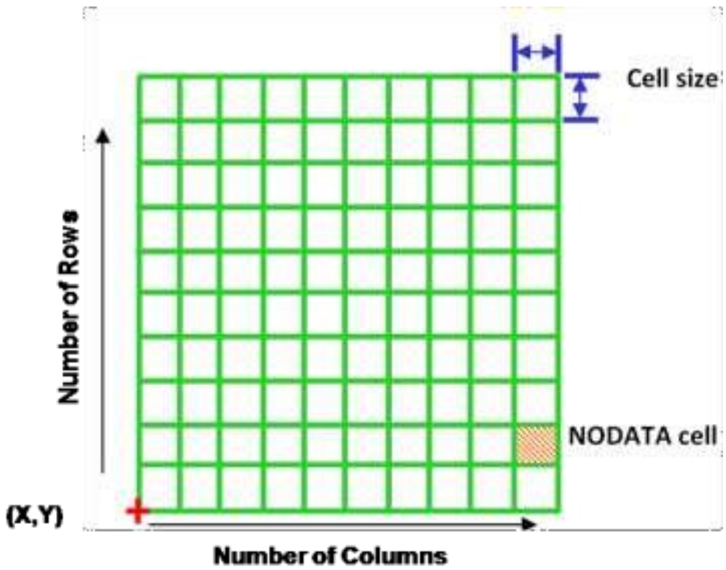



Fig. 3: Definition of a Grid in GIS

## 7.5. Data Input in GIS

After receiving existing spatial data, it needs to be converted into digital format which is compatible with the GIS software. This data could be obtained by primary data sources, such as satellite or GPS (Global Positioning System), or secondary data sources such as paper maps. The process of converting paper maps to digital data is called digitizing, and it can be done using digitizer or scanner. Another method is on-screen digitization which is manual digitizing on the computer monitor using a data source such as a raster image or toposheet as the background.

## 7.6. Basic GIS functionality

GIS software combines computer mapping functionality that handles and displays spatial data, with database management system functionality to handle attribute data. The basic functionality of GIS is as follows:

- Querying both spatial and attribute data
- Manipulating the spatial component of the data
- Buffering where all locations lying within a set distance of a feature or set of features are identified
- Overlaying which involves data integration using one or multiple layers using a mathematical overlay operation
- Areal interpolation

## 7.7. Questions GIS can answers

A spatial database created in GIS allows us to ask questions such as 'what is at this location?', 'where are these features found?' and 'what is near this feature?' It also allows us to integrate data from a variety of disparate sources. However, GIS can answer more complicated questions pertaining to like location, condition, trends, patterns, modeling etc. Some of the common questions which GIS can answer are:

- Location: What is at ?
- Condition: Where is it ?
- Trends: What has changed since ?
- Patterns: What spatial patterns exists ?
- Modeling: What if ?

Spatial Questions: Which centers lie within 10 km of each other? Non spatial Questions

## 7.8. Applications of GIS

GIS has emerged as very powerful technology to integrate spatial and attribute data and methods in ways that support traditional forms of geographical analysis, such as map overlay analysis as well as new types of analysis and modeling that are beyond the capability of manual methods. With GIS it is possible to map, model, query, and analyze large quantities of data all held together within a single database. The development of GIS has relied on innovations made in many different disciplines like Geography and Cartography. GIS is now used extensively in government, business, and research for a wide range of applications including environmental resource analysis, land use planning, locational analysis, tax appraisal, utility and infrastructure planning, real estate analysis, marketing and demographic analysis, habitat studies and archaeological analysis. Not only this, GIS can be applied as a tool in almost all disciplines of science and technology like Photogrammetry, Remote Sensing, Surveying, Geodesy, Civil Engineering, Statistics, Computer Science, Operations Research, Artificial Intelligence, Demography and many other branches of the social sciences, natural sciences and engineering. Indeed, some of the most interesting applications of GIS technology discussed below draw upon this interdisciplinary character and heritage.

One of the first major areas of application was in natural resources management, including management of

- wildlife habitat
- wild and scenic rivers
- recreation resources
- floodplains
- wetlands
- agricultural lands
- aquifers
- forests

One of the largest areas of application has been in facilities management. Uses for GIS in this area includes

- locating underground pipes and cables
- balancing loads in electrical networks
- planning facility maintenance
- tracking energy use

Local, state, and federal governments have found GIS particularly useful in land management. GIS has been commonly applied in areas like

- zoning and subdivision planning
- land acquisition
- environmental impact policy
- water quality management
- maintenance of ownership

More recent and innovative uses of GIS have used information based on street-networks. GIS has been found to be particularly useful in

- address matching
- location analysis or site selection
- development of evacuation plans

The range of applications for GIS is growing as systems become more efficient, more common, and less expensive. Some of the newest applications have taken GIS to unexpected areas. The USGS (United States Geological Survey) and the city of Boulder, Colorado in USA have come up with some innovative uses for GIS:

- Global Change and Climate History Project
- Emergency Response Planning
- Site Selection of Water Wells
- Wildfire Hazard Identification and Mitigation System

## 7.9. GIS applications in atmospheric sciences

GIS and other geospatial technologies have become increasingly valuable to the atmospheric sciences, such as weather, climate, hydrometeorology and for societal impact studies.

• **Assessment of wind/storm speed using interpolation**

Inverse Distance Weighted (IDW) interpolation is commonly used in GIS to create raster overlays from point data. Once the data are on a regular grid, contour lines can be threaded through the interpolated values and the map can be drawn as either a vector contour map or as a raster-shaded map.

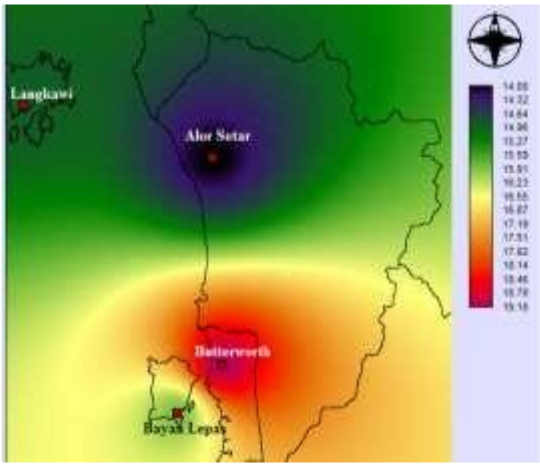



Fig. 4: Wind Speed Map using IDW Method

• Average annual lightning strike density

In figure 5, lighting strike density in an area was mapped using course resolution raster data.

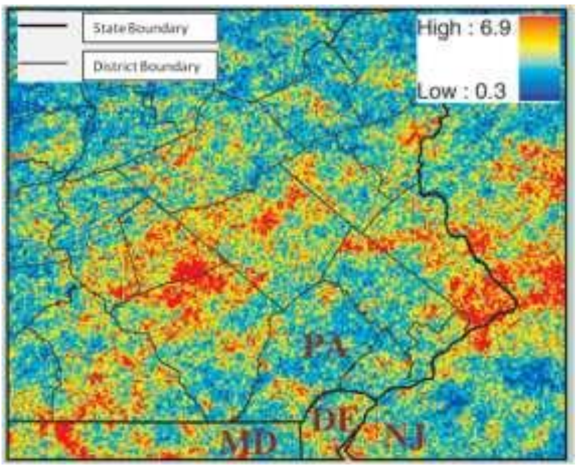
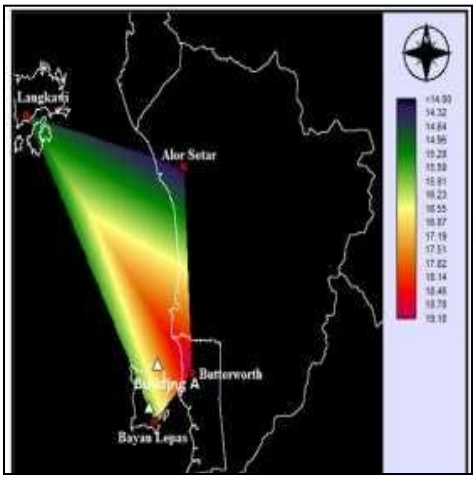



Fig. 5: Average annual lightning strike density (km-2 yr-1) for south-eastern Pennsylvania from 1995 to 2001 (Source: Scott, 2005). In this map the minimum lighting strike density was noted as 0.3 and the highest density was recorded as 6.9, shown in red colour.

- Wind speed mapping using TIN Method and linear models

**TIN (Triangular Irregular Network)** is another tool in GIS and it is a vector data structure. It creates a surface formed by triangles of nearest points. In figure 7 wind speed was mapped and shown as continuous raster surface model. Models can also be developed using linear relationships as shown in figure 8.



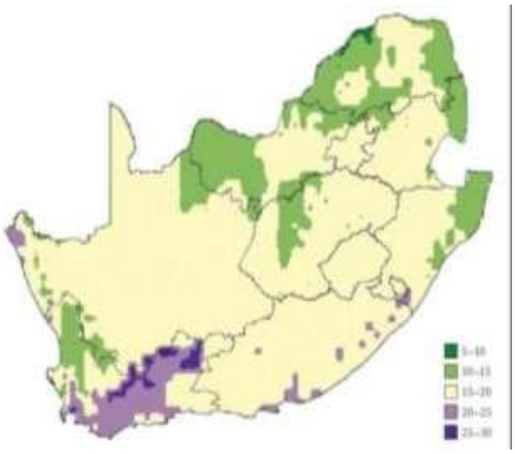



Fig. 7:Mapping of wind speed using TIN Fig. 8: The 1-50 year maximum hourly meanwind speed (m s-1) developed from the linear relationship in South AfricaOther useful applications of GIS in atmospheric/climatic context are:

- Tracking of tornado outbreaks
- Tracking of tsumani arrival
- Speeding power restoration after a storm

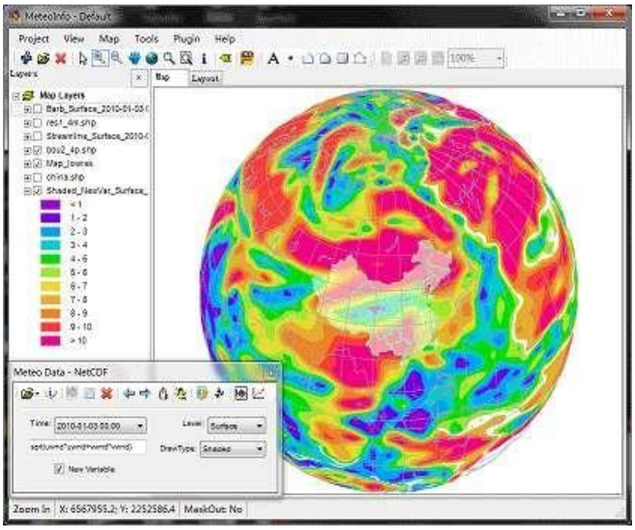



Fig. 6: An open source GIS tool that combines atmospheric data visualization with spatial analysis (Source: gislounge.com)

## 7.10. Global Positioning System (GPS)

The Global Positioning System (GPS) is a space-based navigation system that provides reliable positioning, navigation, and timing services. Most widely used GPS was developed by the US military, which is named as NAVSTAR, in 1950's. Initially it's services were solely available for the use of army, later on it has been made accessible to civilian users too and nowadays it provides continuous worldwide service, free to all. Some other countries have also put in place similar space-based navigation system like that of NAVSTAR-GPS. Examples include GLONASS (Russia), Galileo (Europe) and Beidou (China).

## 7.11 Segments of GPS

There are three major segments of GPS. These are (i) Space segment, (ii) User segment and (iii) Control segment.

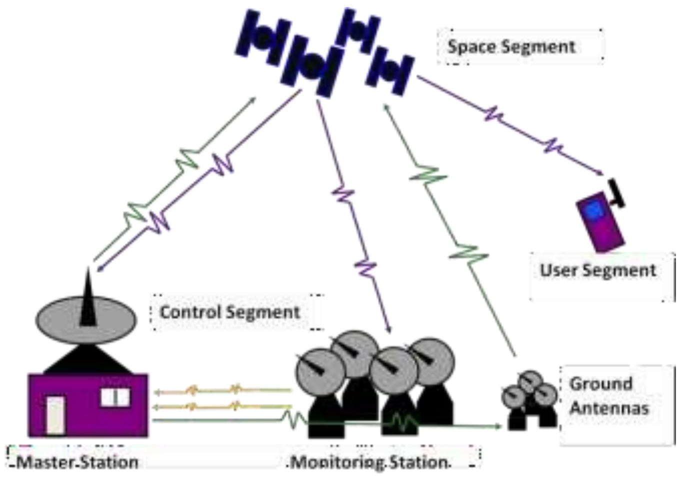



Fig. 9: Three segments of the GPS (Source: Texas Tech University Departments)

### 7.11.1. Space segment

The Space Segment consists of the constellation of spacecraft/satellites and the signals broadcast by them allow users to determine position, velocity and time. The basic functions of the satellites are to:

- Receive and store data transmitted by the control segment stations
- Maintain accurate time by means of several onboard atomic clocks
- Transmit information and signals to users on two L-band frequencies

The Space Segment is an earth-orbiting constellation of 24 active and five spare GPS satellites circling the earth in six orbital planes. Each satellite is oriented at an angle of 55 degrees to the equator. The nominal circular orbit is at 20,200 kilometers (10,900 nautical miles) altitude. Each satellite completes one earth orbit every twelve hours (two orbits every 24 hours). That's an orbital speed of about 4 km per second.

Each GPS satellite (Figure 10) transmits a unique navigational signal centered on two L-band frequencies of the electromagnetic spectrum, permitting the ionospheric propagation effect on the signals to be eliminated. At these frequencies the signals are highly directional and so are easily reflected or blocked by solid objects. Clouds are easily penetrated, but the signals may be blocked by foliage (the extent of blockage is dependent on the type and density of the leaves and branches).

Fig. 10: Block 2 GPS satellite

### 7.11.2. Control segment (CS)

The CS has responsibility for maintaining the satellites and their proper functioning. This includes maintaining the satellites in their proper orbital positions (called station keeping) and monitoring satellite health and status. The CS (Figure 11) also monitors the satellite solar arrays, battery power levels. There are five ground facility stations of NAVSTAR-GPS, viz., Hawaii, Colorado Springs, Ascension Island, Diego Garcia and Kwajalein. All are owned and operated by the U.S. Department of Defence and perform the following functions:

- All the five aforesaid stations are Monitoring Stations, equipped with GPS receivers to track the satellites. The resultant tracking data is sent to the Master Control Station.
- Colorado Springs is the Master Control Station (MCS), where the tracking data are processed in order to compute the satellite ephemerides and satellite clock corrections. It is also the station that initiates alloperations of the space segment, such as spacecraft manoeuvring, signal encryption, satellite clock-keeping etc.

• Three of the stations, viz., Ascension Island, Diego Garcia and Kwajalein are Upload Stations allowing for the uplink of data to the satellites. The data includes the orbit and clock correction information transmitted within the navigation message, as well as command telemetry from the MCS.


Fig. 11: Monitor Stations and Master Control Stations of GPS

Overall operation of the Control and Space Segments is the responsibility of the U.S. Air Force Space Command, Second Space Wing, Satellite Control Squadron at the Falcon Air Force Base, Colorado. The GPS satellites travel at high velocity (4 km s-1), but within a more or less regular orbit pattern. After a satellite has separated from its launch rocket and it begins orbiting the earth, its orbit is defined by its initial position and velocity, and the various force fields acting on the satellite.

### 7.11.3. User Segment

The user receiving equipment, typically referred to as a GPS receiver (Figure 12), processes the L-band signals transmitted from the satellites to determine PVT i.e. position, velocity and time. There has been a significant evolution in the technology of GPS receiving sets since they were initially manufactured in the mid-70. Initially, they were large, bulky and heavy analog devices primarily used for military purposes. With today’s technology, a GPS receiver of comparable or more capability typically weighs less than hundred grams to a few hundred grams and occupies a small volume.

Fig. 12: GPSreceiver

## 7.12. Functioning of GPS

The GPS system consists of three pieces. There are the satellites that transmit the position information, there are the ground stations that are used to control the satellites and update the information, and finally there is the receiver that one purchases. It is the receiver that collects data from the satellites and computes its location anywhere in the world based on information it gets from the satellites. There is a popular misconception that a GPS receiver somehow sends information to the satellites but this is not true, it only receives data.

## 7.13. Indian Global Positioning System – GAGAN

In August 2001 the Airports Authority of India and the Indian Space Research Organization (ISRO) reached an agreement for the establishment of the GAGAN (GPS Aided Geo Augmented Navigation) system (Figure 13).The development plan consists of three different phases-

- Technology Demonstration System (TDS)
- Initial Experimental Phase (IEP)
- Final Operational phase (FOP)

GAGAN Stability tests were successfully completed in June 2013.

The GAGAN is designed to provide the additional accuracy, availability, and integrity necessary to enable users to rely on GPS for all phases of flight, from en route through approach for all qualified airports within the GAGAN service volume. GAGAN will also provide the capability for increased accuracy in position reporting, allowing for more uniform and high-quality Air Traffic Management (ATM). In addition, GAGAN will provide benefits beyond aviation to all modes of transportation, including maritime, highways, railroads and public services such as defense services, security agencies, telecom industry and personal users of position location applications (Source: ISRO Satellite Centre, ISAC).

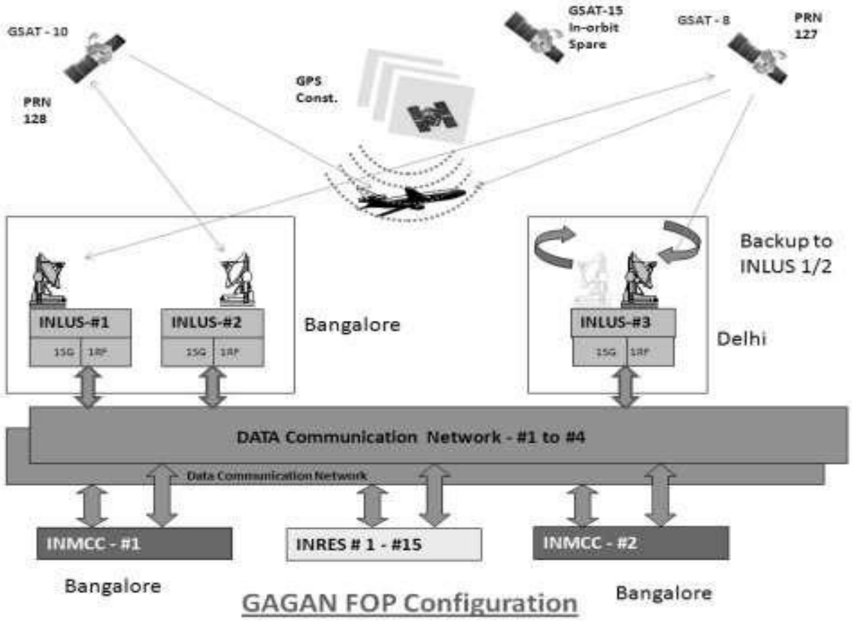



Fig. 13: GAGAN: System of operation

## 7.14. Applications of GPS

### 7.14.1. Timing

In addition to longitude, latitude and altitude, the Global Positioning System (GPS) provides a critical fourth dimension – time. Each GPS satellite contains multiple atomic clocks that contribute very precise time data to the GPS signals. GPS receivers decode these signals, effectively synchronizing each receiver to the atomic clocks. This enables users to determine the time to within 100 billionths of a second, without the cost of owning and operating atomic clocks. Precise time is crucial to a variety of economic activities around the world. Communication systems, electrical power grids and financial networks, all rely on precision timing for synchronization and operational efficiency. The free availability of GPS time has enabled cost savings for companies that depend on precise time and has led to significant advances in capability.

### 7.14.2. Roads and highways

It is estimated that delays from congestion on highways, streets, and transit systems throughout the world result in productivity losses in hundreds of billions of dollars annually. Other negative effects of congestion include property damage, personal injuries, increased air pollution and inefficient fuel consumption. The availability and accuracy of the Global Positioning System (GPS) offers increased efficiencies and safety for vehicles using highways, streets and mass transit systems. Many of the problems associated with the routing and dispatch of commercial vehicles is significantly reduced or eliminated with the help of GPS. Many nationsuse GPS to help survey their road and highway networks, by identifying the location of features on, near, or adjacent to the road networks. These include service stations, maintenance and emergency services and supplies, entry and exit ramps, damage to the road system etc. The information serves as an input to the GIS data gathering process. This database of knowledge helps transportation agencies to reduce maintenance and service costs and enhances the safety of drivers using the roads.

### 7.14.3. Space

The Global Positioning System (GPS) is revolutionizing and revitalizing the way nations operate in space, from guidance systems for crewed vehicles to the management, tracking and control of communication satellite constellations, to monitoring the earth from space. Benefits of using GPS include:

- Navigation solutions: providing high precision orbit determination, and minimum ground control crews, with existing space-qualified GPS units
- Attitude solutions: replacing high cost on-board attitude sensors with low-cost multiple GPS antennae and specialized algorithms.
- Timing solutions: replacing expensive spacecraft atomic clocks with low-cost, precise time GPS receivers.

### 7.14.4. Aviation

Aviators throughout the world use the Global Positioning System (GPS) to increase the safety and efficiency of flight. With its accurate, continuous, and global capabilities, GPS offers seamless satellite navigation services that satisfy many of the requirements for aviation users. Space-based position and navigation enables three-dimensional position determination for all phases of flight from departure, en route, arrival, to airport surface navigation. New and more efficient air routes made possible by GPS are continuing to expand. Vast savings in time and money are being realized. In many cases, aircraft flying over data-sparse areas such as oceans have been able to safely reduce their separation between one another, allowing more aircraft to fly more favourable and efficient routes, saving time, fuel, and increasing cargo revenue.

### 7.14.5. Agriculture

The development and implementation of precision agriculture or site-specific farming has been made possible by combining the Global Positioning System (GPS) and Geographic Information System (GIS). These technologies enable the coupling of real-time data collection with accurate position information, leading to the efficient manipulation and analysis of large amounts of geospatial data. GPS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications of inputs like pesticide or fertilizer applications and yield mapping. GPS allows farmers to work during low visibility field conditions such as rain, dust, fog, and darkness.

### 7.14.6. Surveying and Mapping

Using the near pinpoint accuracy provided by the Global Positioning System (GPS) with ground augmentations, highly accurate surveying and mapping results can be rapidly obtained, thereby significantly reducing the amount of equipment and labour hours that are normally required of other conventional surveying and mapping techniques. Today it is possible for a single surveyor to accomplish in one day what used to takeweeks with an entire team. GPS is unaffected by rain, wind, or reduced sunlight, and is rapidly being adopted by professional surveyors and mapping personnel throughout the world.

### 7.14.7. GPS and Precision Agriculture

The main objective of precision agriculture is to get more and more output by providing optimum input. Precision Agriculture is doing the right thing, at the right place, at the right time. Knowing the right thing to do may involve all kinds of high tech equipments and fancy statistics or other analysis. In this context, GPS becomes part of precision agriculture. For analysis and processing of remote sensed images requires ground truth information, collected in the field, at a variety of sites and often at various times throughout the crop production season. Conventionally this data has been manually recorded on field sheets, air photos or paper maps and considerable time and effort is required to convert it to digital format for use in remote sensing or GIS. For image analysis the ground data must be digitized in order to create a mask for training the software to recognize different conditions and classify the remote sensing imagery. Now we have an interactive, portable system to record field data directly into a digital database consisting of yield, soil, road, water and contour maps overlain on air photos or remote sensing imagery. A GPS receiver is linked to a note book computer displaying appropriate, pre loaded information layers, and a software package then combines incoming GPS signals with the displayed data to allow the user to see where they are with respect to the map components.

In agricultural production soil is the media on which seeds are shown or a plant is planted. Whether growing forage, feed, food or fibre, plant growth depends on soil conditions and soil quality. The following section describes how GPS are used for soil sampling and mapping purposes.

### 7.14.8. Soil sampling using GPS

Soil Sampling is like the foundation of a house. No matter how much effort we put into building the house, the house is only as good as the foundation. The same principle applies to precision agriculture. To effectively manage soil-plant interrelationships, thematic information on soil across the length and breadth of the field is very important. Grid sampling is used for precision agriculture because it is simple and does not require soil science experience. Once the soil data has been collected, the data can be displayed and analyzed.

There are two basic types of grid sampling (Figure 17) used to collect soil data for precision agriculture.

These are:

- Area sampling (grid cell)
- Point sampling with interpolation (grid point)

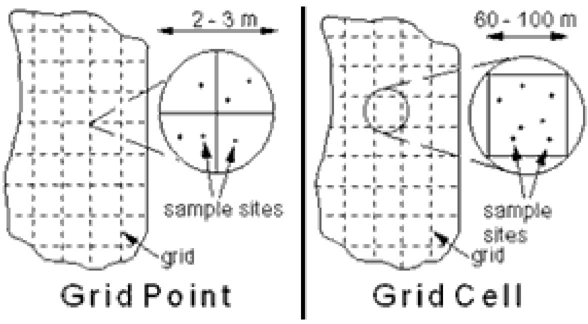



Fig. 14: Types of grid sampling

Determining and mapping the variation in soil characteristics across a field requires an accurate knowledge of the position that the samples were taken. Whichever grid sampling method is used, the coordinate location of the soil sample should be accurate for developing a soils data layer and for navigating back to those locations for re-sampling. This requires the use of a GPS receiver and a source of differential corrections so the producer can acquire an accurate (1- 2 meter) horizontal position that represents the soil sample location. Having acquired the coordinates, the position can be entered into a database while in the field. After the soil sample location has been accurately acquired and entered into a database, all the physical soils data (texture, pH, nutrients etc.) can be tagged to the coordinate location.

## 7.15. Summary

We have learnt the following in this lesson:

- GIS is system for capturing, storing, integrating, manipulating, analyzing and displaying spatially data.
- GPS is basically a system to determine precise location of an object and its main purpose is to aid in navigation.
- Hardware, Software, Data, People and Method are the major components of GIS.
- Vector and Raster are the two important data formats in GIS.
- Querying, Overlaying and Buffering are the key functions of GIS.
- There are three major segments of GPS- Space segment (satellites), Control segment (ground stations) and User segment (the receiver)
- Some functional GPS service systems in the world include NAVSTAR (USA), GLONASS (Russia), Galileo (Europe) etc. India has also developed its own Global Positioning System (GAGAN).
- In combination with various scientific and applied disciplines (e.g., Computer Science, Statistics, Meteorology, Soil Science, Geography, Cartography, Photogrammetry & Remote Sensing, Civil Engineering) the applications of GIS and GPS, nowadays, caters to the need of a very wide range of sectors. Examples include roadways or waterways transportation, aviation, artificial intelligence, real time weather monitoring & forecasting, climatic mapping, rescue and search operations during exigencies, disaster management, land cover change detection & land use planning, agriculture (particularly the precision agriculture), natural resources exploration (e.g., oil & mineral mapping), corporate governance and implementation/monitoring of societal programmes.

# Unit 8: GIS database: Storage and Compaction Techniques

**Unit Structure**



## 8.0 Learning objectives

1. Understand the relevance of data compaction techniques.
2. Learn about four data compaction techniques in raster GIS.
3. Recognize the spaghetti and topological data models in Vector GIS
4. Appreciate the need for data compaction techniques.

## 8.1. Introduction

"The object based spatial database (those obtained by field surveying, remote sensing image analysis, photo interpretation, and digitization etc.) are generally represented in the form of coordinate lines and termed as Vector data models" (Parihar,2017). On the other hand, "when the spatial database is structured on the field-based model the basic spatial units are different forms of tessellation (regular as DEM or irregular as TIN) are termed as Raster data model" (Parihar,2017). The storage and manipulation of various location based data sets and related attribute information in both the models is very relevant and consequently have received lot of attention too and that is the premise of this chapter on data storage and compaction techniques in raster and geographic

Information system (GIS). We realize by now that every data to be considered in GIS environment is to be treated as unique and has its own identity with a requirement of a storage and manipulation space. The major concern that arise is when complex entities such as more than two polygons are stored and the adjoining boundaries are entered twice, causing duplication of adjacent line and also sometimes generating in matching problems. In addition, it occupies more space in the computer. To understand this complexity and related concerns this chapter is divided into two sections, one related to the Data Compaction Techniques in Raster GIS and Second related to data storage Topology driven models in Vector GIS .

## 8.2. Data compaction techniques in Raster GIS

Data compaction or compression is Compaction Techniques common in GIS and is based on different algorithms that reduce the size of a computer file, but maintains all the information intact. Compression algorithms may be "lossless" (where no information is lost) or "lossy" (where some information is lost).Lossy algorithm is generally not applied to thematic data , but largely applied when image data is considered. Mostly they are applied to discrete raster data algorithms.

Consequently, Data compression/compaction in a grid based raster GIS environment has been studied and researched upon by many. Many compaction techniques in raster GIS have been evolved in different years and for our purpose the techniques considered here are the following :

- Chain coding,
- Run length coding,
- Block coding and
- Quad trees

### 8.2.1. Chain Coding

Chain coding is largely undertaken as a clockwise coding method and is generally referred as Freeman Chain Coding. To begin with, from the following figure1 locate the 28 cells required for storing the given entity.

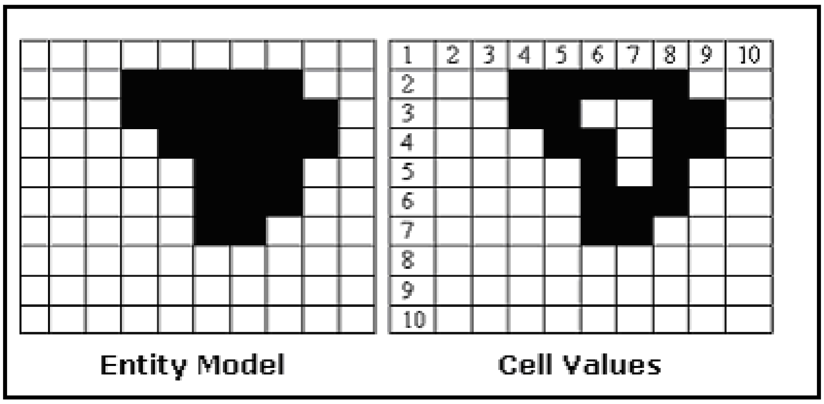



Figure 1: Locating Grid Cells for Chain Coding in Raster GIS

The above technique is simple and straightforward. "In a chain-coded representation of a map, using any starting point on the border of an object, the sequence of cardinal directions of the cells that make up the boundary of the object are recorded systematically in a clockwise direction. The polygon is defined in terms of unit cells measured in cardinal directions" Freeman. The steps are as follows :

i. Identification of points by a number ranging from 0 to 7.
   - For example, East may be identified as 0, North as 1, West as 2 and South as 3. You may select your own numbering system.

ii. Once a move in the direction of the line is made and recorded, the locational grid is re-centered over a new location and the next move defined in the same way.

The advantage of chain coding is that it enables storing raster data and above all it is very useful for detection of sharp turns and area estimation. The short fall is that there is a repetition of data because of repetition of adjoining boundaries.

### 8.2.2. Run-length codes

Run Length Code is an improvement over the conventional chain code technique and suitable to the personal computers with limited storage capacity. It stores a single value for a group of cells instead of storing the value for each individual cell. "This method exploits the fact that many datasets have large homogeneous regions. In this procedure, adjacent cells along a row that have the same value are treated as a group and termed a run. Each row in the grid (one pixel width) is examined in turn, and pixels having the same value, that is, homogeneous pixels are grouped together. It uses a 1D method of grouping pixels with similar or identical values” Heywood,2002. Let us try to understand this from the figure 2 where following steps are undertaken:

i. Locate the pixels with similar values;

ii. Position reference be noted;,

iii. Sequences of pixels with similar values are replaced in the memory by

   a. the ‘positional reference’ to the first pixel in the grouping and
   b. by the ‘number representing’ the number of pixels in the grouping.

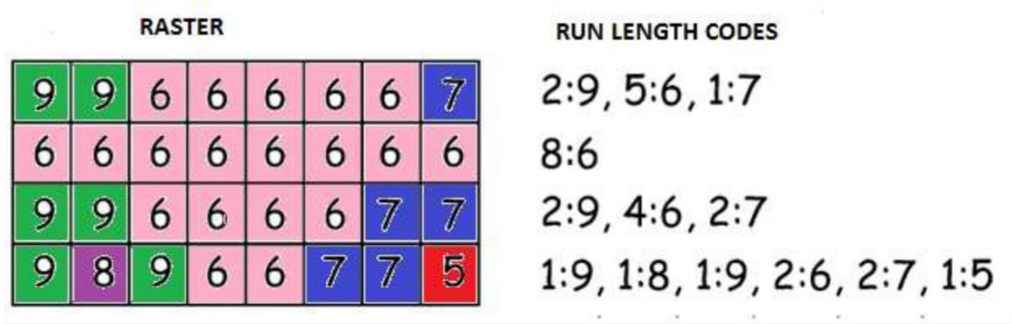



Figure 2: Run Length Coding

The run length coding is common and rather simple method for compression raster data. The left number in row two in Figure 2 depicts the number of cells in run (8 in this case) and the right size is cell value (6 in this case) and the value together noted as 8:6. Though a simple method , it’s major shortcoming in the words of Hey Wood is that “the pixel groups are identified only in one coming is that direction (parallel to the x-axis) as a result the nearby rows, that is, those above and below the current row which may have the same values of the group are represented separately”.

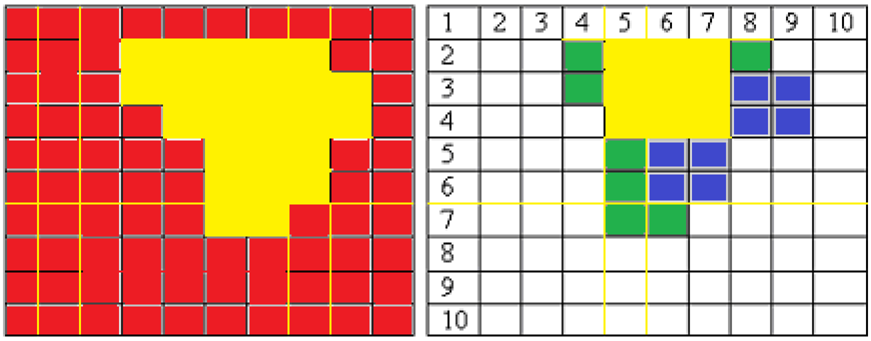
### 8.2.3. Block codes

Block codes “are a two-dimensional extension to run length codes. It assumes that the cells are recorded in the form of blocks of squares. The method uses square blocks to tile the area to be mapped” (Burroughs 1986). This method has largely been applied in performing union and intersection of regions and for detecting properties such as elongation. The steps undertaken in giving Block codes are:

i. Locating as many large square blocks as possible in the given raster image.

ii. The codes be noted through the Medial axis Transformation (MAT) from the square blocks.

iii. The blocks are arranged in the hierarchical form.



Entity Model Cell values

File Structure

| Block size | No. | Cell coordinates |
|---|---|---|
| 1 | 7 | 4,2 8,2 4,2 6,6 6,7 7,7 |
| 4 | 2 | 8,3 7,5 |
| 9 | 1 | 5,2 |

Figure 3: Block Code , Based on Heywood,2002

According to Heywood, 2002, "A unit square represents one cell, whereas a 4 square block represents 2x2cells, a 9 square block represents 3x3 cells and so on. Each block is coded only with the location of a cell (the lower left of the block) and the side length of the block. The larger the square that may be fitted into a region, the more efficient block coding becomes".

### 8.2.4.Quad tree

The fourth raster compression method is Quad tree method. It is a variable spatial resolution model sometimes equated with hierarchical tessellation model. "A quad tree is a term used to describe a hierarchical or tree-based data structure whose common property is that the structure is based on the principle of the recursive decomposition of space to represent both vector and raster data" Burrough,1987 . It is similar to run length coding and are largely used while compressing area features. They generally represent raster data structures with variable spatial resolution. This can be best understood from figure 4:

i. Variable spatial resolutions to be noted;

ii. Each specific area feature to be delineated;

iii. With each area feature the raster cell sizes to be combined and adjusted;

iv. Codes are assigned first to the larger raster cells that fit into one uniform area;

v. Successively smaller cells at each iteration are halved (cell dimension), until the smallest cell size is reached.

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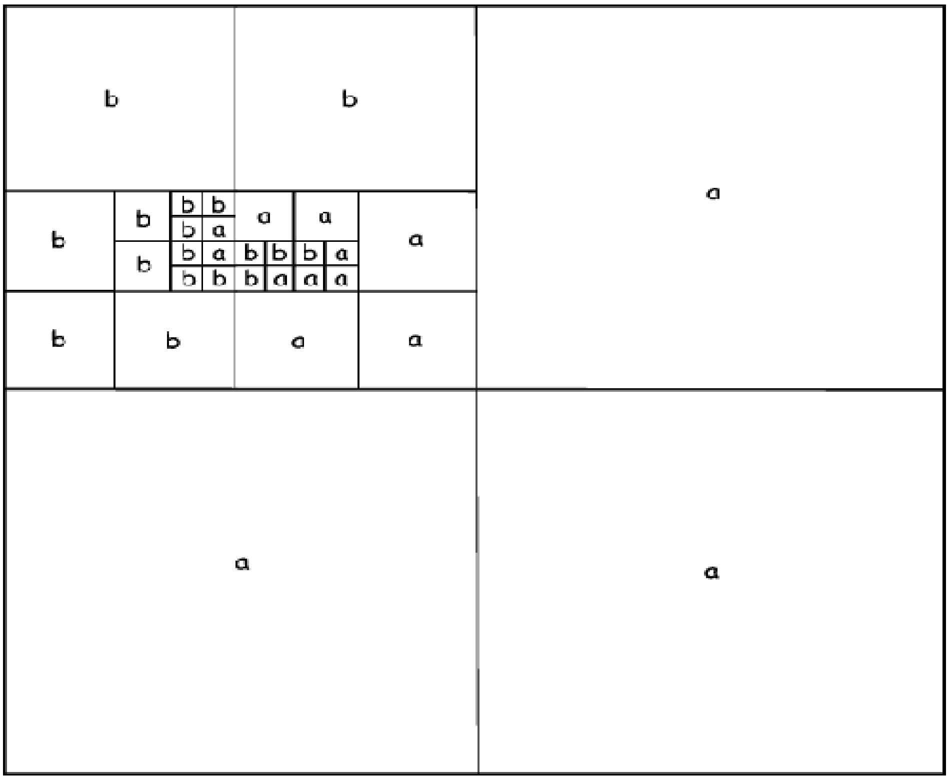


Figure 4: data Compression in Quad tree Method

One of the “advantages of the raster data model is that each cell can be subdivided into smaller cells of the same shape and orientation and the Quadtree model addresses both the resolution and the redundancy issues directly” (Pequot, 1990). Through this method ,operations such as point-in-polygon searches can be performed. However, Burroughs (1984) is of the view that “the largest problems associated with quadtrees is that tree translation is not translation-invariant — two regions of the same shape and size may have quite different quadtree, so consequently shape analysis and pattern recognition are not straight forward". Another disadvantage is that it is time consuming to create a quadtree data structure. This implies that a re-building of the entire quadtree is required , just by a mere change in the original data set.

## 8.3. Data Storage in Vector Data

We know by now that the vector data model represents anything from a simple number to a complex entity. It is an object based approach to the representation of the real world features and is best used to represent discrete objects. It is certainly straight forward when only simple polygon is represented, but with the introduction of complex entities such as more than two polygons, the adjoining boundaries will cause duplication of adjacent line and so need more space in the computer. Moreover, there are also many matching problems that occur while overlapping two sets of same adjoining boundary . To overcome this and the related problems, two models are considered here:

- Spagehetti Model
- Topology Model

#### 8.3.1. Spaghetti Model

Vector data that have been collected but not structured are said to be spaghetti data model like a plate of cooked spaghetti with no ends connected and no intersections affecting the plate. It is also called as non-topological or geometric or path topological model. It was originally developed to organize, manipulate and store line data. The spagehetti model enters each line separately through:

i. Storing the starting node

ii. Storing the end node

iii. Storing the vertices to note the change in direction or path

iv. Not storing /recognizing when the two lines meet or cross each other.

As figure 5 depicts that the spaghetti model records each of the six line depicted in the figure separately. What is to be noted is that connections are note recognized and nor is the crossing over or meeting points or vertices. It looks like a map but without underlying structure. Graphical elements are stored and not the Graphical entities in the spaghetti model.

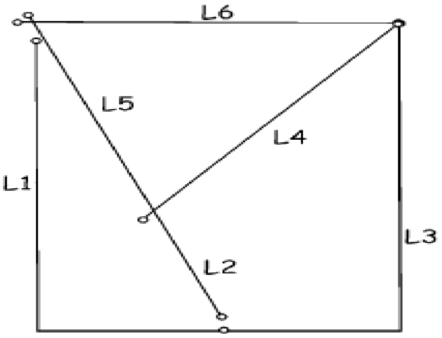



Figure 5: Spaghetti Model with six lines

"The spatial relationships between the features are not retained. In other words it is a collection of points and line segments with no real connection. All the information necessary to draw a map is in place, but is randomly organized ("unlinked"). This makes organization of the data easy, but makes it very difficult to use for analysis".

The spagehetti model does not retain any specific relation.

The positive aspect of the spaghetti model is that it is relatively efficient as a method of cartographic display and used in Computer-Assisted Cartography (CAD) where analysis is not the primary purpose.

### 8.3.1.1. Point Dictionary Model

A marginal improvement over the path topological models (spaghetti model) is the point dictionary model. In this model, both the transformation between numerical coordinates and points is incorporated.

i. All coordinate pairs are numbered sequentially ;

ii. All coordinate pairs are stored in random access allocation.

iii. List of Point ID prepared as the address for accessing the appropriate coordinate.

iv. Each polygon is stored as a circular list of the point ID

Therefore, as depicted in figure 6 , the storage requirements are slightly reduced as x, y pairs are stored only once. However each point ID is still stored twice for common boundaries. "Though, this model saved space in the system but the adjacency problem remained. Thus the point ID values are first retrieved from the polygon list, which in turn are used to retrieve the respective coordinates".

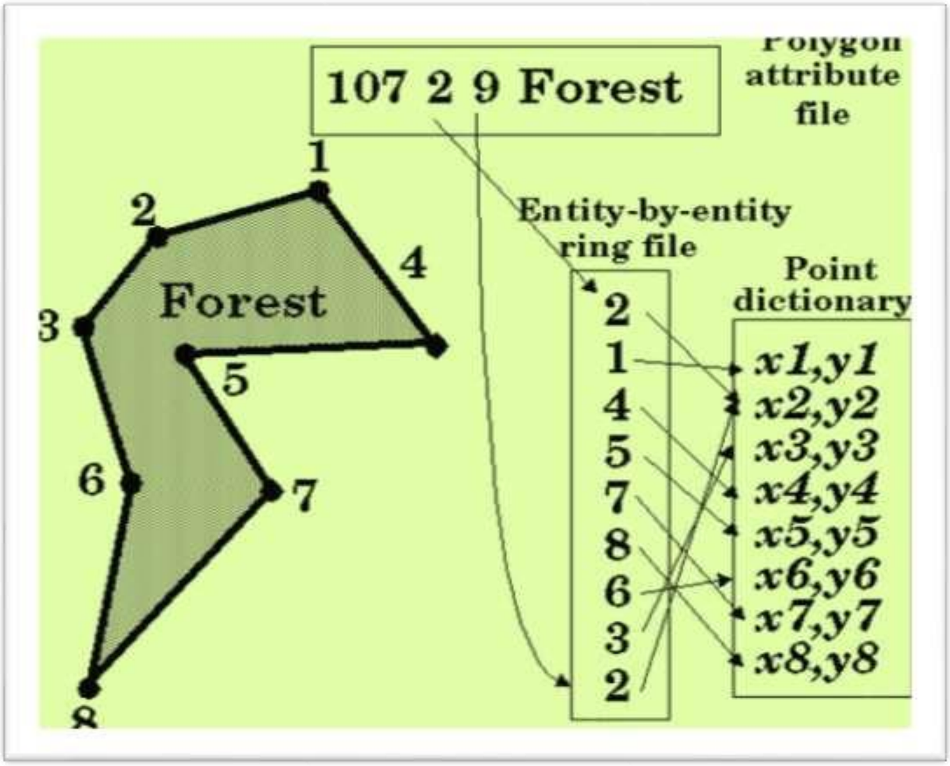



Figure 6: Point Dictionary Model

#### 8.3.1.2. Chain Dictionary Model

Chain Dictionary model is used to reduce and even overcome most of the time ,the adjancy problem. The retrieval of area feature or polygon is a three-step procedure in the chain dictionary model, including:

i. Retrieval of polygon ID,

ii. Retrieval of point ID and

iii. Retrieval of corresponding coordinates.

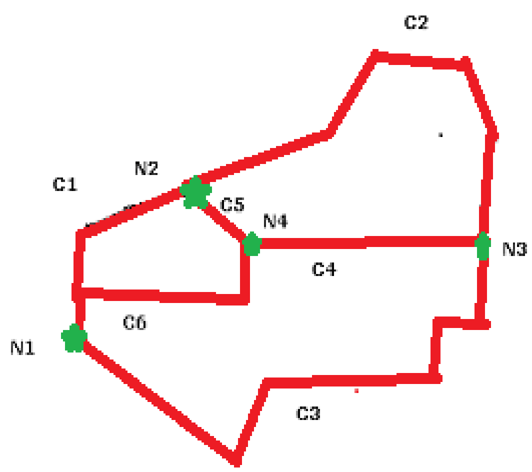



Figure 7: Chain Dictionary Model

In this model the interconnections are between polygons-chains-points where each polygon/area is given a circular list of chains and they are predefined. Each chain is made of number of points and these points are with unique ids and points are noted as a list. Certainly, this model has reduced the space requirement and the access time.

### 8.3.2. Topology model

Unlike Spaghetti model topological model explicitly build relationships. Topology is the term used to describe the making of spatial relationships. In fact, topology adds 'intelligence' to the database in a Geospatial environment by explicitly building linkages and evolving relationships. "Topology is one of the most useful relationships maintained in many spatial databases. It is defined as the mathematics of connectivity or adjacency of points or lines that determines spatial relationships in a GIS. The topological data structure logically determines exactly how and where points and lines connect on a map by means of nodes (topological junctions)" Burrough,1987.

In the process of topology building (relationship), points, lines and areas are calculated and encoded. Topological data define the logical connection between points, lines and areas for geographical description and analysis. Connections between spatial objects, for example, information on areas, which bound a line segment, are considered to be topological data. From this adjacent spatial objects may also be identified. The topology of any line would thus include the starting node, its destination node and the left and right polygons through which the line passes.

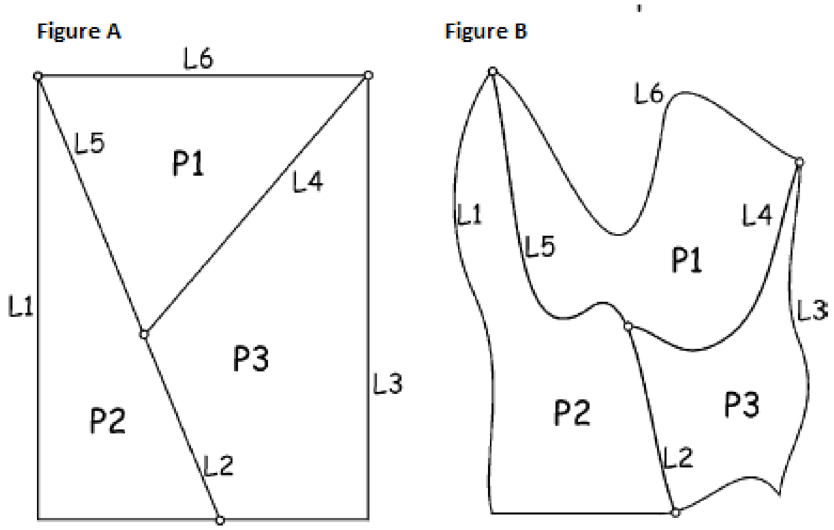



Figure 8: (A) Topological Model & (B) Topological Warped Model

The topological structure permits as shown in figure 8 , encoding of the geometry of the data with no redundancy. The report (2009) notes, “The geometry of the data is encoded with little or no redundancy in arc-node structure. The database can also include attribute data for each node, arc and polygon. These are expanded in the attribute table, which explicitly links it to the geometry of the spatial object. As for example, the three basic topological relationships in ARC/INFO are as :

i. **Connectivity** (arcs connect to each other at nodes and provides information about linkages among spatial features.)

“Arc-node topology, was developed several decades ago as a convenient way to store information of this sort. It is used to encode information used in the US Bureau of Census TIGER boundary files and is the basis of the spatial modeling system used by the Arc/Info software system”.

ii. **Area definition** (Arcs that connect to surround an area define a polygon) “Polygons are defined by a series of x, y coordinates that connect to enclose an area. Systems like GeoMedia store polygons in this format. But Arc/Info stores the arcs defining the polygon. A list of arcs that make up each polygon is stored and used to construct the polygon as and when required”

iii. **Contiguity** (arcs have direction and left and right polygon)”

“Every arc has direction (from node and to node). This direction has been maintained in the list of polygons as on the left and right sides of each arc. Thus any polygons sharing a common arc are adjacent”.

The five “axioms in topology are as follows:

- All arcs end in points or nodes.
- Arcs cannot intersect except at their nodes
- Areas are completely enclosed by arcs.
- Areas do not overlap
- Every location is within some area” GIS Fundamentals,p.3.

Now let us understand the Planar topology (figure 9). All features in planar topology occur in a two dimensional surface. There can be no overlap among lines or polygons in the same layer.These lines are non planar because all lie in the same plane and therefore line crosses over and under line segment. The lines would intersect at node.

Similarly in the case of polygons in a planar surface if and when overlap , they need to be resolved as placed one above the other with nodes located at the intersection of the boundaries. If we look closely at figure 9 we will find the presence of three polygons.

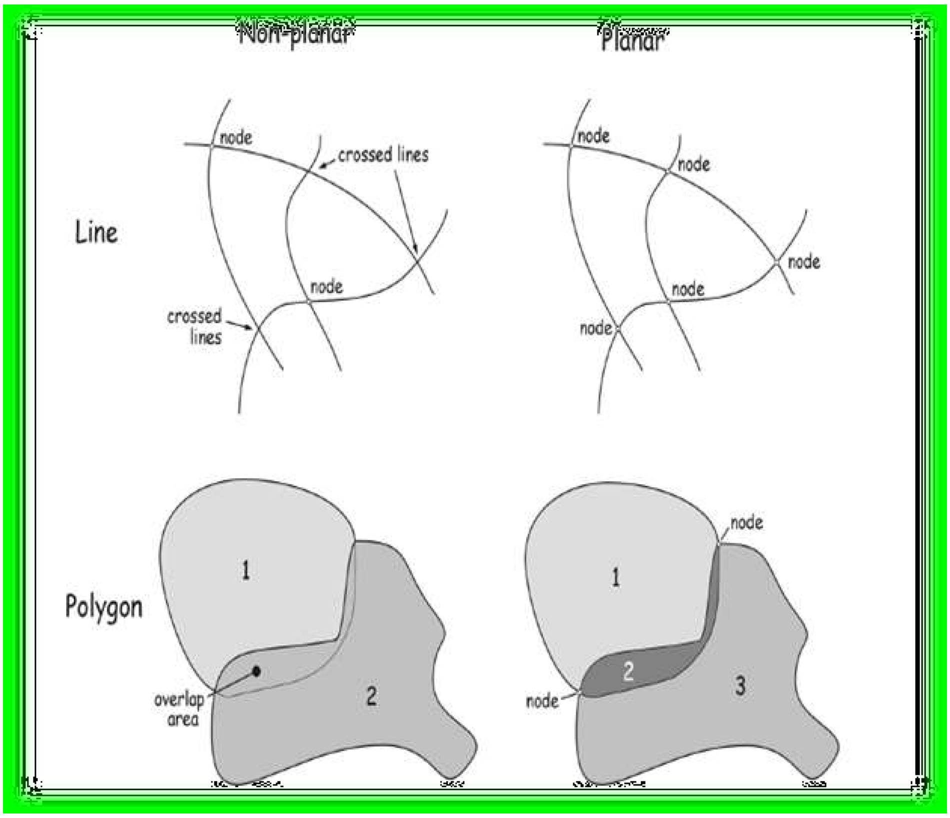



Figure 9: Non planar and Planar topology in Lines and polygons

In other words, topology defines connections between features, identifies adjacent polygons and can define one feature, such as an area as a set of lines. The rule of thumb for topological data structures is that anything of interest on a map must be explicitly defined as a point, line or area in order for systems to perform any sort of spatial analysis on the data. “The geometric characteristics of a spatial entity may be described in terms of its two-dimensional shape, its distance between like or different entities, how it is connected to other entities and what entities occupy the space adjacent to it”. Such characteristics may be easily described either in words or by a system of coordinate grids on a map. Spatial entities can be described in terms of their dimensional characteristics. If these entities were to be changed by some kind of a transformation, all the characteristics of these spatial entities would likewise change. Shape can be made smaller, lines made longer and so on. In other words, there is a fundamental change to the entity itself. If a map is stretched and distorted, some of its properties may change, for example, distance, direction (angles) and relative location of objects. However, other properties such as ‘next to’, ‘is contained in’ and ‘crosses’ remain unchanged. Therefore, a strict topological property is one that remains unchanged by geometric distortions or transformations of the surface. In topology the neighborhood function and adjacency properties are important features. They are important for performing spatial analyses because we need to know the position of the feature both in absolute space and with respect to its neighboring features. Many of the methods of solving mathematical and geometric relationships work better if we know which areas share common boundaries. Some systems store boundaries as several individual line segments and include arc attributes (or pointers), which indicate which polygon falls on each side of the line segment. By storing common boundaries instead of complete polygon boundaries, duplication in digitizing is avoided, as is the problem where two versions of each common boundary do not coincide.

**BOX 1**

**What is mathematical topology?**

“Topology is the branch of mathematics, based on graph theory, which deals with geometric properties and remains unchanged under certain transformation such as bending or stretching. The characteristic of this model is that it explicitly records adjacency information among spatial entities viz. points, lines and polygons. Mathematical topology assumes that geographic features occur on a two-dimensional plane. Through planar enforcement, spatial features can be represented through nodes (0-dimensional cells); edges, sometimes called arcs (one-dimensional cells); or polygons (two-dimensional cells). Because features can exist only on a plane, lines that cross are broken into separate lines that terminate at nodes representing intersections rather than simple vertices. GIS with the aid of topology not only have the power to record location and simple attribute information but also can examine spatial relationships based upon location, as well as functional and logical relationships among geographic features” Notch,1967.

The order of connectivity defines the shape of an arc or polygon. The computer stores this information in various tables of the database structure. By storing information in logical and ordered relationship missing information, e.g., a line segment of a polygon is readily apparent. A GIS manipulates, analyzes, and uses topological data in determining data relationships.

## 8.4. Summary

1. Data compaction or compression is common in GIS and is based on different algorithms that reduce the size of a computer file, but maintains all the information intact.
2. There are generally two types of Compression algorithms where one may be “lossless” (where no information is lost) or “lossy” (where some information is lost).
3. All four types of Data compression techniques in Raster GIS are relevant and they include the methods called as Chain coding; Run length coding; Block coding and Quad trees. Their limitations should be studied keenly before using them.
4. Vector data that have been collected but not structured are said to be spaghetti data model and also called as non-topological or geometric or path topological model. It was originally developed to organize, manipulate and store line data.
5. Unlike Spaghetti model topological model explicitly build relationships. Topology is the term used to describe the making of spatial relationships. In fact, topology adds ‘intelligence’ to the database in a Geospatial environment by explicitly building linkages and evolving relationships between each point, line , polygon and attribute information.

## Terminal Questions:

1. Classify the compaction techniques used in Raster and Vector data models.
2. Comment on the role of topological structures in GIS.
3. Illustrate with three examples from the real world where the statement, ‘Lossy algorithm is largely applied to discrete raster data algorithms’ holds true.
4. Answer the following questions based on the diagrams given below:

a. Name the compaction technique each figure represent.

b. Which of the following figure looks like a map but without underlying structure?

c. Count the number of lines and number of nodes that each figure represents.

5. From the following figure answer the number of blocks that each layer represents.

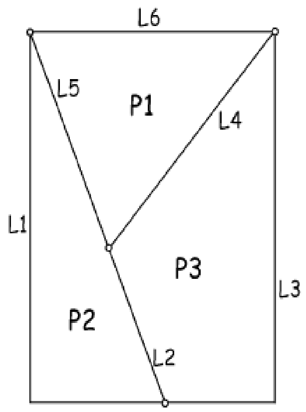



Figure A

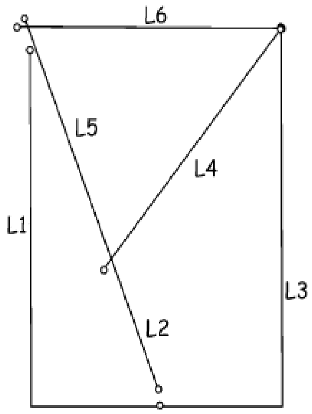



Figure B

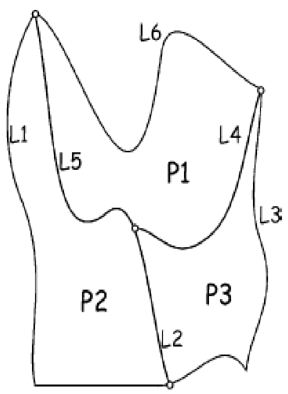



Figure c

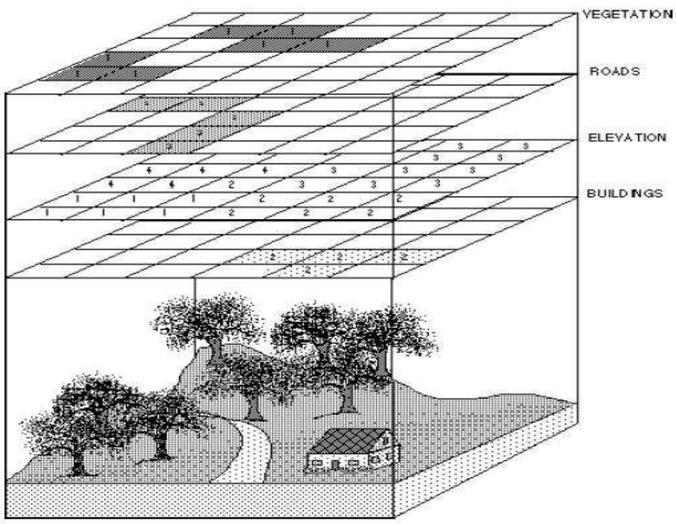



Figure D

i. Building layer

ii. Elevation layer

iii. Roads Layer

iv. Vegetation Layer

# Unit 9: Integration of RS and GIS modelling

**Unit Structure**



## 9.0. Learning objectives

After studying this unit you will be able to explain:

- About integration of remote sensing
- Learners will also know about GIS modelling
- Learners will also know about types of GIS model

## 9.1. Introduction

The well-worn argument that geo-information is a pre-requisite for" development. Most map makers absolve themselves from responsibility for c) "' the poor state of mapping with their territory. As the mapping will take several years to complete, it is clear that the National Survey and Mapping organization has to take initiatives to supply upto date geo- information for the users on their various requirements and expectations.

The integration of satellite data into a Geographic Information System (GIS) is one of the great idea that focus on the rapid acceptance of GIS technology in to the geo-information oriented applications in operational environments. Institutionalizing of the GIS and Remote Sensing process into everyday decision making has greater efficiency to overcome the problems identified in mapping at a National Mapping agency.

Hence, authors identified key issues of integration of Remote Sensing with GIS and the proposed structure perhaps most significant, however, is that the integrated approach leads to a new view of supplying geo- information rather than being static documents to completely recreate at periodic intervals.

## 9.2. Integration of Remote Sensing With GIS

The volume of Remote Sensing is so large, its associated powerful image processing technology is used to manage geo-information with preprocessing analysis, accuracy assessment and information distribution.

GIS are more and more being used for the storage and analysis of geo- referenced data and also it handles the linkages between spatial entities and their discrete attributes. GIS system have become accepted as a standard way of handling geographic data and performing analysis on those data for a number of earth related disciplines- With the availability of high resolution satellite data and its processing technologies. integration of digital image analyzing systems with advance GIS systems permit compositing data sources as well as promoting a partnership between man and machine. Furthermore a GIS when combine with upto date remote sensing data could assist in the automated interpretation. change detection and map revision processes. Satellite: data offer repetitive. Synoptic and accurate information of the earth's r surface and as such offer the potential to monitor the dynamic changes F' with GIS. However one should bear in mind the integration will largely depend on the ability to understand and conceptualize the transition between one representation to another.

## 9.3. Technical Impediments to Integration

Geographic phenomena do not occur with a specific data structure. Obviously certain types of objects are well represented in a raster data structure (eg.. elevation. soil type) while others more appropriately represented as vectors (eg. .boundaries. point information) . .'f Consequently. it can be significant strength for a GIS to incorporate advantages 0: both data types. New commercial systems designed expressly around data 1ntegrat10n are also emerged. However, the full potential of integrate GIS with remote sensing will not be realized unless we overcome the dichotomy of data structures for GIS and remote sensing (Ehlers, 1991) .Data accuracy and system communications are other major issues that discussed under problems related in integration.

### 9.3.1. Data Structures

The major problem is caused by the different in the structures used to acquire and store data. Remote Sensing detectors produce raster digital information directly then the raster processing of these data seems 'natural" .GIS systems typically used the vector data structure.

In a model of geo-information extraction from raster imagery, at lower level processed raster data can be used to extract and manipulate at pattern recognition in middle level. At the highest level with the knowledge based information. Hence at the middle and the highest level the image information can be stored as vectors or objects than gray values. Thus, f;; fac1l1tat1ng the 1ntegrat10n approach. Add1tionally. The data structures that used for computer vision, quad trees and other tessellation are also possible data structures to manipulate remote sensing data (Samet., 1984).

Presently, the common used approach dealing with this problem is data conversion even though the raster to vector conversion leads to a loss of accuracy of information.

### 9.3.2. Data Accuracy

The classification accuracy, mapping accuracy and spatial resolution are main data accuracy problem which have to consider when integrating Remote Sensing data with GIS. The problems of classification accuracy present a major difficulty in the integration. Researchers have been suggested to improve Remote Sensing image classification accuracy by referencing the information already available in GIS's.

A data processing system must assess levels of data accuracy and associate the level with the data it provides. Based on the assessment a user can understand how reliable the data are and determine how being to use them. Different methods are used in

Remote Sensing and GIS's for data accuracy assessment. The method are incompatible with each other. Remote Sensing data analyzing mainly uses the error matrix method which provide global accuracy information while GIS operators use error model which provide more local accuracy information. But up to now no effective approach has been reported which facilitate the flow of accuracy information between Remote Sensing image analysis system and GIS's (Fangin Wang., 1991).

### 9.3.3. System Communication

In the communication between Remote Sensing system and GIS, spatial and non spatial data must be transferred in an integration fashion. Facilitating the communication have been mainly made on query/reasoning languages and communication procedures. This method developed usually include the steps of language conversion, query optimization and data translation. Even so mismatch is unavoidable and the communication is still expensive (Fangin Wang, 1991).

### 9.3.4. Software System Architecture

Software system architecture means this "Organizational Context" within .which all the software modules, programs etc. perform certain tasks and communicate with each other and data stores. It reflects the processes r or group of processes defined in the logical architecture.

The software should be selected which has capability for data capture by manual digitizing or scanning, Remote Sensing data on tape and digital form field survey data. Attribute data should be able to enter from alpha-numeric terminals.

Database management system interface should be capable of providing search/query facility to access graphical display from the database to , satisfy a certain search criteria to display certain map elements and also in the opposite direction to access the database from graphical display to textural attribute information about certain map elements and generate a report about them. Also it should have possibility for editing and utility programs to improve the quality of graphical data. Especially there should be image processing system to process and class1fy Remote Sens1ng data. Software system should be able to give out put in paper plot either as verification plot to check the data quality or precision final plots from graphical output and attribute data in report form. Also it should be possible to output digital map sheet on tape as back-up tapes.

### 9.3.5. Hardware System Architecture

The hardware system should be chosen to match the system capability requirements to perform the task imposed by the logical model and the performance requirements necessary for the software system capabilities.

### 9.3.6. Education and Training

To implement the database model have to give training to persons with necessary and innovative skills to manage the transition from existing analogue to digital technologies and to decide how conventional and new processes can best be integrated to optimally serve user needs.

## 9.4. Modelling

Modelling is a simplified version of a concept. It is a simplified representation of a phenomenon or a complex system into simple and understandable concept of real world. It is a graphical, mathematical, physical, or verbal representation of a concept, phenomenon, relationship, structure, system, or an aspect of the real world. Therefore, it can be said that modelling is a representation of reality in either physical form or symbolic form.

A modeling may have following objectives:

a) To facilitate understanding by eliminating unnecessary components,

b) To aid in decision making by simulating 'what if' scenarios,

c) To explain, control, and predict events on the basis of past observations.

Since most phenomenon are very complicated and much too complex, a model contains only those features that are of primary importance to the model maker's purpose.

## 9.5. General types of Models

### 9.5.1. Structural Model

Structural model focuses on the composition and construction of things. There are two types of structural models:

- **Object Model:** This type of model forms a visual representation of an item. Characteristics include scaled, 2 or 3dimensional, symbolic representation.

For example: an architect's blueprint of a building.

- **Action Model:** It tracks the space/time relationships of items. Characteristics include change detection, transition statistics and animation.

For example: a model train along its track.

### 9.5.2. Relational Model

Relational model focuses on the interdependence and relationships among factors. There are two types of Relational models:

- **Functional Model:** This model is based on Input / Output method. It tracks relationships among variables, such as storm runoff prediction. Characteristics include cause/effect linkages and sensitivity analysis.
- **Conceptual Model:** It is perception-based. It incorporates both fact interpretation and value weights, such as suitability for outdoor recreation. Characteristics include heuristics (expert rules) and scenarios.

## 9.6. GIS Models

It is used in the process of building models with spatial data; it is called as GIS modelling. GIS modelling involves symbolic representation of Vocational properties (Where?), as well as Thematic (What?) and Temporal (When?) attributes describing characteristics and conditions with reference to space and time. There are two types of GIS model:

1) **Cartographic Model:** It is automation of manual techniques, which traditionally use drafting aids and transparent overlays, such as a map identifying locations of productive soils and gentle slopes using binary logic expressed as a geo-query.
2) **Spatial Model:** Spatial model is expression of mathematical relationships among mapped variables, such as a map of crop yield throughout a field based on relative amounts of phosphorous, potassium, nitrogen and ph levels using multi-value logic expressed as variables, parameters and relationships.

   Elements of GIS Modelling: A GIS model must have following elements:

- A set of selected spatial variables

- Functional / mathematical relationship between variables.

A model is related to exploratory data analysis, data visualization and data base management. GIS model can be vector based and raster based.

## 9.7. Types of GIS Model

GIS model can be of following types:

### 9.7.1. Binary Models

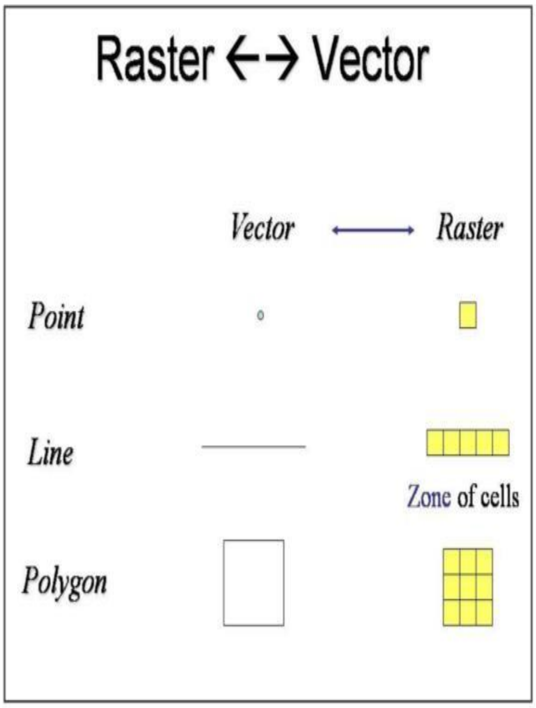
The Binary Model is a probabilistic information retrieval technique that makes some simple assumptions to make the estimation of document/query. A binary model gives a simple yes (1) or no (0) assessment of a location.

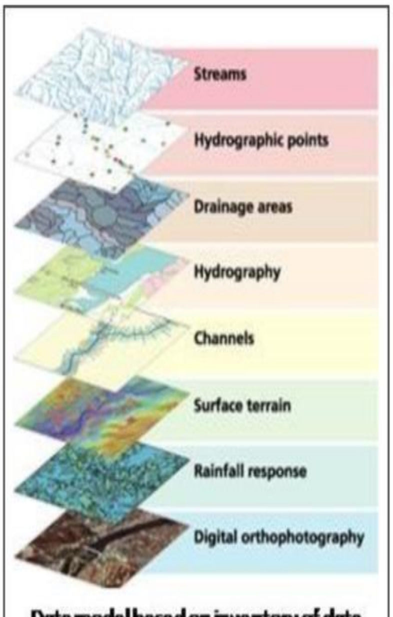
Terms are independently distributed in the set of relevant documents and they are also independently distributed in the set of irrelevant documents.

a document is represented by a vector

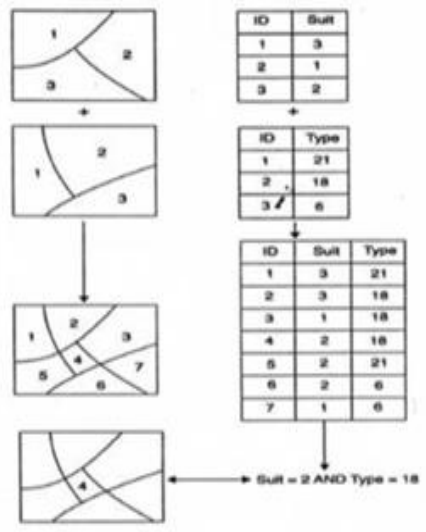
d = (x1, ..., xm)

Where, xt=1 if term t is present in the document d and xt=0 if it's not. Binary model select features from composite maps or from multiple grids that

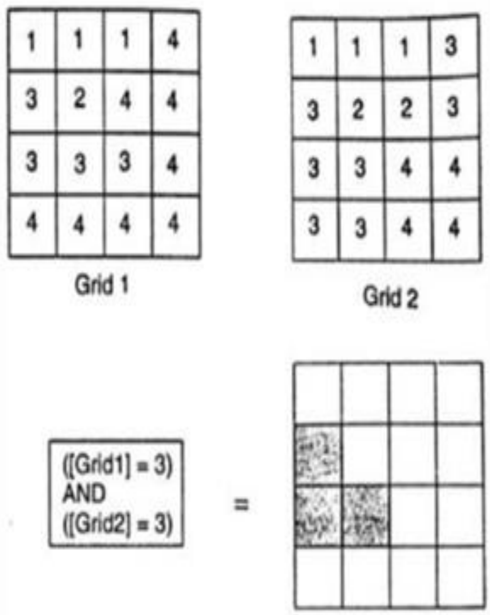



Data model based on inventory of data analysis




An illustration of a vector based Binary (logical) model. The two maps at the top are overlaid so that their spatial features and their attributes of Suit and Type are combined. A logical expression, Suite = 2 AND Type = 18, results in the selection of polygon4 in the output.




An illustration of a raster based binary (logical) model. A query statement, ([Grid 1] =3 AND ([Grid 2] = 3), results in the selection of 3 cells in the output.

### 9.7.2. Index Models (Weight-rating Score Models)

In Index model, standardized values are assigned to spatial elements of each layer. Then a rank map is produced by using index value calculated from a composite map or multiple grids. The index value of a polygon/cell =

$$\sum_{i=1}^{n} w_i \int i$$

Where, $wi$ = weight of factor i and $\int i$ = rating factor of i

It can also be written in this form = (weight1 x score A1) + weight2 x score A2) + .....

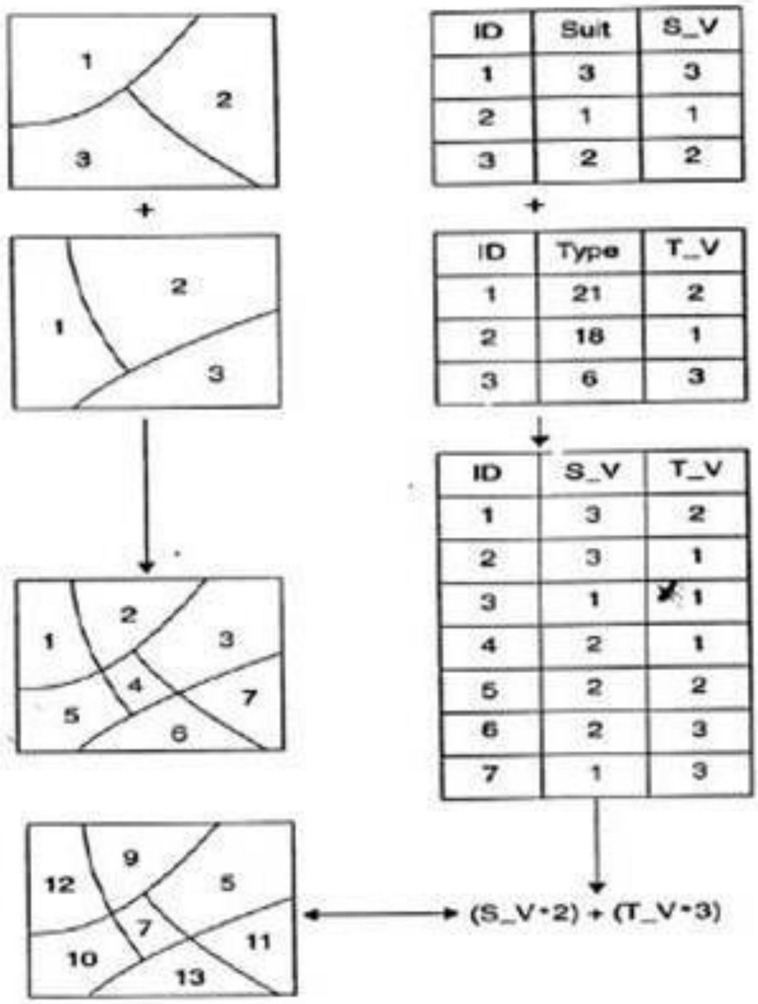
For Index Models following steps are needed:

a) Assign weight to each variable (w).

b) Assign and standardize scores to each class of each variable (data layer)

c) Index value calculation

d) Ranking index values of each polygon/cell.




**An Illustration of a vector based index model.**

**First the observed values of each map are given the numeric scores from 1 to 3. The Suit values of 1,2 and 3 are given the scores of 1,2, 1nd 3 respectively. The type values of 6, 18 and 21 are given the scores of 3, 1 and 2 respectively. Second the two maps are overlaid. Third, a weight of 2 is assigned to the map with Suit and weight of 3 to the map with Type. Finally, the index values are calculated for each polygon in the output. For example, Polygon 4 has an index value of 7 (2*2+1*3)**

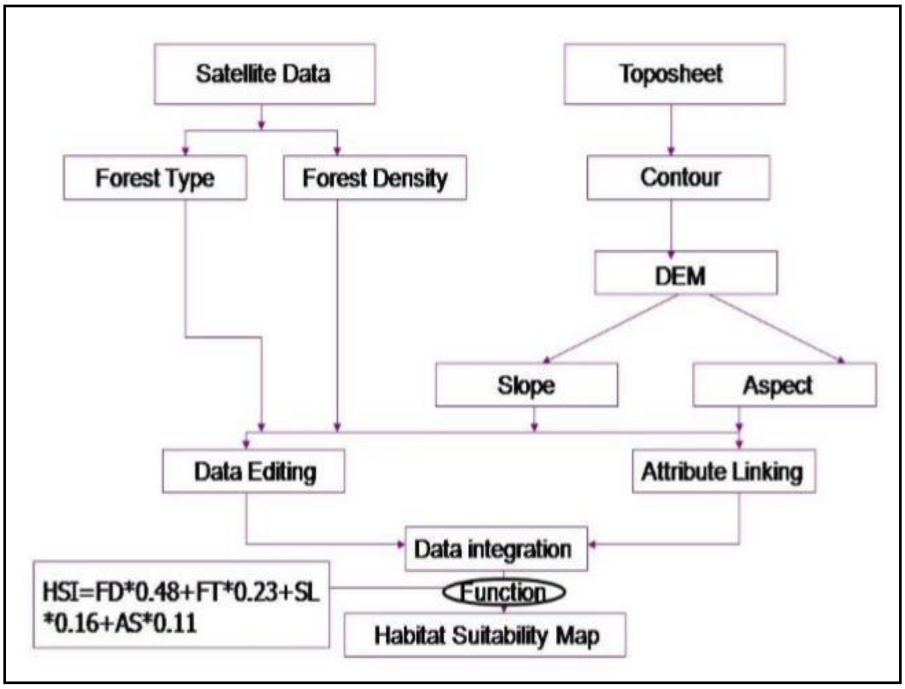
### 9.7.2.1. Examples of Index Modelling

Use of Analytical Hierarchy Process (AHP) along with Remote Sensing GIS for modelling Habitat Suitability Index (HIS)

**Database Creation:** Identification of factors that influence the spatial distribution of animal species is important for habitat suitability index. Therefore, literatures survey on factors influencing tigers' distribution, data from field surveys and suggestions from conservation experts were considered as input data for modelling. Vegetation types, forest density, slope and aspect were selected as variables for developing habitat suitability model. Factors like Forest Types, Forest Density, Aspects and Slope were obtained after analysis of remote sensing imagery in GIS domain.

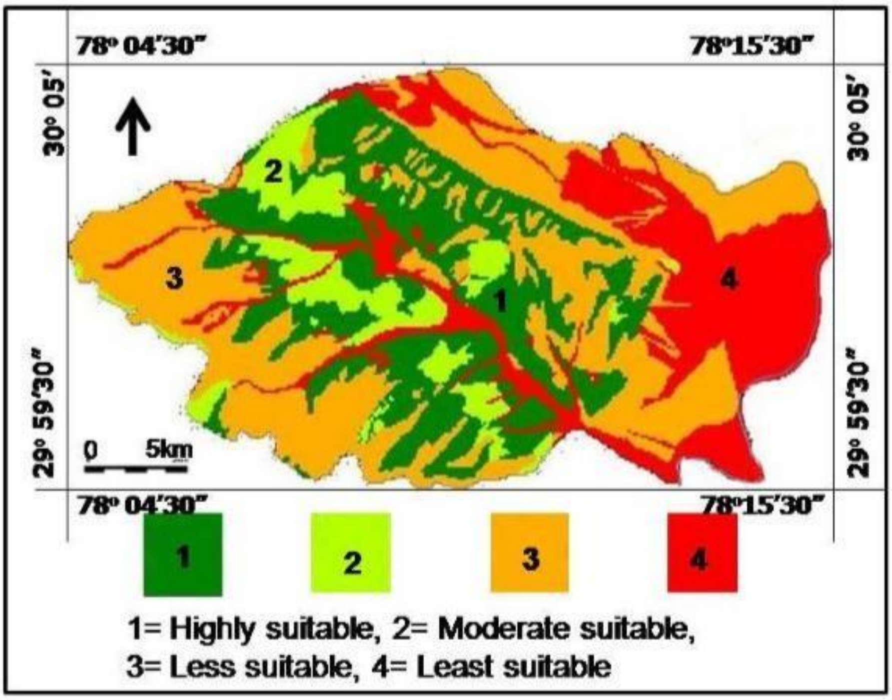
Topographic maps of study area (scale 1:50,000) were scanned and transferred to ERDAS IMAGINE 8.7 for rectification. From topographic sheets, on screen digitization's of contours (of 30 m interval) were done for generating the digital elevation model (DEM). Further, DEM was used to generate Slope and Aspect maps. Vector files of Forest Type and Forest Density maps of study area were extracted from IRS-1D-LISSIII of 2002 imageries and after rectification; these were transferred to ArcView 3.2 for onscreen digitisation. In the present study Forest Type was categories into four classes of Sal forest, Sal mixed forest, mixed forest and Scrub & grassland and accordingly attributes were allotted. Forest Density was categories into four classes of >70%, 40-70%, 10-40% and 0-10% and subsequently attributes were allotted accordingly. After preparation of map layers of Forest Types, Forest Density, Aspect and Slope, weight allotment procedure was carried out with the help of specialist and field visit experience.

**Identification of weights of factors:** In the process of habitat evaluation, identification of relative weights among factors is a primary step. The analytic hierarchy process (AHP) is a decision- making method, which was first derived by Saaty in 1977. It is a combination of quantitative and qualitative processes dealing with complex technological, economical, and socio-political problems. For the advance of providing methodology frame and reducing uncertainty, AHP is widely used in environmental evaluation and regional sustainable management. In this, numerical values are assigned to judge relative importance of each factor. In the construction of pair-wise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell. In the process of AHP, the prime task of calculation is the eigenvector corresponding to the largest Eigen value of the matrix. Each element in the eigenvector indicates the relative priority of corresponding factor, i.e. if a factor is preferred to another; its eigenvector component is larger than that of the other. A sum/product method is used to obtain the Eigen value and the subsequent eigenvector. The weights finally derived by AHP are used for developing the HSI model.




HSI was calculated as the sum of habitat suitability factors multiplied by corresponding weights determined by AHP. Each reclassified raster layer corresponding to the factors selected, were combined by Raster Calculator function in ArcView to generate the spatial distribution map of HSI. The HSI values in the grid cells are a series of continuous values. To visualize distribution of different levels of habitat suitability index and to facilitate the process of understanding, these values are classified into different classes of highly suitable, moderately suitable, less suitable and least suitable.

**Regression Models:** Regression analysis refers to techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps us to understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed.




Regression models are of following types:

(1) **Linear Regression:** A spatial regression model can then be used for decision-making. For example, it can answer where suitable locations for police stations are? Spatial regression models are also used to predict future crime locations and even in other cities.

Some of the terminology in regression models:

- Dependent variable (y): What are we trying to predict. (Location of crimes)
- Independent variable (x): Explanatory variables that explain the dependent variable. (Income, education, etc.)
- Beta-coefficient: Weights reflecting the relationship between the explanatory and dependent variable.
- Residual: The value not explained by the model

## Regression Formula:

$$y = \beta_0 + (\beta_1 \text{ x } x_1) + (\beta_2 \text{ x } x_2) + \ldots.. + (\beta_n \text{ x } x_n) + \varepsilon$$

Development of Habitat Suitability Index (H.S.I.) is an example of Regression model. It gives an idea about the capacity of a given habitat to support a selected species.

(2) **Logistic Regression:** Logistic regression is a form of regression which is used when the dependent is a dichotomy and the independents are continuous variables, categorical variables, or both and computer software uses following formula for analyzing the probability:

$$In\ (\mathrm{ODDS}) = \left(\frac{Y}{1-Y}\right) = \mathrm{a} + \mathrm{bx}$$

Where, $Y$ is the predicted probability of the event which is coded with

1 (presence) rather than with 0 (Absence), 1-$Y$ is the predicted probability of the other decision, and x is predictor variable.

The logistic regression is used to develop Habitat Suitability Index (H.S.I.) for wild animal also. Here an example is taken to show the use of logistic regression in developing H.S.I for Gaur (a wild animal).

**Steps to develop H.S.I. model using logistic regression**

• Field visits for collecting data on wild animas' presence/absence. GPS locations of direct or indirect evidences (hoof mark and feeding evidence) of wild animals were marked on FCC. Wherever any direct or indirect evidences of a particular species were found, it was recorded 'presence' for that particular species only and for other species 'absence' was marked. While conducting the field visits ground truthing was also done.

• Create input data base layers of dependent and independent variables. Landuse land cover map, forest crown density map, distance from settlement, road and drainage, elevation, aspect and fragmentation index were taken as variables. These variables were developed after analysing collateral data and satellite imageries of the study area.

• Co-registration of all input layers upto sub-pixel accuracy level.

• After preparation of layer maps, modelling process for H.S.I. for gaur was started. GPS locations of gaurs' presence/absence obtained from the field survey were transferred into ArcView 3.2 and were attached as attributes to all the locations.

• All the independent variables were transferred into raster themes and used for further analysis.

• The points of animal detection were then 'intersected' with all the input layers to produce the habitat use-environmental variables matrix. This worksheet was employed for further statistical analysis. Here, cases of animal sightings were taken as 'Boolean' (presence/absence).

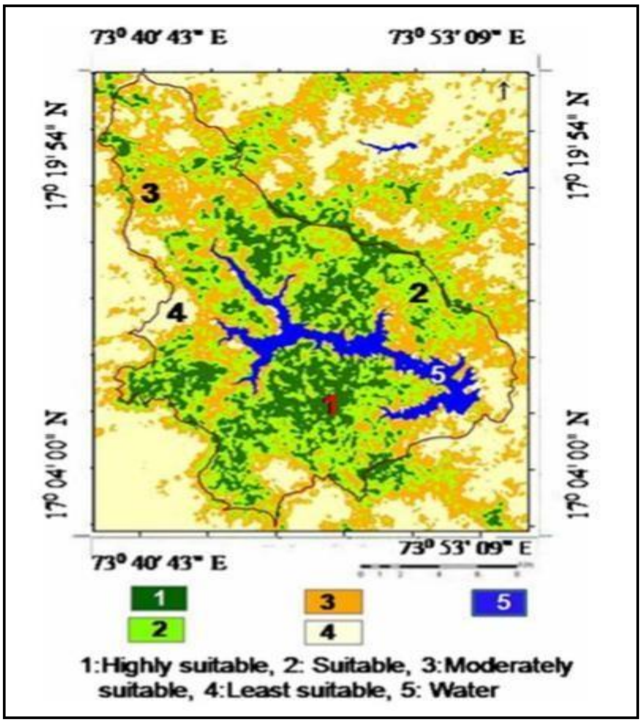
- Logistic regression was run for H.S.I. modelling.
- The coefficients derived from logistic regression were used as weight for variables to integrate all layers in GIS domain to arrive at the probability/suitability map.

$$\text{HSI}= \left[\frac{\{\exp(FT*C)+(FD*C)+(EL*C)+(AS*C)+(RD*C)+(DD*C)+(SD*C)+(FI*C)+(\text{Constant})\}}{\{1+(\exp(FT*C)+(FD*C)+(EL*C)+(AS*C)+(RD*C)+(DD*C)+(SD*C)+(FI*C)+(\text{Constant}))\}}\right]$$

Where, exp = Exponential, DD=distance from drainage, DS=distance from settlement, FD=forest, EL=Elevation, DD=Drainage distance, RD=Road distance, SD=Settlement distance, AS=Aspect, FI=Fragmentation index, C=Coefficient value.

- The estimated log-odds image was then logit transformed to produce the intended probability map. As the log-transform squashed lower values and exaggerates higher values, the classification accuracies had been calculated at cut-off of 0.5. The output map was sliced to 'not suitable' at value lower than 0.5 and 'suitable' at values higher than that.

- Suitability map was further categorized into four classes of 'highly suitable', 'suitable', 'moderately suitable' and 'least suitable'.




**Process Models**

Next generation of geographic information systems will be driven by process models. These are usually composed of algorithms and heuristics (problem solving technique by trial and error method) that will act on users' requests for the GIS to perform some service for them. For this, it is connected to digital networks to contextualize those requests, and interact seamlessly with other databases and processes to achieve users' goals. Process models are used for following main purposes:

**Estimation:**

The goal of estimation is to determine the value of the regression function for a particular combination of the values of the predictor variables. Regression function values can be estimated for any combination of predictor variable values, including values for which no data have been measured or observed. Function values estimated for points within the observed space of predictor variable values are sometimes called interpolations. Estimation of regression function values for points outside the observed space of predictor variable values, called extrapolations.

**Prediction:**

The goal of prediction is to determine value of a new observation of the response variable. It also determines values (of a specified proportion) of all future observations of the response variable. Predictions can be made for any combination of predictor variable values, including values for which no data have been observed.

**Calibration:**

The goal of calibration is to quantitatively relate measurements made using one measurement system to those of another measurement system. This is done so that measurements can be compared in common units or to tie results from a relative measurement method to absolute unit.

**Optimization:**

Optimization is performed to determine the values of process inputs that should be used to obtain the desired process output. Typical optimization goals might be to maximize the yield of a process, to minimize the processing time required to fabricate a product.

**Example of Process Models: Soil & Water Assessment Tool (SWAT):**

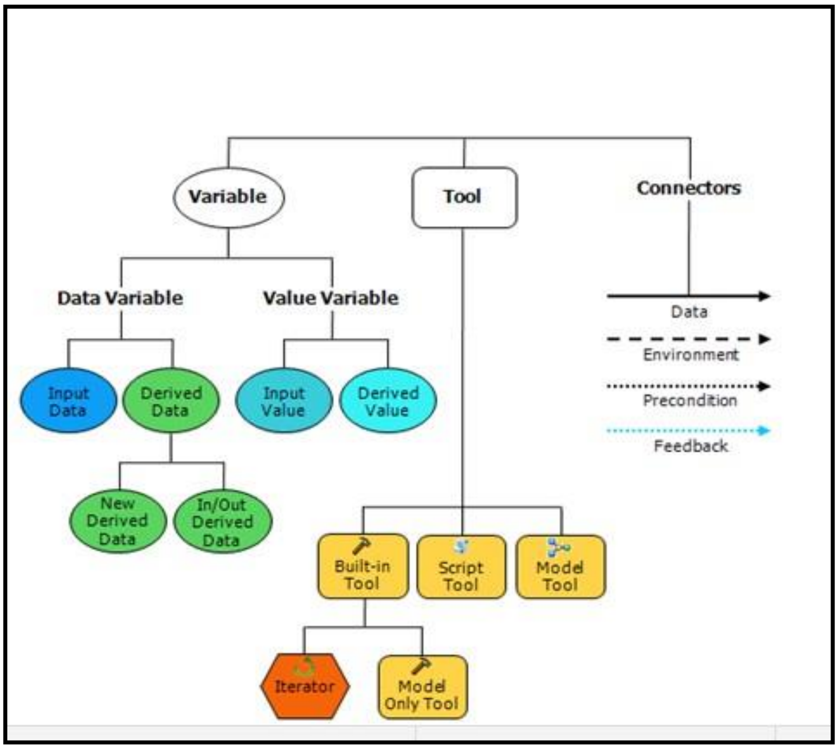
The Soil and Water Assessment Tool (SWAT) is a spatially referenced watershed model used to simulate the impacts of land use, land management, and climate on water quantity. This graphic applying SWAT models. The SWAT requires following information as input files and provides results in the form of output files as mentioned below.

**Inputs:** Inputs are Land management practice such as Crop rotation, irrigation, fertilizer use, pesticide application rates, and physical characteristics of the basin & sub basin (precipitation, temperature, soil, vegetation & topography).

**Output:** A number of output files are generated by SWAT. These files can be grouped by the type of data stored in the file. There are four output files generated in every SWAT simulation. These files are the standard output file (.std), the Hydrologic Response Units (HRU) output file (.sbs), the sub-basin output file (bsb), and the main channel or reach output file (.rch). Other files that may be generated include pesticide summary file (.pso), Stream Water Quality Summary File (.wqo), Reservoir Summary File (.rsv), Lake Water Quality Summary File (.lqo). Output data provides simulated values of surface water flow, ground water flow, crop growth, sediment & chemical yields.

## 9.8. Modelling in ArcMap

A model contains only three things; Elements, Connectors and Text label.

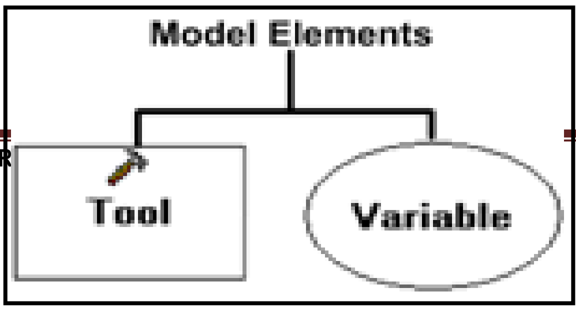



**Elements**

Elements are the data and tools with whom we work. There are two types of model elements:

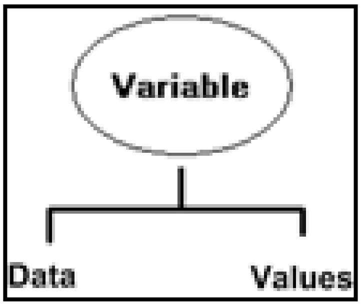
a) Tools and

b) Variables, shown here in an organizational chart:



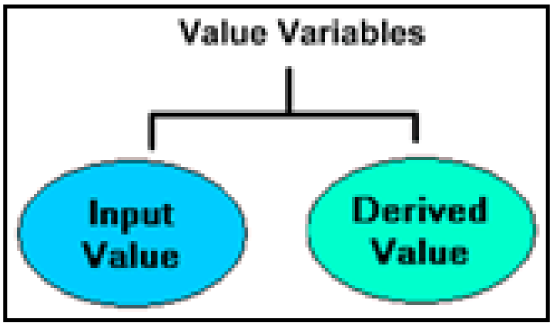
**Tools:** Tool elements are represented with rectangles and are created when we add a tool from Arc Toolbox.

**Variables:** Variables are represented with ovals. It holds values that can be changed. There are two types of variables




**Data Variables:** It reference data on disk or in an in-memory layer (such as a layer in the ArcMap table of contents).

**Values:** Values are everything else such as numbers, strings, spatial references, and geographic extents. There are two types of value variables: Input value and Derived value.




**Connectors**

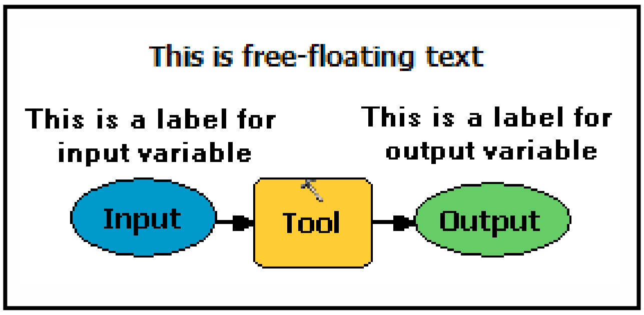
Connectors connect data and values to tools. The connector arrows show the direction of processing. There are four types of connectors:

- **Data:** Data connectors connect data and value variables to tools.
- **Environment:** Environment connectors connect a variable containing an environment setting (data or value) to a tool. When the tool is executed, it will use the environment setting.
- **Precondition:** Precondition connectors connect a variable to a tool. The tool will execute only after the contents of the precondition variable are created.

• **Feedback:** Feedback connectors connect the output of a tool back into the same tool as input.

**Text Labels**

In addition to the variable, tool, and connector model elements, there are text label elements, which are graphic elements for explanatory text in a model. A label is not part of the processing sequence. Labels can be attached to elements or float freely in the model diagram.




## Conclusion

Integration of Remote Sensing and GIS technologies will significantly promoted the ability to handle geo-information. It is possible to obtain 1 high benefits in producing and updating maps with proposed system. It has facilities to do repetitive task without complaining, sort things fast, draw and store points, lines or area fastly and retrieving of geo- information rapidly. Thus the new system leads to geo-information which, are accurate and reliable in rather short time for decision making. But sometimes it takes the same time to do a job the first time whether using a computer or by hand. The difference is on the second or third time around, repeating the process with only a few changes to make a new map.

**(A) Frequently Asked Questions-**

**Q1**. Define modeling in GIS?

Ans: Modelling is a simplified representation of a phenomenon or a complex system into simple and understandable concept of real world. It is a graphical, mathematical, physical, or verbal representation of a concept, phenomenon, relationship, structure, system, or an aspect of the real world. In other word, we can say that Modelling is a simplified version of a concept. It can also be said that modelling is a representation of reality in either physical form or symbolic form.

**Q2.** What are the different Elements of GIS modelling?

Ans: A model is related to exploratory data analysis, data visualization and data base management. A GIS model can be vector based and raster based, however, it must have following elements:

a) A set of selected spatial variables

b) Functional / mathematical relationship between variables.

**Q3.** Illustrate Process Model with an example of Soil & Water Assessment Tool (SWAT)?

Ans: The Soil and Water Assessment Tool (SWAT) is a suitable example of process model. SWAT is a spatially referenced watershed model used to simulate the impacts of land use, land management, and climate on water quantity. This graphic, illustrates the general processes associated with developing and applying SWAT models. The SWAT requires following information as input files and provides results in the form of output files as mentioned below:

**Q4.** What are the objectives a model may have?

Ans: A model contains only those features that are of primary importance to the model maker's. Therefore, a model must has following objectives:

a) To facilitate understanding by eliminating unnecessary components,

b) To aid in decision making by simulating 'what if' scenarios,

c) To explain, control, and predict events on the basis of past observations.

**Q5**. Describe Regression Models?

Ans: Regression analysis refers to techniques for modeling and analyzing several

variable and one or more independent variables. More specifically, regression analysis helps us to understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Linear Regression, Logistic Regression and Process Models are the examples of regression model.

**(B) Multiple Choice Questions-**

**1.** Which of the following components are found in a regression model

a) Independent variables

b) Dependent variables

c) Both a and b

d) None of the above

Ans: c

**2.** A process model fulfils which of the following purpose (s)

a) Estimation

b) Prediction

c) Optimization

d) All of the above

Ans: d

**3.** In the process of Analytical Hierarchy Process (AHP) which of the following statement(s) is/are NOT true

a) If a factor is preferred to another, its eigenvector component is larger than that of the other

b) A sum/product method is used to obtain the Eigen value and the subsequent eigenvector

c) In the construction of pair-wise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell.

d) None of the above

Ans: d

**4.** When Geographical Information System (GIS) is used in the process of building models with spatial data, it involves symbolic representation of

a) Locational attribute (Where?)

b) Thematic attribute (What?)

c) Temporal attribute (When?)

d) All of the above

Ans: d

**5.** Which of the following statement is NOT true

a) Modelling is a simplified representation of a phenomenon into simple and understandable concept of real world.

b) It is a graphical, mathematical, physical, or verbal representation of a phenomenon.

c) Modelling is a complex version of a concept.

d) Modelling is a representation of reality in either physical form or symbolic form.

Ans: c

**Suggested Readings:**

1. Goodchild, M. F. (2003). Geographic Information Science and Systems for Environmental Management. Annual Review of Environment and Resources, Vol. 28: pp. 493-519.

2. Granger, K. J. (1990). Process modelling and Geographic Information Systems: Breathing life into spatial analysis. Mathematics and Computers in Simulation, Vol. 32(1): pp. 243-247.

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# Unit 10: Resource Mapping I: Land Resources

**Unit Structure**



## 10.0 Learning objectives

After studying this unit you will be able to explain:

- It will encompass the requirements and problems associated with land resources.
- It will identify the different areas where geospatial technology can contribute.
- It will explore and discuss various applications of Remote Sensing and GIS in land management.

At the end of this module, the learner would know about the importance, methodology and how the management of the land resources can be made easy by RS/GIS technology.

## 10.1 Land resources

Land includes al1 the natural environmental resources contained on the earth's surface like soil, terrain, water, climate and weather. Human welfare and socioeconomic development depend on the capability of the land resources to provide food, fuel, timber, fiber and other raw materials, many other products of plants and animals as well as shelter and recreation. Pressures on land is everywhere and the need to achieve a balance between the exploitation and conservation of the land resources have made rational resources use and management at all levels (world, regional, sub-national and local) a vital issue. Global and regional institutions as well as individual countries also need to look at the present and future requirements for produce and goods from the available land resources and how to satisfy these requirements considering them against the possibilities and constraints of a sustainable production from these resources. Land resource management is linked to the sustainable development.

Land resource consists of soil, forests, crops, livestock, etc., the land component of the earth's hydrologic cycle (snow cover, soil moisture and associated runoff, underground water) and mineral resources. Most of these land resources are used for production of food, fodder, fuel wood, fiber and for making improvements in productivity of land. Some of the basic land resources information needs are on soil characteristics; slope and degree of roughness; surface and groundwater availability; present land cover and use characteristics; biological conditions, such as disease and insect infestations of crops, grass land and forest land; urban development, etc. The geospatial technology like RS/GIS/ Global Positioning System(GPS) are having various applications in land suitability and productivity assessment; land use planning, land degradation assessment, quantification of land resources constraints; land management, agricultural technology transfer, agricultural inputs recommendations, farming systems analysis and development; environmental impact assessment; monitoring land resources development; agro-ecological characterization for research planning; agro-economic zoning for land development and nature conservation and ecosystem research and management etc. It also provides information about the land use/land cover classification, soil classification, land capability classification, soil slope and relief features, which are used for the resources management and regional planning.

## 10.2 Concept of Resource mapping

Remote sensing uses devices known as sensors that can measure and record the electromagnetic energy. Active sensors such as radar and laser have their own source of energy and can emit a controlled beam of energy to the surface and can measure the amount of reflected energy. These sensors are used to measure the time delay between the emission and return and can determine the location, height, speed and direction of an object under investigation. As active sensors can emit their own controlled signals, they can be operated both day and night, regardless of the energy available from external sources. Passive sensors, on the contrary, can only work using the natural sources of energy. As a result, most passive sensors use the sun as a source of energy and can only work during daytime. However, passive sensors that measure the longer wavelengths related to the earth's temperature does not depend on the external source of illumination and can be operated at any time.

## 10.2.1. Methods in Remote Sensing

a) **Remote sensing image data:** Data can be used from different satellites such as Land Remote-Sensing Satellite (LANDSAT) (spatial resolution 30m), LISS III (spatial resolution 23.5m) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data (spatial resolution 15m). These images provided suitable cloud-free spatial coverage with relatively high spatial and spectral resolutions.

b) **Geometric correction:** Accurate registration of multispectral remote sensing data is essential for analyzing land use and land cover conditions of a particular geographic location. The geometric correction of remote sensing data is done for the distortions and degradations caused by the errors due to variation in altitude, velocity of the sensor platform, variations in scan speed and in the sweep of the sensor's field of view, earth curvature and relief displacement. The images are georeferenced using the polyconic projections with Root Mean Square Error (RMS) and LANDSAT-7 ETM+ data are reprojected to polyconic projections.

c) **Ground reference data:** In image analysis, ground reference data play important roles to determine information classes, interpret decisions, and assess the accuracies of the results. Substantial reference data and a thorough knowledge of the geographic area are required at this stage.

d) **Classification scheme:** Classification schemes provide frameworks for organizing and categorizing information that can be extracted from image data. A proper classification scheme includes classes that are both important to the study and discernible from the data on hand. Image enhancement, contrast stretching and false color composites are worked out and the interpretation of images are carried out using the various interpretation keys like the shape, size, pattern, tone, texture, shadows, location, association and resolution.

e) **Image Classification Techniques:** The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes. Classes have to be distinguished in an image and classification needs to have different spectral characteristics. This can be analyzed by comparing spectral reflectance curves. Image classification gives results to a certain level of reliability. The principle of image classification is that a pixel is assigned to a class based on its feature vector by comparing it to predefined clusters in the feature space. Doing so for all image pixels result in a classified image.

f) **Unsupervised Classification**: The unsupervised classification approach is an automated classification method that creates a thematic raster layer from a remotely sensed image by letting the software identifies statistical patterns in the data without using any ground truth data.

g) **Supervised Classification**: Here the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptions of various land cover types present in the image. Training samples that describe the typical spectral pattern of land cover classes are defined. Pixels in the image are compared numerically to the training samples and are labeled to land cover classes that have similar characteristics.

h) **Fuzzy supervised classification approach:** This approach allows for multiple and partial class memberships at the level of individual pixels and accommodate fuzziness in all three stages of a supervised classification of remotely sensed imagery. This approach considers that each pixel might belong to several different classes without definite boundaries.

i) **Accuracy assessment:** In thematic mapping from remotely sensed data, the term accuracy is used typically to express the degree of ‘correctness’ of a map or classification. A thematic map derived with a classification may be considered accurate if it provides an unbiased representation of the land cover of the region it portrays. In essence, therefore, classification accuracy is typically taken to mean the degree to which the derived image classification agrees with reality or conforms to the ‘truth’. A set of reference pixels representing geographic points on the classified image is required for the accuracy assessment. Randomly selected reference pixels lessen or eliminate the possibility of bias. A random stratified sampling method was used to prepare the ground reference data. This sampling method allocates the sample size for each land use based on its spatial extent.

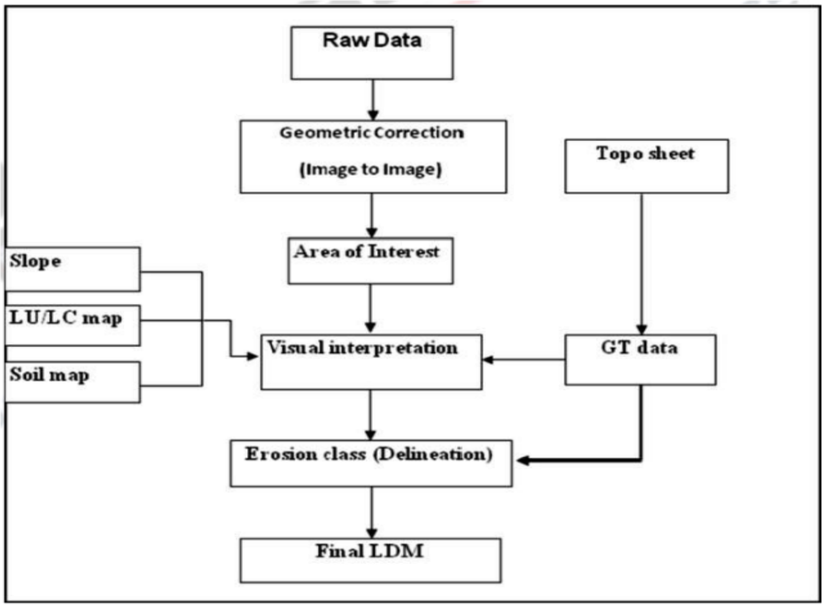


**Figure: Flow diagram of generation of Land Resources Map (Adopted and modified from Tagore et al., 2012).**

j) **Land Use Classification System:** Different classes of Land use- covers like Settlements, Forests, Agriculture, waste land etc. classified. By comparing the data of two different time interval the rate of increase, decrease and percent change can be estimated for each land use class. The map and data base generated from the technique itself has wide application like land use planning, flood management etc.

k) **Land Use Mapping and Distribution:** A supervised maximum likelihood classification may be implemented for the two images and the final classification products provide an overview of the major land use / land cover features of lands for two time intervals and classifications like Water Body, Forest Reserve, Built up Area Vegetation and Farmland etc. can be done.

## 10.2.2. Land Information System

An increasingly useful application of GIS is the development of Land Information System, which provides upto date records of land tenure, land values, landuse, ownership details etc. in both textural and graphic formats. In such a system, the land parcel (survey boundary) is the principal unit around which the collection, storage and retrieval of information operate. The information contained in a cadastral system makes it possible to identify the extent and level of development and management of land (assuming the quality of information in the cadasters is adequate) to make effective plans for the future.

With the availability of high-resolution data from state - of - art satellite like IRS-1C and proposed satellites like Cartosat with 2m resolution, the satellite data with integration of cadastral boundaries help in generating information in greater details and facilitate updating of existing records. They also serve as useful inputs in prioritizing implementation of area development plans and effective monitoring.

Concern about the rapid degradation of many renewable natural resources have led to wide range of application of satellite remote sensing and GIS technology. It was realized that satellites, by their repetitive scanning can detect trend of resource status over a period and are particularly well suited to observe dynamic factors that change rapidly such as vegetation, moisture, water, etc. There are some diverse fields in which remote sensing and GIS technology are used for natural resource assessment: In India, LANDSAT map at 1:1 million scale (MSS false color data) were replaced by IRS-1A data at a scale of 1:250000. Land use/cover Change detection is very essential for better understanding of landscape dynamic during a known period of time having sustainable management. Soil resource mapping of India was initiated in 1986 using a 3-tier approach comprising image interpretation; field mapping and laboratory analysis and cartography and printing. One hundred seventy six false colour composites (FCC‟s) imagery of LANDSAT MSS and IRS 1B data on 1:250,000 scale were interpreted visually to prepare pre-field physiography cum photomorphic maps considering, geology, terrain, environmental conditions, landscape elements and image characteristics.For the purpose of consistently and repeatedly monitor forests over larger areas, it is preferable to use remote sensing data and automated image analysis techniques. Several types of remote sensing data, including aerial photography, multi-spectral scanner (MSS), radar (Radio Detection and Ranging), Lidar (Light Detection and Ranging) laser and Videography data have been used by forest agencies to detect, identify, classify, evaluate and measure various forest cover types and their changes.Earth Observation Satellite (EOS) data has been extensively used to map surface water bodies, monitor their spread and estimate the volume of water. The SWIR band of AWIFS sensor in IRS-P6 was found to be useful in better discrimination of snow and cloud, besides delineating the transition and patch in snow covered areas. Snow-melt runoff forecasts are being made using IRS WiFS/AWiFS and NOAA/AVHRR data. These forecasts enable better planning of water resources by the respective water management boards.In India, satellite data is widely used to study many aspects of coastal zone. During last thirty years, availability of remote sensing data has ensured synoptic and repetitive coverage for the entire Earth. This information has been extremely useful in generation of spatial information on coastal environment at various scales and with reasonable classification and control accuracy. In India, coastal wetland, land use and landform and shoreline-change maps have been produced on 1:250,000, 1:50,000 and 1:25,000 scale using IRS LISS I, II and III, LANDSAT MSS/TM and SPOT data (Nayak, 2002). IV. REMOTE SENSING AND GISFOR NATURAL RESOURCE MANAGEMENT Natural Resources Management System (NNRMS) is a national level inter-agency system for integrated natural resources in country. NNRMS is established in 1983 and is supported by Planning Commission, Government of India. NNRMS supports the optimal utilization of country's natural resources by providing for a proper and systematic inventory of natural resources available using remote sensing data in conjunction with conventional data/techniques. In doing so, NNRMS adopts various advanced technologies of satellite and aerial remote 155 | P a g e sensing; Geographical Information Systems (GIS); precise Positioning Systems; database and networking infrastructure and advanced ground-based survey techniques. The NNRMS activities have been restructured in the recent times to reflect the changing technological and applications dimensions in the country and elsewhere. Accordingly, a 3-tier strategy is being considered with the following direction:  Organizing the spatial databases with GIS capabilities and working towards a Natural Resources Repository with front-end NNRMS portal for data and value added services Taking cognizance of the convergent technologies, integrating satellite communications and remote sensing applications for disaster management and Village Resource Centers with the concept of working with the community User funded projects meeting the objectives/goals of the user departments/agencies both at the national and regional/local scale. Figure: Elements of NNRMS Sour Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL) FASAL is a countrywide project funded by the

Ministry of Agriculture and Cooperation and executed by DOS along with various State Remote Sensing Applications Centers, State Departments of Agriculture and AgriculturalUniversities. Crop production forecasting of major crops (kharif rice, rabi rice, wheat, jute, potato, mustard) and at district level (wheat, cotton, mustard, sorghum, sugarcane), in the country has been done for 2009-10. Kharif rice production forecasting for 2009-10 using three-date Synthetic Aperture Radar (SAR) data for state and national level shows that around 14% reduction in acreage and 19% reduction in production, as compared to 2008-09. The reduction is mainly due to lower acreage in the States of Bihar, Jharkhand, Madhya Pradesh, Uttar Pradesh and West Bengal due to insufficient rainfall. 156 | P a g e 4.2 National Agricultural Drought Assessment and Monitoring System Near real time assessment of agricultural drought at district level for 9 states and sub district level for 4 states, in terms of prevalence, severity and persistence, during kharif season (June-Nov) and submission of monthly drought reports to the Ministry of Agriculture and State Departments of Agriculture and Relief of different states has been the main focus of this project. The methodology essentially reflects the integration of satellite derived crop condition/surface wetness with ground collected rainfall and crop area progression to evolve decision rules on the prevalence, intensity and persistence of agricultural drought situation. The drought information is effectively used for contingency planning and for drought declaration process. 4.3 National Wastelands monitoring at the behest of Department of Land Resources (DoLR) of Ministry of Rural Development, identification and inventorying of wastelands using satellite data on 1:50,000 scales was initiated in 1986 and completed in 2000 and the National wastelands atlas was brought out in the year 2000. The extent of wastelands at that time was 63.85 M ha. Consequent to the request from the Ministry, National Wastelands Updating Project was taken up by NRSC at the behest of Ministry of Rural Development, Govt. of India, during 2002-03 to update the earlier wasteland maps by using one time 2003 satellite data. This was completed in 2005 and the extent of wastelands was 55.64 M ha. In order to assess the impact of various wasteland rehabilitation programmes taken up across the country, National Wasteland Monitoring Project was taken up by DOS at the instance of MRD, using three seasons" data (Resourcesat-1 LISS-III) for the year 2005-06. The study has been completed and it reveals that the extent of wastelands in the country is reduced to 46.88 M ha (14.81% of the total geographical area).

# Unit 11: Resource Mapping II: Geo-science applications (Terrain and earth resources evaluation)

**Unit Structure**



## 11.0. Learning objectives

After studying this unit you will be able to explain:

- Understand the role of GIS in terrain mapping
- Learn about computation of terrain variables and approaches to model the terrain
- Learn basic methods to derive the most important parameters of geomorphometry (slope, aspect)

## 11.1. Introduction

Earth surface or terrain represents a continuous and undulating feature. It is critical to study terrain as it influences the hydrological cycle, which is interlinked with extreme environmental events like floods and drought. In high relief areas, variables such as altitude strongly influence both human and physical environments. The terrain can change the precipitation quantity due to elevation and rain shadow effect, causing the climatic variations among the different geographical regions. The surface water direction is also significantly based on the terrain and terrain study can help in understanding of drainage characteristics. The performance of radar can be affected by the terrain of the region as signal may be blocked by higher terrain. Lastly, human colonization has been critically based on the terrain of the region. The topography is usually analyzed through consideration of elevation, slope and orientation of the physical features. Terrain mapping and analysis has become easier with advent of geographical information systems (GIS). The mapping in GIS allows considering the terrain and a 3D data model is essential to derive information like - altitude, aspect, slope, watershed delineation etc. traditionally surveying was utilized to collect the elevation data, which is extremely expensive and time consuming. With technological enhancements, stereogrammetry techniques and radar data has been successfully applied in collection of elevation data, where in optical data is not utilized. However, in GIS models the elevation data is not treated as third co-ordinate, z with x and y co-ordinates, instead it is either an attribute value for vector data or grid value in raster data. The data in vector format uses a series of irregularly spaced elevation points connected to form triangulated irregular network (TIN) based on Delaunay triangulation, while the raster data considers the topographic surface as equally spaced cells or grids to form a digital elevation model(DEM).Thus, the digital terrain models are actually referred to as 2.5d models, which can be visualized in 3d in GIS.

## 11.2. Digital elevation model (DEM)

DEM represents topographic surface or elevation through equally spaced rectangular grid cells, with elevation as the cell value, as given in Fig 1. The grid is created by interpolating elevation data available for known finite points through aerial photographs or radar altimeter. Since spatial information is available in a regular grid, the altitude data stores implicit information, which can extracted through appropriate methods. The data can be utilized to estimate steep slopes, the profile between two points, upstream cells etc. Thus, the data finds its use in hydrological modeling, terrain stability etc. The grid format is the most widely used as it is simple. However, the grid is non-adaptive and density of the grid cannot be adjusted based on increase of complexity of the topographic features.

## 11.3. Triangulated Irregular Network (TIN)

TIN consists of irregularly distributed points forming a vector data. The triangles are built up on these points, where in the corner of each triangle is equal to the elevation of the terrain as given in Fig 1. The edges of the triangles provide information of slope and its direction. This data structure allows for the efficient storage of terrain information as the triangulation allows a variable density and distribution of points. It can be adapted to more complex terrain with higher number data points at high relief terrains and less data points in flat regions of the terrain. Several algorithms allow for selection of significant points like the maximum-z tolerance algorithm. This algorithm allows selection of points based on elevation difference between two successive points. So the only points that are selected are above the threshold value, z given. A TIN can be created from a set of points (x,y,z) or isolines and also from the DEM. The TIN compared to DEM can include features such as peaks, slope breaks and conic pits, and may give a more accurate structure for terrain. However, TIN can have distortions at the edges due to sudden drop of elevations and is more complicated to implement than to implement algorithms based on raster data.

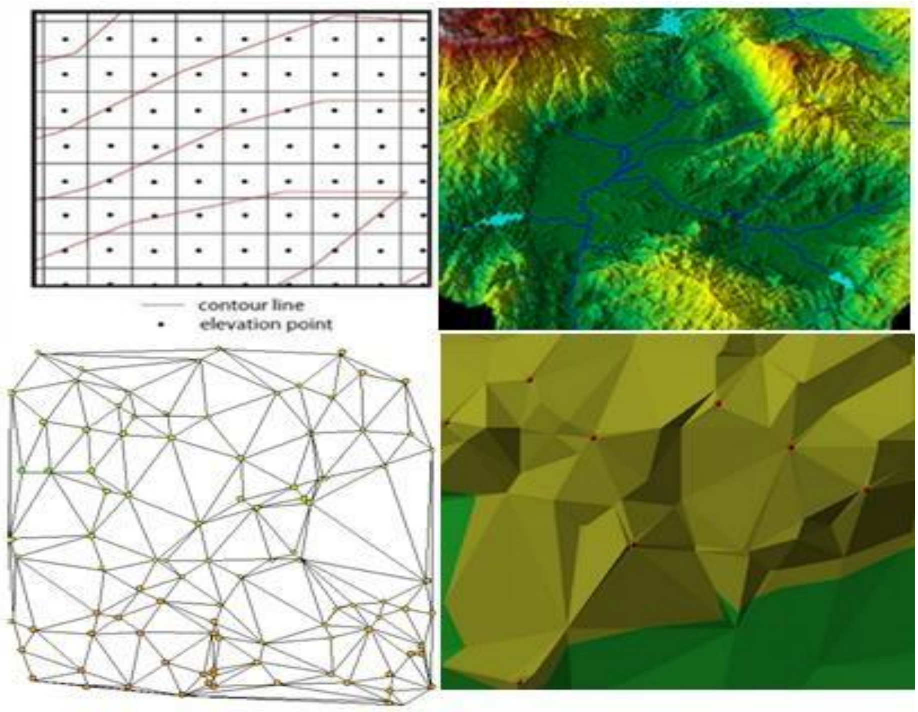


Fig 1. Illustration of DEM and TIN

Other than DEM and TIN, a digital surface model (DSM) can also be utilized to represent the terrain. This model includes features above the ground, such as buildings and vegetation, and is used to distinguish a bare-earth elevation model. That is the difference in DEM and DSM would provide the height of the feature like the forest canopy or building. Both the gridded as well as the vector format are known as DSM.

## 11.4. Terrain mapping

### 11.4.1. Contours from DEM and vertical profiling

Contours are the isolines of elevation that reflect topography. These lines do not intersect. Usually contours are available from the survey maps. However, with the advent of GIS software, contours can be automatically obtained from the available DEM or TIN data. The contours are closely spaced in steep slopes and are curved in upstream direction along a stream. On the other hand, we can have vertical profiling, which shows changes in elevation along a line. For example, a slope gradient along a road or stream can be estimated from the elevation data available from the DEM or TIN.

### 11.4.2. Hill shading

Hill shading is also known as the shaded relief, which helps in visualization of the terrain with the interaction of sunlight with surface features. Thus, hill shading ability of GIS software, helps in computation of the relative radiance of each raster cell based on the sun's azimuth, direction of incoming light, sun' s altitude, angle of incoming light, surface slope and surface aspect. The surface slope and aspect derivation is considered in next section. Thus, the equation for calculating relative radiance value of raster cell is-

$$R_f = \cos(A_f - A_s)\sin(H_f)\cos(H_s) + \sin(H_s)\cos(H_f)$$

where, Af is aspect of surface, As is sun azimuth, Hf is the slope and Hs is the sun altitude.

### 11.4.3. Hypsometric tinting and perspective viewing

Helps in visualizing the progression in elevation and the perspective viewing based on the distance, angle, elevation difference provide a 3-d visualization of the terrain. The 3d viewing thus helps in visualization of high and low terrain.

## 11.5. DEM for terrain analysis

The following section provides the various information that can be extracted from the DEM and applied for various applications.

### 11.5.1 Slope and aspect

Slope measures the rate of change in elevation at the surface either as percentage or degree while aspect provides the directional orientation of the slope. Slope and aspect are important information for hydrological applications and morphometric studies. So, slope as percent is defined as 100 times of rise divided by run or can be represented for Fig 2 as Slope in percent =(A/B)*100 or slope in degrees= tan-1(A/B).

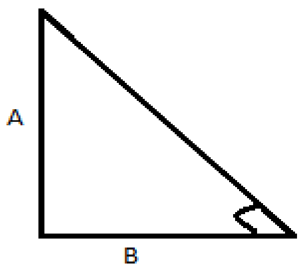


Fig. 2 Illustration of calculating slope

Now, for the raster slope needs to be calculated in both the x-and y-direction and is expressed using the finite difference approach as the first derivative of the elevation in that direction. Therefore, the slope in both the directions separately can be expressed thus, the total slope is

$$S_x = \frac{\partial h_x}{\partial x}$$

$$S_y = \frac{\partial h_y}{\partial x}$$

Thus, the total slope is

$$S = \sqrt{\left(\frac{\partial h_x}{\partial x}\right)^2 + \left(\frac{\partial h_y}{\partial y}\right)^2}$$

Now, if we consider an example raster, Fig 3, with pixel values being h1...h9.

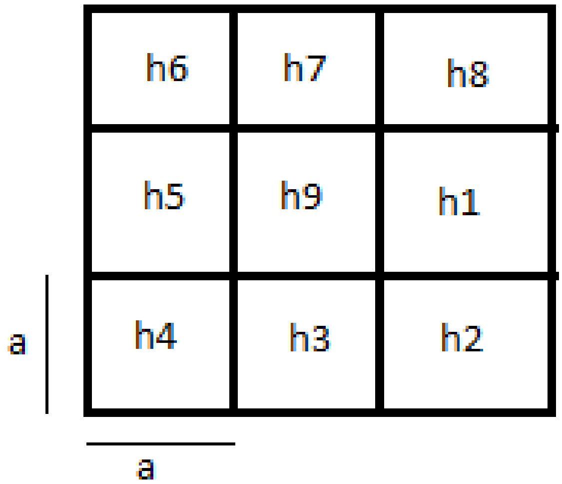


Fig 3. Raster example for calculating slope

The slope at center pixel, S = $\sqrt{\left(\frac{h1-h5}{2a}\right)^2+\left(\frac{h_3-h_7}{2a}\right)^2}$

Other than slope, aspect is based on directional angle and can be calculated for the Fig 3. as A= arctan ((h3-h7)/(h1-h5)) and is calculated in radians (1Radian=57.296 degrees). Aspect gives the direction of slope at the raster pixel being considered. The aspect varies between 0 to 360 degrees, with 0 degree representing the North. Aspect is manipulated to representative of the four directions ( N,S, E and W) or eight directions (N, S, E, W, NE, SE, SW and NW). Thus, once the directional angle is obtained, it is converted to direction as follows - If slope in x-direction is zero, then if slope in y-direction is less than zero, aspect is 180 else 360. If slope in x- direction is greater than zero, aspect is 90-(A*57.296), while if slope in x-direction is less than zero, aspect is 270-(A*57.296).

### 11.5.2 Profile and plan curvature

The DEM can also be utilized to extract the information of surface curvature, which informs whether the pixel is concave on convex in position. The profile curvature is estimated along the direction of maximum slope, while plan curvature is estimated along the maximum slope. The two curvatures can be estimated as given in Fig 4.

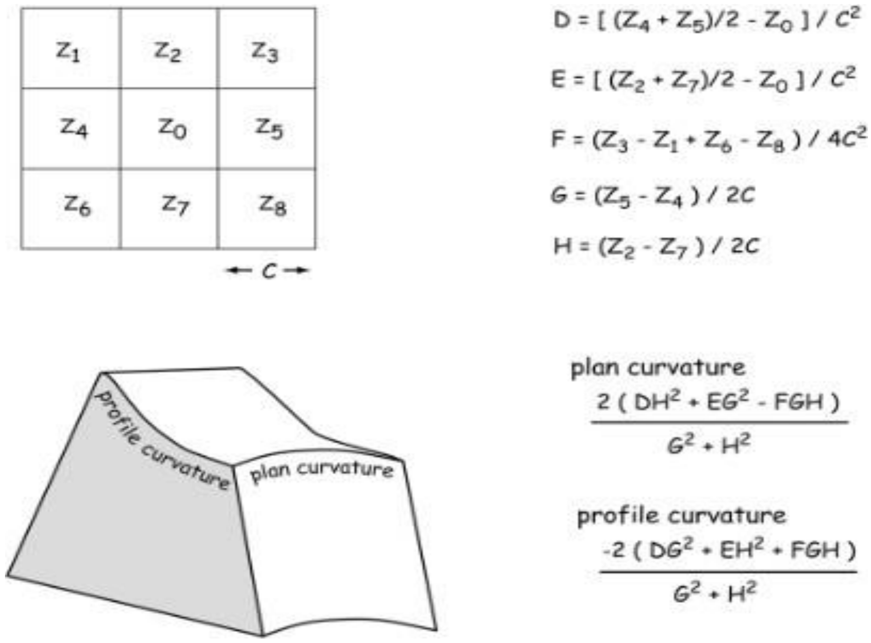

Fig 4. Estimation of Profile and plan curvature

### 11.5.3 Morpho-metric parameters

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms. This analysis can be achieved through measurement of relief aspects and slope contribution. The morphometric analysis provides quantitative description of the basin and few of the parameters are described below

#### 11.5.3.1 Convergence index

Convergence index is based on aspect. The index is obtained by averaging the aspect of slope directions of adjacent cells from the direction of central cell and subtracting 90 degrees, given by equation

$$CI = \left( \frac{1}{8} \sum_{i=1}^{8} \theta_i \right) - 90^{\circ}$$

and shown in Fig 5.

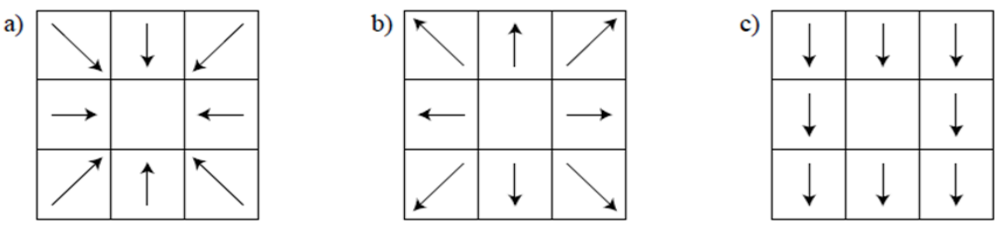

Fig 5. Convergence index for the three images is -90 (a), 90 (b), 90 (c).

#### 11.5.3.2 Curvature

The change in slope per unit distance. It is a very helpful measure to understand the surface water flow. Therefore it is widely used in the field of hydrology. The pixels with positive curvature indicate the flow dispersal and negative values indicates the flow accumulation.

#### 11.5.3.3 Morphometric Protection Index

The algorithm for morphometric protection index analyses the immediate surroundings of each cell up to a given distance and evaluates how the relief protects it. It is equivalent to the positive openness, which is an angular measure of the relation between surface relief and horizontal distance. It resembles digital images of shaded relief or slope angle, but emphasizes dominant surface concavities and convexities.

#### 11.5.3.4 Real Surface Area

This is equivalent to measuring the rigidity, in that it takes into account texture (i.e. the “ups and downs” within each cell) as well as cell size. As the value increases, surface texture, or roughness, increases.

#### 11.5.3.5 Topographic Position Index

The TPI algorithm compares a DEM cell value to the mean value of its neighbors. The mean value is calculated based on the shape selected by the user. Positive values represent features typically higher than surrounding features, negative values represent lower features, and values near zero are either flat or areas of constant slope.

## 11.6. Errors in DEM

It is seen here that a lot of information can be extracted from the DEM. However, the DEM can have some errors and the most common ones are “sinks” and “spires”. Sinks occur when a very low elevation, relative to surrounding cells, occurs, while spires occur when a very high elevation, relative to surrounding cells, occurs. Bothe the errors result in tightly packed contours. The sinks can create an issue when one utilizes them for delineating the surface flow direction etc. Other than this, the coarse resolution DEM may not be able to capture high variability in the terrain.

## 11.7. Summary

In this module, we discussed about the various models that can be utilized to represent the terrain. The terrain mapping can be done both using the raster model, DEM and vector model, TIN. The elevation data from the DEM has been shown to be utilized for calculation of various terrain variables, slope, aspect, curvature. etc. The terrain variables are useful in various applications like drainage basin delineation, watershed analysis, understanding the relief of the area. The DEM is computationally easier to use as compared to the TIN. Thus, the analyst needs to weigh the limitations of both before deciding to use either of the models.

**FAQs**

**Q 1. Differentiate between DEM and TIN**

**Ans.** DEM represents topographic surface or elevation through equally spaced rectangular grid cells, with elevation as the cell value. The grid is created by interpolating elevation data available for known finite points through aerial photographs or radar altimeter. The grid format is the most widely used as it is simple. However, the grid is non-adaptive and density of the grid cannot be adjusted based on increase of complexity of the topographic features.

TIN consists of irregularly distributed points forming a vector data. The triangles are built up on these points, where in the corner of each triangle is equal to the elevation of the terrain. The edges of the triangles provide information of slope and its direction. It can be adapted to more complex terrain with higher number data points at high relief terrains and less data points in flat regions of the terrain.

The TIN compared to DEM can include features such as peaks, slope breaks and conic pits, and may give a more accurate structure for terrain. However, TIN can have distortions at the edges due to sudden drop of elevations and is more complicated to implement than to implement algorithms based on raster data.

**Q2. Explain Topographic position index**

**Ans:** The TPI algorithm compares a DEM cell value to the mean value of its neighbors. The mean value is calculated based on the shape selected by the user. Positive values represent features typically higher than surrounding features, negative values represent lower features, and values near zero are either flat or areas of constant slope.

**Q3. List the factors that influence hill shading.**

**Ans.** Hill shading ability of GIS software helps in computation of the relative radiance of each raster cell. The hill shading is influenced by the 1.sun's azimuth, direction of incoming light, 2.sun's altitude, and angle of incoming light, 3.surface slope 4.surface aspect.

**Q4. Explain DSM**

**Ans:** Other than DEM and TIN, a digital surface model (DSM) can also be utilized to represent the terrain. This model includes features above the ground, such as buildings and vegetation, and is used to distinguish a bare-earth elevation model. That is the difference in DEM and DSM would provide the height of the feature like the forest canopy or building. Both the gridded as well as the vector format are known as DSM.

**Q 5. Explain isolines**

Ans: Contour lines representing constant elevation are known as isolines. The isolines are parallel to each other and do not intersect. The DEM can be utilized to delineate contour map. The contours are closely spaced in steep slopes and are curved in upstream direction along a stream.

**<u>MCQs</u>**

**1.** DTMs can be created by digitizing from a paper map

a) true

b) false

Ans: a

**2.** DSM represents the elevation data without inclusion of height of features

a) true

b) false

Ans: b

**3.** TIN is a vector based model to represent elevation of the terrain

a) true

b) false

Ans: a

**4.** In DEM, third coordinate z, representing the elevation is taken as the cell value of the pixel

a) true

b) false

Ans: a

**5.** In TIN model data for the region is represented as network of linked

a) squares

b) triangles

c) both triangles and squares

Ans: b

**6.** 10m spatial resolution is coarser than the 30 m spatial resolution

a) true

b) false

Ans: b

**Reference Books:**

1. Geographic Information Systems An Introduction, 1990, Prentice Hall, New Jersey by Star, J. & Estes, J.

2. Introduction to Geographical Information Systems by Kang-Tsung Chung

# Unit 12: Resource Mapping III: Water Resources

**Unit Structure**



## 12.0 Learning objectives

After studying this unit you will be able to explain:

- To explain conceptual model for groundwater flow system
- To apply remote sensing and GIS techniques for hydraulic potential and flux
- Understand the interaction of groundwater and land surface
- Understand the occurrence of ground water in different terrain
- Applying remote sensing and GIS techniques for water pollution studies

## 12.1 Introduction

Groundwater is a vital natural resource for mankind. This resource is extensively being used for drinking and household utilization; irrigation and industrial purpose. It plays an important role for the economic development and food security of the country. Only 2.5% of the earth's water is available as freshwater. Groundwater comprises nearly 30% of freshwater resource of the world whereas glaciers and ice cap consist of 68.7% (http://water.usgs.gov/edu/earthwherewater.html) which is difficult to access for direct utilization. Remaining freshwater is present in lake, river, stream, atmosphere and wetland. Therefore groundwater is an important source of freshwater. The annual replenishable ground water resource of India is 431 billion cubic meters (bcm), net annual availability is 396 bcm whereas the annual ground water draft for irrigation, domestic and industrial use is 243 bcm (CGWB, 2009; Murry, 2013). In the country like

India nearly 90% of rural population and 30 % of urban population depend up on the groundwater for drinking and domestic use (NRSA, 2008; Murry, 2013).

Demand of groundwater is increasing day by day due to rapid increase in population, urbanization, industrialization and agriculture. It leads to decline in groundwater level and anthropogenic activity deteriorating the quality. Similar problems are also prevailing for the useable surface water. Hence it is important to study the ground water potential and its quality of our country for a better sustainability.

Occurrence and distribution of groundwater is controlled by the lithology, structure, geomorphology and rainfall pattern of an area. So detail investigations of these controlling parameters are required for groundwater modeling and management. Groundwater modeling and management required reliable input data which is most of the time difficult to obtain. The standard point sampling methods for input parameter are biased because of heterogeneity in subsurface layers and structures, and restriction of sample from harsh terrain. Additionally this method is expensive and time consuming. So the remote sensing and GIS technique provided ample scope to generate input data to study groundwater and its quality of an area more efficiently at lower cost and time. However for validation ground verifications are required

## 12.2 Remote sensing and GIS techniques for Groundwater studies

Remote sensing provides information in space and time and GIS techniques helps to store, interpret and retrieve spatial data. It is very essential for an inaccessible area. This technique is very successful for surface hydrology, but for subsurface hydrology remotely sensed images such as airborne and space borne; passive or active microwave image; data from specific satellite sensor with different spatio-temporal or spectral resolutions can be analyzed to infer the groundwater behavior from surface expressions and its quality. Generally these data are combined with the numerical modeling, GIS and ground-based information. The basic principle for the remote sensing groundwater is to find out the shallow groundwater flow. These flows are driven by the surface forcing and other geological parameters which can be inferred from the surface data.

Based on the topographic driving force Tóth (1963) conceptualized a model (Fig. 1) of groundwater flow system for local and regional scale. This model shows that the ground water recharged at higher elevation in the regional scale tend to move deeper compare to local scale recharge. So based on the topographical information from remote sensing data predicting local or regional scale groundwater flow will be more effective (Becker, 2005). The rate and behavior of flow depend up on the geology and it can be expressed by the Darcy's Law. Darcy's law defines the flow of fluid in a porous medium and also states that there is a linear relationship between flow velocity and hydraulic gradient (I) for any given saturated soil or medium under steady laminar flow conditions. It can be stated as

$$q = K.\ I$$

Where 'q' is the specific discharge vector representing flow per unit area (flux of ground water), 'K' is the hydraulic conductivity which is a function of geology, 'I' is the hydraulic gradient which is a function of surface forcing (Becker, 2005). Geological maps prepared in combination with remotely sensing data and ground verification provides useful information about the hydraulic conductivity, water bearing formations, lineaments such as faults, fractures in the hard-rock terrain. This information is used for groundwater prospecting as evident from literature.

For preparation of groundwater model of an area, surface water treated as the boundary conditions for the subsurface flow equation which is based Darcy's law. Remotely sensed imageries are used to define boundary conditions such as streams, lakes, wetlands, seepage areas, recharge zones, or evapotranspiration zones for prediction of ground water flow. The important mathematical boundary conditions are hydraulic head (Fig. 2), flux or discharge (Fig. 3), mixed (both head and discharge). So the remote sensing applications in ground water studies can be structured into the sensing of hydraulic potential (heads) and hydraulic flux (or discharge).

**12.2.1 Sensing of Hydraulic Potential (heads)**: To measure groundwater head sensors like visible, microwave and gravity sensors may be used. Ground water storage and hydraulic gradient can be deduced from hydraulic head.

**12.2.2 Surface Water Elevations:** Generally the elevation of surface water depicts the possible groundwater head of that region. Therefore the spring or first-order stream originates at an elevation where water table intersects the slope. In the catchment scale it provides an opportunity for dynamic monitoring of water table. Sometime it may be difficult if hydraulic conductivity changes considerably. Use of satellite based altimetry and interferometry for obtaining surface water elevations provides higher accuracy (Becker, 2005) compare to digital elevation models (DEMs) and topographic digital line graphs (DLGs).

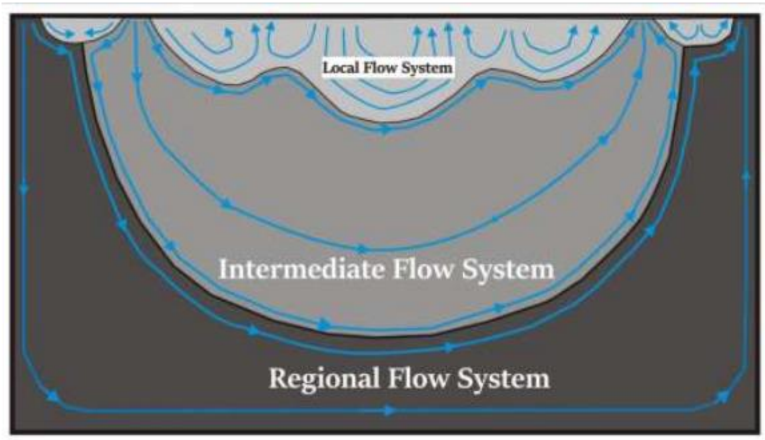


**Figure 1: Conceptual model (Tóth) of topographically driven ground water flow systems (after Becker, 2005; Fetter 2001).**

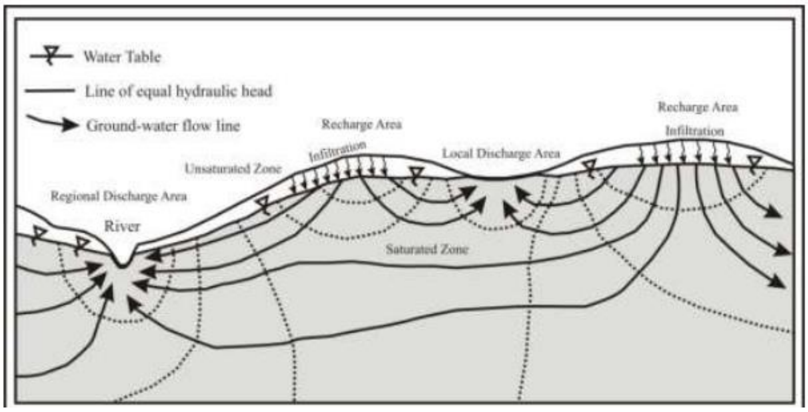


**Figure 2: Schematic illustration of the groundwater flow system, distribution of groundwater recharge and discharge in relation to surface topography and distribution of hydraulic head for a simple water table aquifer (after Fleming and Rupp, 1994).**

**12.2.3 Water Column Mass:** Water storage in the subsurface and hydraulic head in an aquifer can be estimated using satellite or aerial gravity surveys. This method is useful for studying very large aquifer system due to very coarse spatial resolution. Additionally this method does not have the vertical resolution; hence the influences from water present in the atmosphere and vegetation, and unsaturated water content i.e. soil moisture has to be removed to enhance the accuracy in estimates of saturated water mass (Becker, 2005). Determination of ground water potential gradient is difficult using this method because of coarse spatial resolution which requires aquifer to be continuous over hundreds of kilometer. Data obtained from the NASA Gravity Recovery and Climate Experiment (GRACE) satellite proved to be an asset for estimating ground water storage.

**12.2.4 Heat Capacity:** Heat capacity of saturated soil is higher than the dry soil. Using this property of soil, depth of water table can be estimated from remotely sensed thermal image. This technique is very useful to locate shallow water tables and this was proposed by Cartwright (1968) and Chase (1969) in the early days of remote sensing application. Some researchers have found that night time thermal images are more useful to predict depth of shallow water table compare to the day time thermal image. Annual variation in soil temperature like heat sink during summer and heat source in the winter should be taken into consideration for locating the depth of water table. This technique should be used cautiously in the snowpack areas where it amplify the heat signature of shallow ground water through heat of fusion during snow melt or heat change in the snowpack (Becker, 2005).

**12.2.5 Land Subsidence:** Ground water generally occupies the pore space of the sediments. In case of unconsolidated sediment, addition (recharge) or withdrawal (depletion) of water from the pore space will change the net volume. During recharge effective pressure will be high in the pore space hence it will increase the volume as well as water level (Becker, 2005). Withdrawal of water will cause reduction in the pore pressure which leads to decrease in volume and compaction of unconsolidated sediment. This will result in land subsidence. This volume change will be reflected as variation in the surface elevation. Although this variation is small, it can be measured by interferometric synthetic aperture radar (InSAR). For this analysis image of a location is taken from different angle and time. Accuracy of elevation change estimated by In SAR analysis is control by topography and concentration of water vapor in the atmosphere. This accuracy is different for humid (10cm) and dry (1mm) region (Galloway et al 1998). Using surface elevation change storativity of a porous medium can also be estimated with the help of other data such as geodetic controls from GPS, water level, hydrological flux and strain measurement of the study area. Integration of numeric model with InSAR analysis widens the application of this method and provides better resolution and spatial extent of land subsidence than ground base measurement (Becker, 2005).

**12.3.6 Soil Moisture:** Presence of shallow water table can be predicated based on the soil moisture content. Different remote sensing method has been applied extensively to delineate shallow water table from soil moisture content and vegetation stress or proliferation (Becker, 2005). Visible and near-infrared sensor is also used to monitor the change of vegetation cover/agricultural performance which can be linked with the water logging or change in the soil moisture content. Passive and active microwave sensor can be used to monitor flood and ground water recharge. Predicting water table depth from soil moisture content is conditional because it requires surface soil should be continuous as drying of surface soil may decouple from the subsurface soil moisture

## 12.3 Ground water and Land Surface

Surplus water after evaporation infiltrates the surface and recharges the ground water table. In this case movement of water is reverse while comparing with the discharge of ground water discussed in the previous section. Vegetation cover is also control the infiltration of surface water hence it regulate the ground water recharge (Becker, 2005). Growth, speciation and abundance of vegetation of a region is depend up on the availability of water and nutrients, atmospheric moisture content, salinity and acidity/alkalinity. Different plant species provides clue to the occurrence of ground water but the link between them varies considerably in different climatic regime. In the arid environment ground water discharge or shallow water table is the only source of water for vegetation whereas in the humid climate region it is more complex. Soil chemistry also plays a major role to support selective plant species, hence while considering the vegetation species assemblage to study the ground water condition, data on soil chemistry should be taken into consideration (Becker, 2005). Distribution, growth and type of plant species are used as indicator in the remote sensing and GIS method to determine the ground water conditions. However, it is difficult to estimate the change of ground water flow from vegetation cover due to its late response to the flow change. Some researchers (Batelaan et al., 1998) classified vegetation cover using principal component analysis to study the ground water discharge in a wetland in

Belgium. They also estimated the flow rates and travel time using combined data of remote sensing and hydrochemistry in a GIS GRASS environment. Although based on type of vegetation indicator classifying interaction of ground water with the surface i.e. recharge/ discharge area, appears simple but in practice it is tricky.

Vegetation moisture flux is an important parameter for developing a model to study the hydrological cycle. Understanding different component of hydrological cycle is a key research area for remote sensing community for appropriate application of this technique (Becker, 2005). A Model has been developed to consider the contributions from soil, vegetation and atmosphere transfer (SVAT) of moisture. SVAT models are being used for shallow subsurface study but it does not have much application directly on ground water study. However SVAT model has been coupled with ground water flow finite-difference model (MODFLOW) for understanding ground water (Salvucci and Entekhabi, 1995). Generally the residence time of ground water is longer than the soil and atmospheric water, hence changes in the ground water condition is also in the longer time scale compare to other two. Shallow subsurface water or soil water is subjected to differential drying or evapo-transpiration locally but in the larger scale it is more or less uniform.

Different models have been used in sole or combination to predict movement of ground water. Combination of water table dependent vadose zone model and MODFLOW was used to delineate recharge and discharge zone, and to predict movement of net soil water (Levine and Salvucci, 1999). Simplified atmospheric model coupled with MODFLOW used to determine long term interactions between ground water and atmosphere (York et al., 2002).

## 12.4 Image interpretation for ground water study

Remotely sensed images depict the terrain and sometime provide valuable information about the subsurface geology. Hence interpretation of these images for extracting information about the ground water required expertise and background knowledge about the terrain. Information about surficial feature which control the recharge, groundwater out flow and configuration of subsurface geology are targeted during interpretations of images. Same geological formation may appear differently in the images due to local weathering condition, erosion or accumulation of sediment/debris

(Meijerink et al. 2007). Sometime vegetation cover masks the outcrop. Hence field verifications are required. Image interpretations are generally gets validated using field work, geological map, geophysical and drill whole data. While interpreting surface features for ground water studies various topographic evidences are being examined based on the hydrogeological properties of outcrop or any geological formation (Meijerink et al. 2007). Some of them are a) permeable conditions such as thick sand/colluvial deposits or noneroded thick soils over dipping rock sequences, b) type of surface runoff, c) presence of lineaments and its association with vegetation, d) presence of water in rivulets, e) disappearance of base flow in the river bed indicating infiltration or loss to the rock formation/larger fractures and f) reappearance of water further downstream indicates an alluvial fan aquifer (Meijerink et al. 2007). Hydrological properties will be depended up on the climate, geology and geomorphology. For ground water study geomorphological interpretation is very important. For example, drainage density can be directly link with the permeability of the region as low drainage density indicates high permeable condition, but it is not always true. Many instance (sheet wash dominant area over pediments, crystalline basement rock) presence of impermeable rock also leads to development of low drainage density. Hence it is tricky to interpret the image.

Hydrological image interpretation of different geological terrain required basic understanding of geology of that region. Terrains consisting of unconsolidated sediment mostly the quaternary deposits have been extensively studied for ground water exploration, withdrawal and management. Preliminary investigation of this deposits are to know the geomorphological process (fluvial, aeolian, coastal, lacustrine or glacial) responsible for development of this deposits and type of materials (Meijerink et al. 2007). Generally this deposit conceals the complex sub-surface features which has no or very little surface expressions. Such areas are investigated by different remote sensing images like thermal, infrared images, soil moisture study in combination with other field and geophysical data.

## 12.5 Remote sensing and GIS in water pollution studies

For sustainable management and development of water resource the monitoring water quality and quantity is very essential (Sharma et al. 2015). Remote sensing and GIS techniques are used directly or indirectly for studying water quality and quantity with temporal changes mainly for the river, lake, snow/glacier or ground water resources. Concentrations of specific parameters and specific properties of water are being monitored using suitable sensors for assessment of water quality.

Emitted energy (reflectance) of surface water will change due to turbidity, presence of phytoplankton/algae, specific chemical constituents or dissolve organic matter, oil spill etc. (Sharma et al., 2015). Based on the emitted energy from the water surface, which is recorded by different sensor, water quality is monitored and the change in the energy is studied by the remote sensing tools. In India water quality of river, lake and pond etc. has been analyzed by many researchers using remote sensing tool. Suspended materials are common pollutant in the surface water. Different sensors carried by satellite, aircraft or aerial images are helpful for estimating this pollutant. Following empirical equation for quantifying presence of suspended material or other dissolved organic/chemical constituents in water are used.

$$R = X + YZ \text{ or } R = XYZ$$

Where R= reflectance, Z= water quality parameter, X & Y = empirically derived factors (Sharma et al., 2015; Ritchie et al., 1974). This equation can be rewritten (Sharma et al., 2015; Schiebe et al., 1992) based on the physical relationship model between spectral and physical properties of surface water.

$$Ri= Si[1 - e\ x\ ], \text{ where } x = Cs/Pi$$

Here Ri = reflectance of surface water for specific wave band i, Cs = concentration of suspended sediments, Si = reflectance saturation level at high suspended sediment concentration for wave band i, Pi = concentration parameter, which is equal to the concentration for reflectance of 63% of saturation level in wave band i (Sharma et al. 2015). Similar to turbidity presence of chlorophyll will change the reflectance of surface water hence various algorithm and wavelength are used to monitor surface water bodies and eutrophication of in lake. Seasonal change of chlorophyll concentration can be estimated using following equation (applied for Chesapeake Bay by Harding et al. 1995):

$$\text{Log10 [Chlorophyll]} = x + y\ (\text{-Log10Z}), \text{ where } Z = [(R2\ )\ 2\ /\ (R1R3\ )]$$

Here, x & y = empirical value derived from in situ measurement, R1 = radiance at 460 nm, R2 = radiance at 490 nm, R3 = radiance at 520 nm (Sharma et al. 2015). Now various satellite sensors like IKONOS, OCTS (ocean color and temperature scanner), MOS (Modular optical scanners) are used for measuring chlorophyll in the surface water (Sharma et al. 2015).

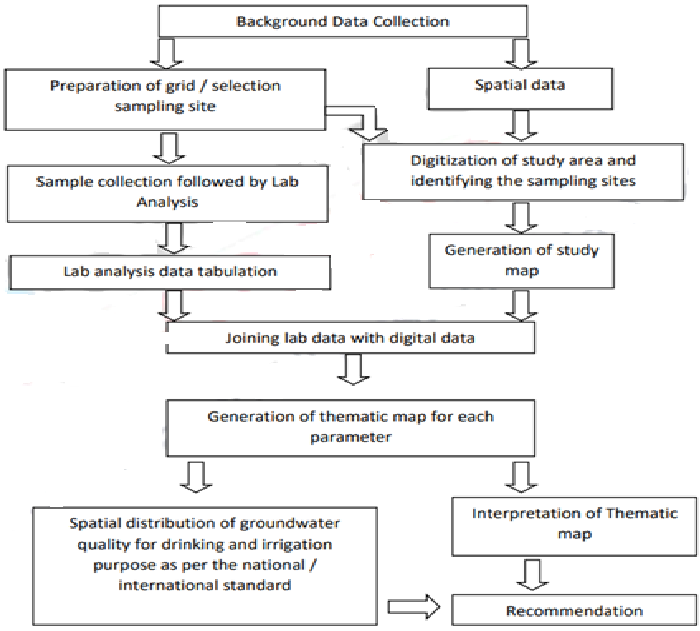


**Figure 3: Flow chart for application of remote sensing and GIS technique for water pollution study**

Remote sensing and GIS techniques are also used for preparing map showing spatial variation of groundwater quality parameter such as arsenic, fluoride, chloride, TDS (total dissolve solid), TH (total hardness) nitrate, iron, SAR (Sodium absorption ratio) and bacterial contamination to identify affected area and for risk assessment. In addition to this salt water intrusion is another issue in the coastal areas. For this study groundwater samples are collected from predetermined area followed by chemical analysis and then maps for different chemical constituents are prepared. Generally these maps carry the water quality index based on different national/international standard (BIS- Bureau of Indian standard, WHO - world health organization) for domestic use or irrigation purpose (Sharma et al. 2015). The flow chart for application of remote sensing and GIS technique for water pollution study is illustrated in the figure.

# Unit 13: Biodiversity Measurement and Monitoring

**Unit Structure**



## 13.0. Learning objectives

After studying this unit you will be able to explain:

1. To familiarize the reader with the biodiversity and the
2. Application of remote sensing (RS) and geographical information system (GIS) in conservation of biological diversity.

## 13.1. Introduction

Biological diversity or biodiversity has been defined by Convention on Biological Diversity (CBD) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part". This includes the diversity within species, between species and of ecosystems. Biodiversity can also be defined as the natural variety and variability within and among living organisms and the ecological complexes in which they occur naturally, as well as the ways of interaction among organisms and with that of physical environment (Noss, 1990). It is a multidimensional concept that includes different components (e.g. the genetic, population, species and community levels), and each of them has structural, functional and compositional attributes (e.g. size of population, species composition and distribution of alleles).

Due to the complex nature of biodiversity, it becomes very difficult to express and assess the biodiversity. It must be related to not only the variability of life forms, but also with the ecological complexes of which they are recognized as important components. Conservation has become an essential mean of interacting with the rapid degradation and conversion of ecosystem, which lead to serious impacts on biodiversity. As rates of habitat loss and species destruction continue to mount, the need for conserving biodiversity has become increasingly vital during the last decade (Wilson 1988; Kondratyev 1998). In order to design significant conservation strategies, comprehensive information on the species distribution, as well as the information regarding changes in distribution with time, is required.

Understanding biodiversity patterns distribution is very crucial so far as conservation strategies are concerned. Conservation of biodiversity is an indispensable issue due to increasing climate change and anthropogenic factors. Various rich biodiversity zones are under serious threat and have been degrading at an alarming rate. Thus it's very important to preserve these zones and their habitats at local, regional and national levels. In order to implement conservation schemes for the sake of biodiversity conservation, comprehensive information on the distribution of species on a temporal basis are required. Biodiversity conservation has been put to the highest priority through Convention on Biological Diversity (CBD). It is expressed at different levels - genetic, species and landscape level. Although biodiversity is generally considered at the species level, the comprehension at the landscape level has been given priority worldwide as the interaction with the habitat part is very well understood in the latter.

Biological diversity is proximately associated with global environmental changes and global issues, such as climate change, land use and land cover (LULC) changes and sustainable developments (Nagendra et al., 2010). During the past several decades, human beings have caused serious impacts on ecosystems more rapidly due to rapid and large scale industrialization, urbanization and other activities. As a result, such activities posed serious threat to the survival of biodiversity and their natural habitat. This loss is further amplified by the lack of awareness, ethics, knowledge of biodiversity, especially of those communities living in close relationship with the ecosystem. The challenges with regard to biological diversity include inventories to determine the extent and location of biodiversity existence and its dynamics.

Therefore, it becomes very important to link biodiversity and human interaction with respect to use of natural resources in order to sustain and preserve the biodiversity.

## 13.2. Geospatial Technologies

(1) **Remote Sensing (RS)** literally means acquiring information about an object, area or phenomenon without coming in direct contact with it (Joseph et al., 2011).

According to White (1977), Remote Sensing includes all methods of obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance, and the treatment and processing of the picture data.

According to the United Nations (95th Plenary meeting, 3rd December, 1986), remote sensing (RS) means sensing of earth's surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of land use, natural resource management and the protection of the environment.

**(2) Geographical Information System (GIS)** is a computer based information system which integrates a variety of qualities and characteristics to geographical location and helps in planning and decision making. In GIS system the map information supplemented with additional information, can be displayed and referenced using computers. It can provide spatial information with appropriate conventional statistics.

Burrough (1986) defined GIS as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose.

## 13.3. Role of remote sensing (RS) and geographical information system (GIS) in Biodiversity

It is very difficult to acquire information regarding species distribution with respect to location and time simply on the basis of field assessment and monitoring (Heywood, 1995). In recent times, remote sensing and biodiversity communities have established cordial relationship to share their ideas, problems and their solutions on a single platform. Such relationships have been appreciably strengthened with the advancements of satellite remote sensing technology in past few decades.

Consequently, the advancement has boosted the interdisciplinary research at local and regional scale with high temporal resolution to assess the changes in species distribution, loss of habitats, etc. Assessing and predicting ecosystem responses to global environmental climate change and subsequent consequences on humans are prime targets for scientific community. The management and conservation of wildlife and Biodiversity require a reliable and relevant data on the species distribution, abundance, habitats and threats as well. Different organizations and countries are being focused into the so-called information 'super highway'. Reviewing the requirement for biodiversity information has been noticed and addressed by protected areas managers, decision makers, scientists, researchers and many others. The meeting of protected area managers at the Fourth World Parks Congress understood that individuals and organizations engaged in efforts of protected areas need better information for making decisions (IUCN, 1993). Dealing with biodiversity information, database need to be geographically based, and it must be able to predict where new populations of endangered species with a limited known range might be expected, specifying potential hot spots.

Therefore, Remote Sensing (RS) and Geographic information system (GIS) a modern day geo-spatial technology, helps in data (information) collection for biodiversity conservation management and planning.

The conventional methods for data collection on biodiversity have been found to be costly and time consuming. Comparatively, RS and GIS are the most efficient and cost effective ways for collection of information and subsequent management of our natural resources. It offers a systematic, synoptic view at regular time intervals, and has been considered as useful for this purpose (Debinski and Humphrey 1997; Innes and Koch 1998). Coupled with Geographical Information Systems (GIS), remotely sensed data can generate information about soil, temperature, rainfall, topography, landscape history and other climatic conditions, besides current habitat and soil coverage—factors on which species distribution depends (Noss, 1996). Relationships between remotely sensed/GIS data and species distribution patterns, can be used to predict the distribution of single or a set of species over an area (Debinski and Humphrey 1997). Between remote sensing science and conservation biology, the potential for synergies has been highlighted and acknowledged in the past by practitioners, researchers and data providers to better understand how remote sensing based studies can be utilized in monitoring and conservation of biodiversity (Duro et al., 2007; Gillespie et al., 2008).

GIS is a tool that can be used for monitoring biodiversity where it accommodates large varieties of spatial and attribute data. Embedded in a GIS, the information is used to target surveys and monitoring schemes. Data on species and habitat distribution from different dates allow monitoring of the location and the extent of change. Over the last few years, there has been a revolution in the availability of information and in the development and application of tools for managing information (Harrison, 1995). It can help in changing the very approach of wildlife management based more on current information and location oriented.

Turner et al. proposed two types of remote sensing (RS) approaches, viz. direct and indirect remote sensing approaches (Rapport et al., 1998). The former refers to the direct observation of individual organisms, group of species, or ecological communities from satellite sensors, such as high spatial resolution and hyper-spectral sensors (Directive, 1992). Indirect approaches are based on certain environmental parameters derived from remotely sensed data as proxies. For instance, habitat parameters, such as land cover, species composition, etc., regarded as a substitute for exact estimation of ranges and patterns of species and their richness (Gibbons et al., 2008).

Remote sensing provides consistent data of earth at various scales at all levels ranging from local to global. In addition to this, remote sensing does not require labour and it also save time when compared to ground-based observations. It covers a wide-scale terrestrial, atmospheric and oceanographic data collection as well as the monitoring of environmental changes at global-scale. Remote sensing plays a major role in monitoring changes in biodiversity and terrestrial, marine and freshwater ecosystems where it provides repetitive images on regular periodic intervals that make it predominantly appropriate for monitoring. It facilitates a vast amount of information for understanding and monitoring biodiversity and its dynamics. The RS monitors the changes in terrestrial ecosystems include changes in ecosystem extent, forest extent; health (e.g., by monitoring greenness, though estimating health can be a challenge). The RS provides a wide range of information that helps in estimating species distributions and in integration with models also estimates the overall biodiversity. Wildlife and Biodiversity Management has stressed the requirement of having updated spatial information for (a) decision-making, and (b) implementation of plans. The updated spatial data information provided by RS need to be integrated with the conventional database. According to the IUCN (1996), “The main purpose of wildlife conservation is to maintain maximum plant and animal diversity through genetic traits, ecological functions and bio-geo-chemical cycles, as well as uphold aesthetic values.” Remote Sensing techniques play a vital role in wildlife and biodiversity management because of its exclusive characteristics of synoptic view, repetitive coverage, and uniformity. In forest management, the RS has a major role to play a revision and updating of working plan, wildlife management, forest fire control, soil and water conservation, land utilization studies, grazing management, mapping social forestry sites and for other important species of general afforestation programmes.

### 13.3.1. Forest Management

#### 13.3.1.1. Forestry Conversion Studies

With the population explosion and urbanization, the forest lands are being converted at a rapid rate which causes a serious damage to the forest biodiversity. The forest cover distribution and its change is a crucial issue so far as forest management is concerned. Also to develop the methods for estimating and evaluating the extent of forest resource and its changes to support the policy makers to take a decision that may ensure and maintain the rich biodiversity of forest resource. Monitoring of the changes in the forest cover has been quite important task because of its significant impact on climatic change. The RS technique and GIS coupled with ground survey can be reliable in providing information on spatial distribution of forests and its changes. With the rapid destruction of forests and encroachment the use of multi-temporal satellite data using data analysis procedure provide a way to generate maps based on spatial changes by image differencing methods and logical operations. Such maps would help in assessing the extent of conversion of forest land based on multi-temporal satellite data.

#### 13.3.1.2. Forest Fire Damage

Fire is one of the natural or man-made disasters causing damage to the forest biodiversity and the ecosystem worldwide, which ultimately have adverse effects on soil, forests and humans. During the process of forest burning, the soil nutrients are reduced and the soil is left bare making it more prone to soil and water erosion.

Therefore, it is very essential to have precise and timely information of the total area burned, topography, type of forest etc. It is very difficult to manage fires effectively without any information related to the distribution and dynamics of forest fires. RS and GIS can play a crucial role in detecting burnt forest and developing a spatial model to forecast and assess the forest fire and subsequent impacts on forest biodiversity. The use of multi- mission IRS data has been implemented to identify forest ground fire damaged areas with the combined use of IRS 1A and IRS 1B.

### 13.3.2. Wildlife Management

Wildlife distribution and protection are the prime focus area of wildlife management. So far as the management is concerned the geospatial technology is very effective in analyzing, managing and visualizing wildlife data. GIS enables analysis and mapping of distribution of wildlife, their movements and pattern of habitat use, which can provide precious information for the development of wildlife management strategies (Gibson et al., 2004). In recent times, the rapid technological improvements in GIS, as well as in remote sensing techniques have significantly increased their accessibility and efficacy in ecological management and research (Guisan and Zimmermann 2000).

### 13.3.3. Management of Grasslands

Grasslands are the world's most wide-ranging terrestrial ecosystem, and are considered as major feed sources for livestock. Global Positioning System (GPS) and other ground-based sensor technologies have been recognized as valuable tools for grassland and herd management. With the availability of space-borne remote sensing data, it becomes possible to assess and monitor grassland ecosystems, based on the data related to their status about biomass, productivity level, quality, phenological stage, species composition and change, their biophysical parameters and management characteristics (i.e. degradation, grazing intensity).

### 13.3.4. Agricultural biodiversity

Agricultural biodiversity is a broad term that consists of all components of biodiversity related to food and agriculture, and all components of biodiversity that ecosystem, its structure and processes. The term Agro-bioinformatics is application of Informatics for management, presentation, discovery, exploration and analysis of Agriculture and related issues. Agro- bioinformatics is a type of electronic documentation of biographical, taxonomical and ecological aspects related to agriculture. It may consider a multidimensional database in which information stored in digital form, using RS and GIS. Furthermore spatial analysis significantly helps to understand agriculture biodiversity constraints.

The combination of multi-spectral and multi-temporal remote sensing data along with local knowledge and simulation models has been effectively verified as a valuable approach to identify and monitor a wide range of agriculturally related characteristics (Oliver et al. 2010). The Spatial variability in crops creates a need for precision agriculture. The identification of such spatial variability is possible through the use of geospatial technology (remotely sensed images of the crops and GIS modeling approach). The spatial variability in crop yield can be accessed through RS and other geospatial techniques (Taylor et al., 1997). In recent times, aerial images have been broadly used for crop yield prediction before harvest (Senay et al., 1998). Vegetation analysis and change detection in vegetation patterns are significant for management and monitoring of natural resource, such as crop vigor analysis (Thiam and Eastman 1999). Spectral bands such as visible red, green, and blue band and near- infrared (NIR) regions of the electromagnetic spectrum have been used effectively to monitor crop health, crop cover, soil moisture, crop yield and nitrogen stress (Magri et al., 2005). There are different spectral indices which are used to estimate crop distribution, crop yield, crop cover etc. These indices include: (a) normalized difference vegetation index (NDVI), based on red and near-infrared (NIR) spectral bands (b) green vegetation index (GVI), based on green and NIR (c) soil adjusted vegetation index (SAVI), based on red and NIR (d) perpendicular vegetation index (PVI), based on red and NIR spectral bands.

## 13.4. Conclusions

At the end of the module, the reader would have gained an insight into the role of remote sensing and GIS in the studies pertaining to biodiversity. Besides, the reader would also have gained an insight into the applications of remote sensing and GIS in management of forest, wildlife and grasslands, besides assessing agricultural diversity.

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# Unit 14: Forest Status

**Unit Structure**



## 14.0 Learning objectives

After studying this unit you will be able to explain:

- About different forests
- Causes and concerns for decline of forests
- Status of forest
- Applications of remote sensing in forest studies
- Applications of remote sensing in wildlife mapping

## 14.1. Forests

Forests play an essential function in global ecosystems and provide a multitude of services such as "shelter, habitats, fuel, food, fodder, fibre, timber, medicines, security and employment; regulating freshwater supplies; storing carbon and cycling nutrients; and helping to stabilize the global climate". Owing to this since long "forests have been under pressure due to increasing demands for shelter, agricultural land, meat production, and fuel and timber extraction, but in recent decades this pressure has increased due to competing demands for agricultural expansion and biofuel production, rapid urbanization and infrastructure development, and increased global demand for forest products" (GEO5).

According to Global Forest Assessment Report 2015, "in 1990 the world had 4,128 million ha of forest (31.6 percent of global land area); by 2015 this area has decreased to 3,999 million ha (30.6 percent)". Forest gains and losses occur continuously globally, and are very complicated to monitor even with high resolution satellite imagery. It is so because natural forest and planted forest area vary dramatically across national conditions and vegetation types. The biggest forest area loss is recorded in the tropics, particularly in (South and South East Asia, Central and South America, and all three sub-regions of Africa).

The top ten forest countries account for some 67 percent of global forest area (Table1). About 1/5th part of geographical region in India is forested; status is grim when compared to other regions. An apparent part of the worldwide forest estate is as of now assigned for various utilize permitting both generation and preservation without prioritising or organizing either. All around 1.049 Mha or one fourth of the timberland domain were assigned as multi-use forests in 2015, an expansion of 81.8 Mha ha (8.5%) since 1990. Multi-use forests enrolled "the greatest gain in South America (87.5 Mha), Oceania (52.5 Mha), and East Asia (48.3 Mha), and enlisted the largest decreases in South and Southeast Asia (56.5 Mha), Europe (31.9 Mha), and North America (19.6 Mha)". Expanding interest for woodland and rural items debilitates to undermine endeavors to capture biodiversity decay and keep up the uprightness of the forests.

## 14.2. Forest Types

It is very difficult to define 'Forest' due to variation in purpose of forest use and their scale. All around the world roughly 800 definitions to define the forests and wooded areas are in use (Lund 2012). Food and Agricultural Organization (FAO) defined forest as land area of more than 0.5 ha with trees higher than 5 m height and more than 10 percent tree cover, or trees capable to attain 5 m height under in situ condition,

**Table1 T**op ten countries by forest Area in 2015 (Source: FAO, 2015)

| | Country | Forest area (000 ha) | % of country area | % global forest area |
|---|---|---|---|---|
| 1 | Russian Federation | 814931 | 48 | 20 |
| 2 | Brazil | 493538 | 58 | 12 |
| 3 | Canada | 347069 | 35 | 9 |
| 4 | United States of America | 310095 | 32 | 8 |
| 5 | China | 208321 | 22 | 5 |
| 6 | Democratic Republic of the Congo | 152578 | 65 | 4 |
| 7 | Australia | 124751 | 16 | 3 |
| 8 | Indonesia | 91010 | 50 | 2 |
| 9 | Peru | 73973 | 58 | 2 |
| 10 | India | 70682 | 22 | 2 |
| | **Total** | **2686948** | | **67** |

Nevertheless it does not include the lands under agricultural or urban practices (FAO 2010). India first time defined forest during the Kyoto Protocol by adopting the definition of United Nations Framework Convention on Climate Change (UNFCCC). Accordingly; forest is a land area having at least 0.05 ha land area and 15% tree cover with at least 2 m tree height. As per UNFCCC this definition includes the closed as well as open forests. These two forests differ in their tree cover. The tree cover between 10 to 40% is considered for open forest while more than 40% reflects closed forest. United Nations Environment Programme follows 40% criteria of tree cover to define the forest (UNEP 2011).

Total forest cover in India is 78.92 million hectare which is 24.01 % of the total geographical area of the country (FSI 2011). It is less than the recommended forest cover (at least one third of the total geographical area of the country). The climax vegetation is represented by either forests or desert vegetation (Mishra, 1989). Primarily on the basis of temperature, Indian vegetation is categorized in four major zones; viz:

(i) Alpine (mean annual temperature is below 7° C, mean January temperature under -17° C, winter is severe with much snow),

(ii) Temperate (mean annual temperature between 7 and 17° C, mean January temperature between -1 and 10 ° C, winter is pronounced with frost and some snow),

(iii) Subtropical (mean annual temperature ranges 17-24° C, mean January temperature ranges 10 to 18° C, winter is definite but not severe, frost is rare) and

(iv) Tropical (mean annual temperature over 24° C, mean January temperature over 18° C, winter is none and no frost.

In 1968, Champion and Seth categorized the Indian forests into five major categories (Figure 1). (i) Tropical (ii) Montane subtropical (iii) Montane temperate (iv) Sub-alpine and (v) Alpine. Due to differences in annual temperature, rainfall and dry periods among the forests; the forests types are futher divided into sub-types or groups (Figure 1) Thus, India has a total of 16 forest vegetation types, presented in Table 1 (Champion and Seth 2005).

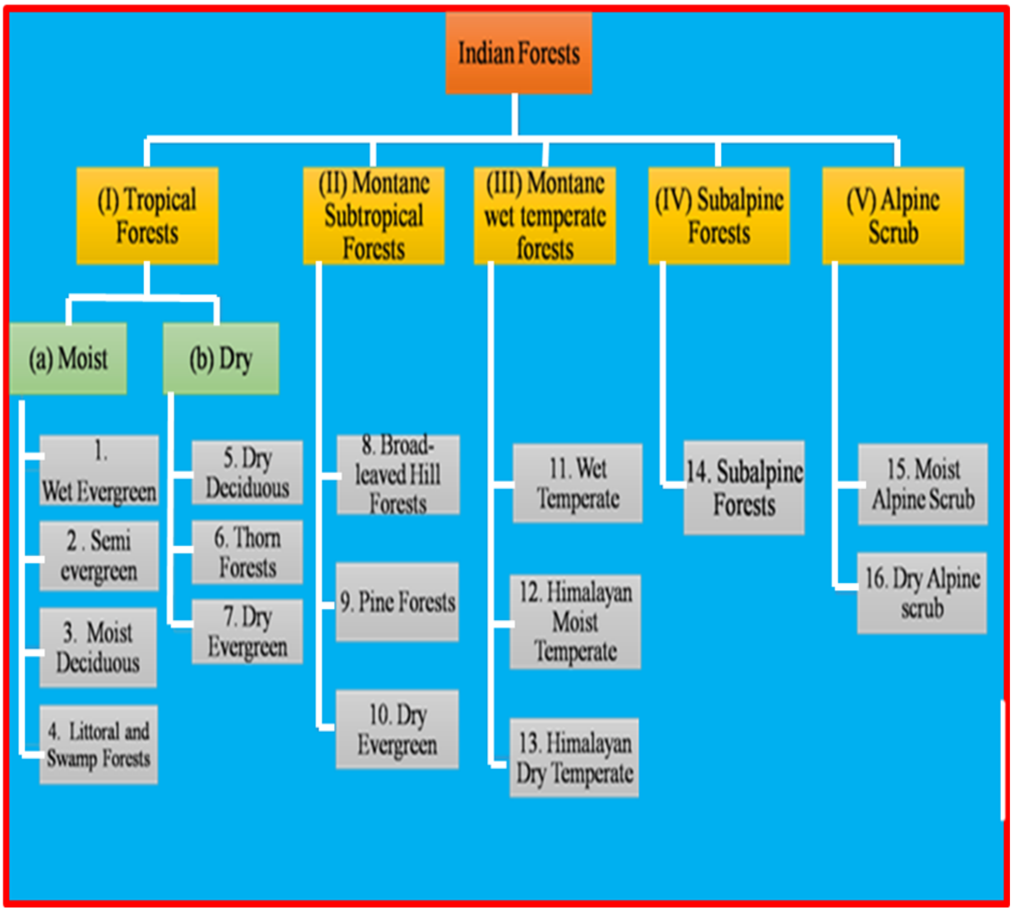


Figure 1. Forests types of India as per classification of Champion and Seth (1968).

A brief description on the sixteen forests types in India as described by Champion and Seth (1968) is given below:

**(I) Tropical wet evergreen forests:** These forests are similar to tropical rain forests, dominated by evergreen trees with close canopy. Evergreen trees are the climax vegetation. Number of species per hectare has been estimated in a range of 40 to 100. Legumes, myrtales,figs and Dipterocarpus are locally dominant trees with Shorea as a common species of North India and Hopea of southern India. Distribution of these forests in India is shown in Figure 2. The tree height ranges between 75m and 100m. There is well developed stratification, having 4-5 strata (Mishra 1989).

**(II) Tropical semi-evergreen forests:**

These forests experience rainfall in between 2000 and 2500mm. Such forests are occurring in Assam, Lusai, Kalimpong and Orrisa hills (Figure 2). In these forests top stories are dominated by the deciduous species while middle and lower stories are dominated by the evergreen species. Albizzia, Bombax, Cinnamomum, Dipterocarpus, Eugenia, Mangifera, Quercus, Terminalia and Xylia are the major genera (Singh et al 2014).

(III) **Tropical moist deciduous forests:** These forests are also dominated by the deciduous species. Understorey is predominated by the evergreen species. The height of trees varies from 30 to 40 m. Rainfall occurs around 1200-2500mm. Adina, Anogeissus, Calycopteris, Cedrela, Pongamia and Termilia are the common species.

(IV) **Littoral and swamp forests:** Such forests are found in coastal regions of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu and Gujarat (Figure 2). The species are mainly evergreen, composed of mangrove and freshwater swamp forests (Singh et al 2014). The predominated species Rhizophora, Avicennia, Sonneratia species. As for as swamp forests is concerned, they occur in Valleys of Brahmaputra and the common trees are Barringtonia, Cephalanthus and Glochidion species. Flora of these forests are very poor (Mishra 1989).

(V) **Tropical dry deciduous forests:** The temperature and rainfall are major determinant factors for the distribution of these forests. The rainfall varies in the range of 800-1200mm. They are also known as tropical monsoon forests occurring in areas of Vindhyan and South India; viz: Maharashtra, Uttar Pradesh, Bihar and Madhya Pradesh (Figure 2). These forests are entirely deciduous, may or may not have Teak and Sal or mixed deciduous vegetation locally dominated by Adina, Anogeissus, Diospyros, Hardwickia, Holarrhena and Terminalia species. The forests are stratified in three layers (Mishra 1989, Sagar et al 2003).

(VI) **Tropical thorn forests:** These forests are also known as xeric forests due to occurrence of very less rainfall which lies in a range of 200-800mm. The dry season is very long. Maharashtra. Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, Uttar Pradesh, Rajasthan, Gujrat and Punjab are common areas for the occurrence of these forests (Figure 2). Deciduous with low thorny or dry deciduous scrub species of Acacia, Balanites, Euphorbia, Prosopis, Salvadora and Zizyphus predominate in such forests (Mishra 1989 and Singh et al 2014). The stratification is very poor.

(VII) **Tropical dry evergreen forests:** Occurrence of rainfall in these forests lies between 870 and 1200mm. They are found on the eastern coast of Chennai (Figure 2). Trees are mainly hard- leaved evergreen type having nearly 20m height dominated by Drypetes, Manilkara, Memecylon and Mimusops species. Stocking density is often very high.

(VIII) **Sub-tropical broad-leaved hill forests:** The vegetation is composed of mainly broad- leaved and evergreen with high forest trees. Such forests are usually seen on western and central Himalayas and on the hills of south India (Figure 2). In southern India the Calolphyllum and Rhododendron species predominate while in eastern Himalayas Quercus predominate (Singh et al 2014). The tree height has been reported upto 35 m (Mishra 1989).

(IX) Sub-tropical pine forests: These forests mainly occur on hills and largely Pine forests extend in the western and central Himalayas between 1000 to 2000m (Figure 2). Interestingly, Pinus roxburghii predominate in western Himalayas and Pinus kesiya in eastern Himalaya (Singh et al 2014). The forests are predominated by species of Pinus and Quercus. At moist zones of Garhwal region; Shorea-Anogeissus-Pinus association is apparent.

(X) Sub-tropical dry evergreen forests: They are low xerophytic, scrubs and open forests dominated by Acacia, Olea, Dodenea and many hardwood species. These forests are found on the hills of Shiwalik, Western Himalaya mainly Jammu and Punjab region (Figure 2).

(XI) Montane wet temperate forests: They are broad- leaved and closed evergreen forests without conifers. The development of buttress does not occur. Lianas and epiphytes are fewer with thinner stems of lianas. Lichens and mosses are abundant (Mishra 1989). There is predominance of shoal forests with Terminalia, Ilex and Rhododendron species in southern India, while Quercus forests with Acer, Machilus and Rhododendro species predominate in eastern Himalaya (Singh et al 2014). The detailed distribution of these forests with major species and climatic conditions of these forests are indicated in (Table 1).

(XII) Himalayan moist temperate forests: Also, they are broad- leaved evergreen forests with oakes and conifers. In general, these forests occur all along Himalaya at 1500- 3300m altitude in the regions of Jammu & Kashmir, Punjab, Himanchal Pradesh, uttrakhand, West Bengal, Assam and Eastern Himalayas (Figure 2). The tree heights are up to 50m. The main species are Abies, Cedrus, Picea, Tsuga (conifers), Acer, Quercus, Rhododendron and Ulmus (oakes). The species composition differs due to differences in altitudes and between western and eastern Himalayas. These forests experience tremendous anthropogenic pressure which could be due to occurrence of our hill stations in these regions.

(XIII) Himalayan dry temperate forests: Basically, they are the open forests with trees having 50 m heights. These forests are found along inner valleys of Himalayas (Figure 2) experiencing less than 1000mm rainfall. Predominance trees are coniferous species (Juniperous, Picea and Pinus).

(XIV) Sub-Alpine forests: These forests occur in the regions of Jammu & Kashmir, Punjab, Himanchal Pradesh, Uttrakhand, West Bengal and North East (Figure 2) at altitude of 2900-3500m. Temperature and precipitation in these forests are very poor (mean annual temperature 2 °C and precipitation 83-600mm). There is dominance of Abies, Betula and Rhododendron species (Singh et al 2014).

(XV) Moist –Alpine Scrub: They occur throughout the Himalaya, above timberline to 5500m altitude, particularly in the regions of Kashmir, Uttrakhand, Sikkim, Manipur, Western and Eastern Himalayas (Figure 2). The dominant genera are Betula, Juniperus, Rhododendron and Sorbus.

(XVI) Dry-Alpine forests: The forests are alpine xerophytic, occur in very low rainfall (370mm) areas at up to 5500m altitude in the regions of Himanchal Pradesh, Kashmir and Uttrakhand. Juniperous, Eurotia and Salix are dominant.

All of the above forests types are experiencing unpredictable anthropogenic activities, among them the dry deciduous forests are most threatened, hence the situation is more alarming for such grasslands. Because of high anthropogenic pressures in the past several decades, the dry deciduous forest cover is being converted into dry deciduous scrub, dry savanna and dry grasslands which are progressively species poor (Sagar and Singh 2005).

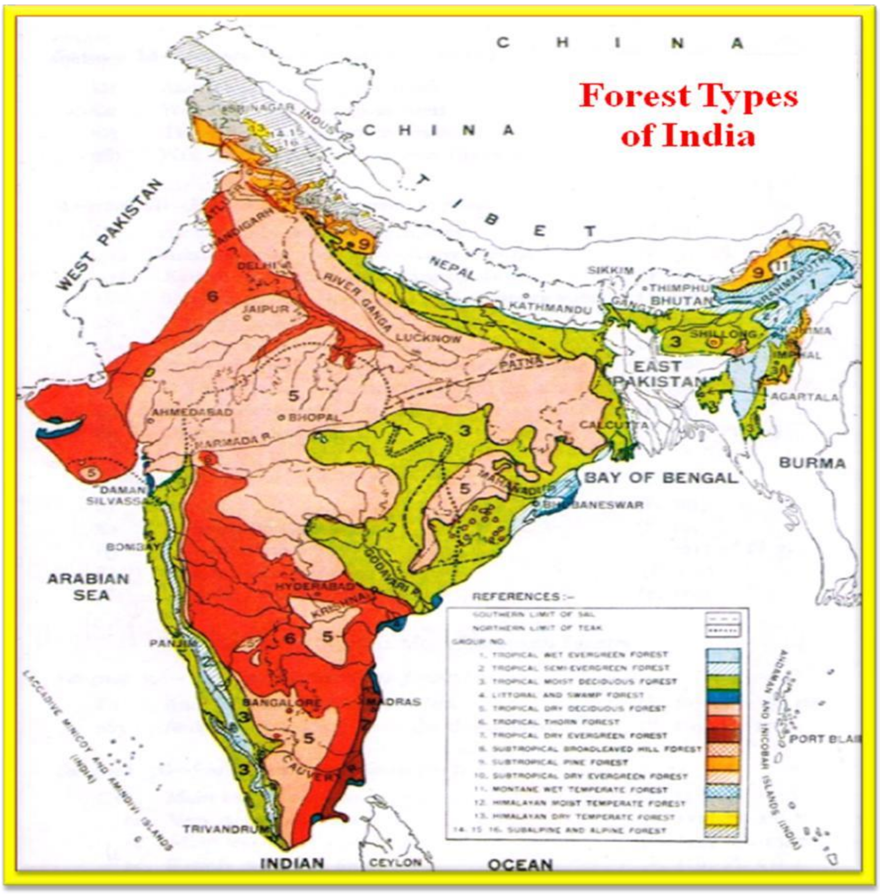


Figure 2. Major Forests types of India (Champion and Seth 2005)

## 14.3. Causes and concerns for decline of natural forest

In developing regions the decline of natural forest was significant between 1990 and 2015 (Figure 1). “Total losses in the tropics have been greatest in Latin America and the Caribbean, followed by those in Africa and in Asia and the Pacific” (Figure 2). Growth of population, industrialization, continued dependence on subsistence agriculture and related agricultural expansion, forest product trade and an absence of alternatives to wood as fuel are the main driving forces in dropping forests in these regions. Rates of deforestation scenario are gruesome in Asia and the Pacific, and in the highlands of West Asia. Increased climatic variability, declining productivity and greater susceptibility to flooding have likewise been credited to high degree of deforestation on the African landmass." In West Asia, the opening up of forests has made greater susceptibility to erosion and land degradation. Woodland status as of now somewhat stable in Europe and North America, as it has been for the past century." Be that as it may, forests in Europe experience the ill effects of acidification, and the boreal (northern) forests in Siberia are vigorously misused too. Although forest cover in India has increased in figures at national level during 2015 assessment, around 2,510 sq. kms of very dense and mid-dense forests have been wiped out since 2013. States of Jammu and Kashmir, Uttarakhand, Kerala, Arunachal Pradesh, Karnataka, Meghalaya, and Telangana have suffered huge loss of forest cover. Around 2,254 sq. km of mid-dense forest cover has been converted into non-forest lands since 2013.

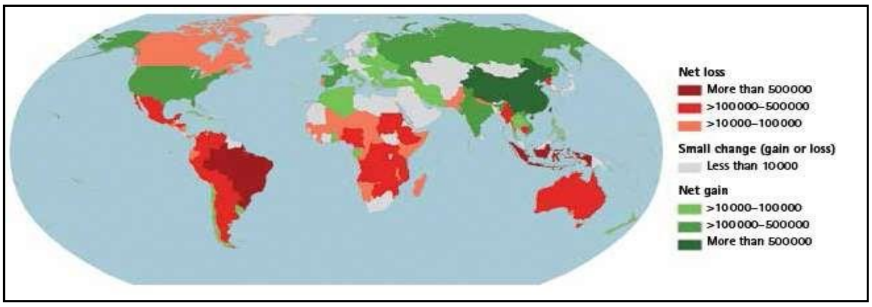


Figure1. Annual net forest gain/loss (ha) by country (1990–2015) (Source: FAO, 2015)

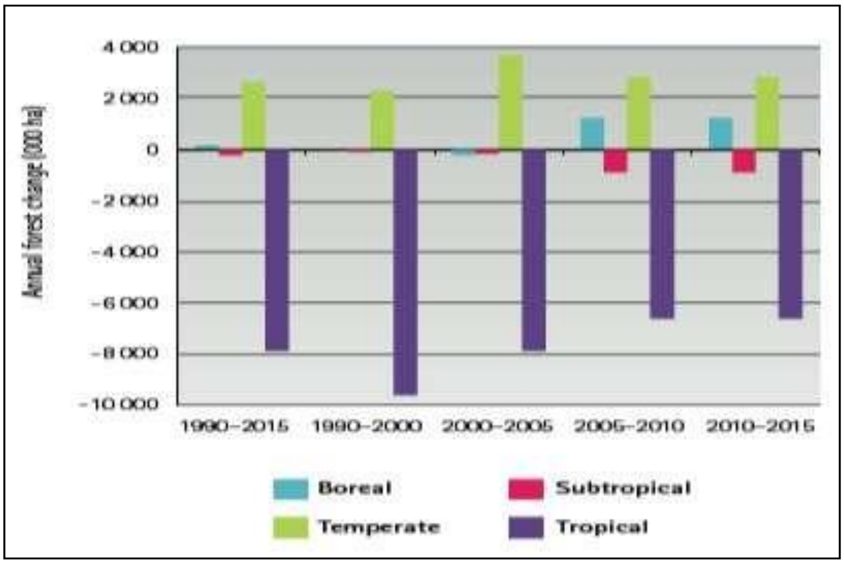


Figure2. Annual forest area change by climatic domain (000 ha per year) (Source: FAO, 2015)

**The major drivers of forest resource stress are:**

**a) Demographic Change:** Between 1948 and 2015 human populations have nearly tripled. It is predicted that the rise will continue. This will no doubt put greater pressure on remaining forest resources to provide goods and services. For instance, "a test of the 62 tropical countries that had a mean rate of natural forest loss above zero in 2000–10, and by employing logarithmic transformations, resulted in a correlation coefficient of r = 0.615 between Log10 (deforestation rate2000–10), and Log10 (population growth rate2000–10). However, the relationship between the rate of change of natural forest area, and the rate of population growth is now more complex than it was in the 1980s and 1990s, owing to the increasing dominance of controlling forces of forest expansion over drivers of deforestation, the differential influences of urban and rural populations, and the effect of time lags. For example, for the five tropical countries with mean population growth rates of 2–4 million persons y-1 in 2000–10 (UN, 2013), the rate of deforestation varied from 71 K ha y-1 (Pakistan) to 3030 K ha y-1 (Brazil), and natural forest area actually rose at a rate of 43 K ha y-1 in India, which had the highest population growth rate in the tropics (16.4 million persons y-1)" (R.J. Keenan et al., 2015).

**b) Agricultural land expansion:** With continue rise in population, it is likely that requirement for alteration of more forest land to agriculture will continue. Unless agricultural productivity increases significantly on existing farm lands, the situation will be prominent in the tropics. At present 37.4 per cent of global geographical area is used for agricultural production. As for India where majority of the population in rural parts have agriculture as the primary occupation, about 42 per cent of the total land surface is under agriculture. It remains the foremost for rural economic growth. "Between 2000 and 2050, global cereal demand is projected to increase by 70–75 per cent while meat consumption is expected to double. Meeting these needs, while avoiding a large expansion of agricultural land and protecting biodiversity, will be a major challenge".

c) **Infrastructure and industrial growth:** Communication, transport, energy, healthcare, housing, and knowledge infrastructure are the major priorities for most of the developing nations as their main focus is on sustaining the economic growth rates. Since, land is the primary necessity; forest clearance has always been the easy way out. “Special economic zones and special economic regions are also expected to have strong influence on the socio- economic profile of people in their catchments, leading to changes in consumption patterns and way of living. The agro and rural industry segment depends upon the farm and non-farm production of raw material, a large proportion of which comes from forest products” (FRA, 2015).

**d) Urbanization:** Urbanization put forth great stress on ecosystems and natural resources. High urbanization rates leading to rise of consumption rates increases the stress on finite forest resources. Latin America and the Caribbean is the most urbanized parts in the developing world. “Africa is urbanizing increasingly, although most of the population remains rural; Asia and Oceania and Latin America and the Caribbean are already largely urbanized and migration streams are increasingly international; and the United States and Europe have high internal migration associated with labour mobility” (FAO).

**e) Demand for wood:** Since 1990 as the demand for wood has increased, the amount of woodland designated to generate it has increased too. “Wood demand has gone from 2.75 billion m3 per year in 1990 to 3.0 billion m3 per year in 2011. For the period 1990–2015, the area designated for wood production and multiple- use increased by over 128 million ha. About two- thirds of the total forest areas designated for multiple-use are found in the high-income countries and only one tenth in the low-income countries” (FAO).

**f) Climate change**: “Climate change is increasing in importance and will have profound impacts, particularly in combination with other threats.” Alterations in precipitation and evaporation are likely to have foremost impacts on hydrological regimes, which will have adverse impact on forest health. “The consequences of climate change on the monsoon pattern and concomitant natural calamities (and their impact on crop production), receding glaciers, biodiversity, land degradation, desertification and soil erosion are being debated. The impact of climate change on forests is expected to be in line with changes in climatic conditions, to be manifested in species composition, profile, productivity, resilience and biodiversity. In the Arctic, tundra habitats are shrinking owing to tree-line advance. In India, with around 70 million tribal and 200 million non-tribal rural people depending on forest resources for their subsistence needs, climate change will have an impact on their livelihoods" (FAO).

**g) Political and institutional environment:** Meeting expectations of the stakeholders requires major adjustments in the responsibilities and structure of the forest administration. "The increasing decentralization of the democratic processes, community empowerment, participation in decision making, increasing inter-sectoral linkages, and economic aspects governing decision making require urgent development of skills for interpreting conservation and ecosystem services in economic terms and support to conservation on the basis of economic imperatives. A long-term strategy will be needed to deal with the challenges of improving governance, accountability and transparency in all spheres of central and local governments, the corporate sector and community levels" (FAO).

## 14.4. Consequences of Forest resource scarcity

**a. Impact on stability of soil:** The roots of trees are most essential for conservation of soil. It works as the protection against avalanches and landslides, for protecting coastal areas, and for stabilization of sand dunes. Loss of forest will lead to slope instability and makes the soil more vulnerable towards erosion by various agents of denudation.

**b. Impact on global climate and pollution:** Forests are also a vital purifier of air and water. They contain about half of the carbon in terrestrial vegetation (represent a considerable biomass / carbon stocks) in terms of their weight, their density and scale. "Forests contribute about 80% to the exchange of carbon between vegetation, soil and atmosphere. Forest fires emit methane (10% of all methane linked to human activities comes from the burning of forest biomass) and nitrous oxide (N2O). These two gases are significant greenhouse gases. Greenhouse gas emissions are known to cause global warming of the planet that currently leads to extremely important climate changes" (FAO). "Scientists predict that the pace and scale of climate change could eventually exceed certain ecological limits or thresholds, leading to surprising and dangerous consequences such as the alteration of the world ocean's chemical composition with increasing proportions of acidifying carbon, the global loss of coral reef ecosystems, or the collapse of the West Antarctic ice sheet" (Febry et al., 2008).

**c. Impact on biodiversity loss:** Primary forest accounts for 80% of land biodiversity. The primary stresses on biodiversity deals with habitat loss and degradation, alien invasive species, climate change, overexploitation, and pollution. “One driver can trigger a series of drivers and pressures that act in a domino fashion. For example, concerns about climate change impacts, including crop vulnerability and food insecurity, gave rise to policies that included mandates to increase biofuel production, such as legislation introduced in 2003 in the EU and in 2008 in the United States. Now, the growing demand for biofuels has taken a toll, with expanses of forests and natural lands in South East Asia being converted into mono-crop plantations.” (GEO5)

**d. Impact on local climate:** Deforestation causes excessive water runoff, leading to disastrous flooding as runoff is no longer guarded by the plant roots. Loss of forest can change the local precipitation regime of a region.

**e. Impact on human health:** The destruction of forest habitats for many species facilitates the transmission of infectious diseases to humans through contact with mosquitoes, monkeys, virus- and bacteria -carrying rodents that are potentially hazardous to humans.

## 14.5. Forest status in future

Forest area change differs considerably by region. As reported in the Global Forest Resources Assessment, 2015, Figure 3 shows “forest area by region as calculated from FRA data for the period 1990-2010 (solid line); projected using Global Forest Resources Model (GFRM) towards 2050 (dotted line); and extrapolated from the country specific aspiration for 2030 as reported in FRA 2015 (large dots). South America has the largest proportion of projected forest loss, followed by Africa. Forests in all other regions are projected to rise though. (Note that the divergence for Asia and Africa is strongly influenced by the low representation of reporting countries, and changing trends expected from certain countries within these regions).”

“South America and North America have the largest areas designated for protection and small projected loss in protected areas. Africa and Asia are projected to suffer the highest portion of protected areas loss (–0.7 percent and –0.9 percent)”. Sub- regions such as Northern Africa, East Asia and Western and Central Asia, have very small protected areas with little or no projected loss in areas, “Loss is expected in Brazil and Mali, and gain is expected in China, India and the Russian Federation. On the other hand, Bhutan, Belarus, the United States of America and the Islamic Republic of Iran had their forest area increase over the past 15 years but expect forest loss in the next 15 years. While, countries such as Argentina, Indonesia, Nepal, Nigeria, Thailand and the United Republic of Tanzania, are expecting losses observed in the past to be reversed into forest area gains.” (FAO) The forests that are under the threat of conversions are clearly the production and multiple-use woodlands within the tropical region. The protected forest areas showed relatively low risk towards the threat of being converted to other land uses in the near future.

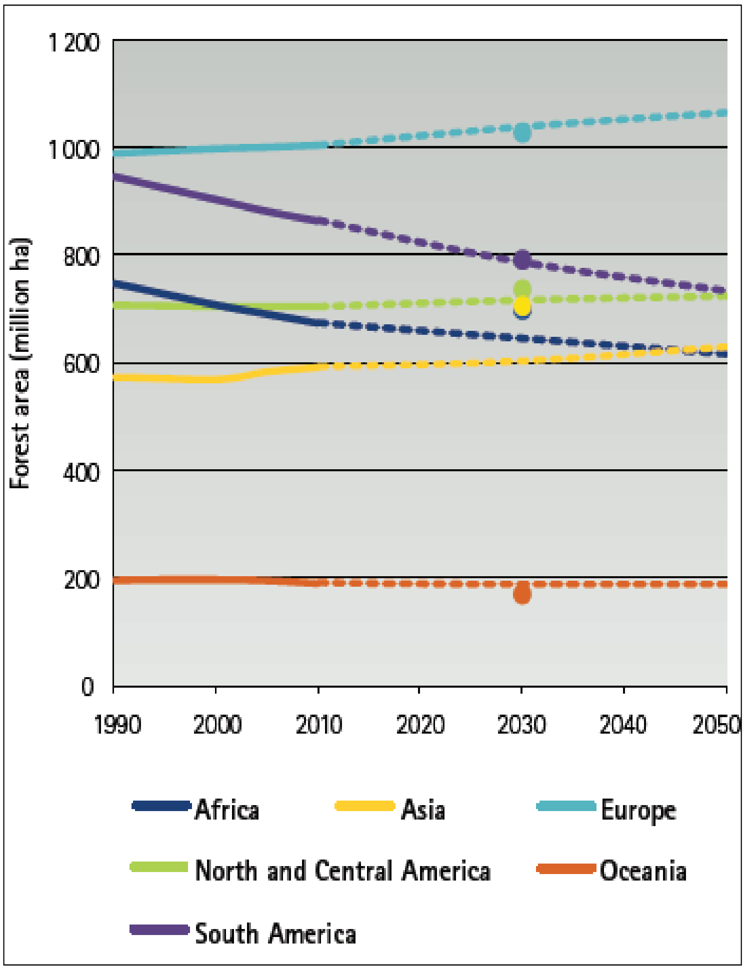


Figure 3 Projected forest area by region (1990–2050) the solid line is from FRA data, the dotted line is projected from the GFRM and the large dots are country aspirations reported in FRA 2015.

## 14.6. Data challenges in Indian forest sector

“What’s missing from Indian forest data?” is indeed an important question towards our actions for forest management. According to the International Institute for Applied Systems Analysis (IIASA) and India’s Technology Information, Forecasting and Assessment Council (TIFAC), in India the serious problems is present not only in forest data quality, but in the uses to which these data are put.

Examples of problem areas include:

• “There is no reliable assessment of the growing stock of trees at state level. Other deficits include a lack of data on different products from forests and a lack of increment and biomass data. It is difficult to make economic assessments and set policies without quality data and information on both the tangible and intangible benefits of forests.”

• “Trees outside forests, mostly growing on private lands, are a major resource in India. Indeed, about 80 percent of all timber produced in India comes from non-forest areas under private ownership. However, there is no efficient inventory for trees outside forests.”

• “Many deficits in the Indian forestry inventory are due to the ongoing degradation of Indian forest resources. Experts suggest that socioeconomic developments have brought forest management, in very large parts of the country, to a standstill. Large tracts are devastated within short periods of time but these degraded areas are not monitored nor are inventories updated”.

• “Non-timber forest products (NTFPs) are of growing importance, particularly for export. Yet there are many data gaps with respect to the production and consumption of NTFPs. Moreover, data are not collected in a uniform fashion.”

• “There are scarcely any data and statistics on ecotourism, either in terms of demand or supply. To develop the forest-related ecotourism, an inventory of areas of potential interest to ecotourists is needed.”

• According to the latest assessment, the forest cover of India is 67.7 million ha with a growing stock of 4.6 billion m3. “This forest cover corresponds to 20.6 percent of the geographical area but falls short of the national goal (National Forest Policy 1988) of achieving forest cover of 33 percent of the land area. But how relevant is this goal?

Of the assessed forest cover of 67.7 million ha, only 5.6 million ha is very dense forest. Some 33.2 million ha is moderately dense forest and 28.9 million ha is open or degraded forest. Thus the forest- cover objective needs to be combined with quality objectives."

## 14.7 Applications of remote sensing in Forest studies

Young and Giese (2003) summarized forest science and management into three categories: A. forest biology and ecology (e.g. forest biomes of the world, forest ecophysiology, forest soils, forest ecosystem ecology, landscape ecology, and forest trees: disease and insect interactions); B. forest management and multiple uses (e.g. forest management and stewardship, nonindustrial private forests, measuring and monitoring forest resources, silviculture and ecosystem management, forest-wildlife management, forest and rangeland management, forest and watershed management, forest and recreation behavior, behavior and management of forest fires, timber harvesting, wood products, and economics and the management of forests for wood and amenity values); and C. forests and society (e.g. urban forest, and social forstry: the community-based management of natural resources). As a matter of fact, remote sensing has more or less served all the three categories. Several examples in remote sensing of forestry studies are provided as follows. The selected examples were included in the papers that were either highly cited or newly published Science Citation Index (SCI) papers.

### 14.7.1 Timber Volume Estimation

Timber volume is simply function of Tree height (ht) and diameter of tree at breast height (DBH). There are some adopted techniques to calculate the volume of standing trees .i.e. volume table, volume equation. These techniques also depend upon the species in the forest stand and the region where the stand is located. Thus the timber volume can be calculated by using any of the above technique depending upon desired accuracy, money, time and labour. In Malili-Celebes (Indinesia), before estimating timber volume from aerial photographs, the relationship between dbh and crown diameter of upper canopy of trees was first investigated. As species identification was impossible on 1:10,000 scale photographs, all species were included in the test.

The regression equation was found to be:

$$d= 3.5C+12.3$$

where, d=dbh and C= crown diameter

### 14.7.2 Species Composition (biodiversity)

Turner et al. (2003) stated that the recent advances in remote sensing, such as the availability of remotely sensed data with high spatial and spectral resolutions, make it possible to detect key environmental parameters, which can be applied to determine the distribution and abundance of species across landscapes via ecological models. This approach, in general referred to as indirect remote sensing of biodiversity, plays a major role in this research area. For example, Defries et al. (2000) applied the 1km Advanced Very High Resolution Radiometer (AVHRR) to estimate and map percentage tree cover and associated proportions of trees with different leaf longevity (evergreen and deciduous) and leaf type (broadleaf and needle leaf).

### 14.7.3 Forest Ecophysiology

Kokaly and Clark (1999) developed an approach to estimate the concentrations of nitrogen, lignin, and cellulose in dried and ground leaves using ban-depth analysis of absorption features (centered at 1.73 μm, 2.10 μm, and 2.30 μm) and stepwise multiple linear regression. As mentioned above, hyperspectral remote sensing was used to estimate the leaf pigment of sugar maple (Acer saccharum) in the Algoma Region, Canada, and promising results were obtained (Zarco-Tejada et al., 2001).

### 14.7.4 Forest Ecosystem

Jin et al. (2011) developed an algorithm based on a semi-empirical PriestleyTaylor approach to estimate continental-scale evapotranspiration (ET) using MODIS satellite observations. The seasonal variation in ET has been indicated as a key factor to the soil moisture and net ecosystem CO2 exchange through water loss from an ecosystem. Lefsky et al. (2002) reviewed Lidar remote sensing for ecosystem studies. Lidar is capable of accurately measuring vertical information besides the horizontal dimension, such as the three dimensional distribution of plant canopies and subcanopy topography (Lefsky et al., 2002). More specifically, Lidar can provide accurate estimates vegetation height, cover, canopy structure, leaf area index (LAI), aboveground biomass, etc (Lefsky et al., 2002).

### 14.7.5 Measuring and Monitoring Forest Resources

Cohen et al. (1995) stated that "remote sensing can play a major part in locating mature and old-growth forests", and applied a number of remote sensing techniques to estimate forest age and structure. Over a 1,237,482 ha area was investigated and an accuracy of 82 per cent was obtained. Maps of species richness have been recognized as a useful tool for biodiversity conservation and management due to its capability of explicitly describing information on the spatial distribution and composition of biological communities (Hernandez-Stefanoni et al., 2011). Hernandez-Stefanoni et al. (2011) tested remotely sensed data with regression kriging estimates for improving the accuracy of tree species richness maps, and concluded that this research will make a great step forward in conservation and management of highly diverse tropical forests.

### 14.7.6 Damage Assessment

The use of remote sensing in the detection of the effects of damaging agents on a forest precedes most other remote sensing forestry uses. Forest damage is defined as any type and intensity of an effect, on one or more trees, produced by an external agent that temporarily or permanently reduces the financial value, or impairs or removes the biological ability of growth and reproduction. In the United States, insects and diseases account for a timber loss equal to our annual growth and this loss exceeds that from fire by seven times. Because the damaging agents are dynamic forces, entomologists and pathologists find that remote sensing techniques are most valuable when they are used at critical periods of stress. One damage causing agent may produce a number of damage syndromes conversely syndrome may have been caused by any number of agents.

a) **Insects:** Forest insects cause symptoms of tree and forest injury which are more easily recognized than those caused by forest diseases or air pollution. For example defoliators of coniferous or hardwood trees frequently cause the foliage to change color from a normal green-yellow to yellow or dark yellow-red. These changes are readily visible, occur over large areas, and can be mapped by direct observation. When many trees are attacked at one time and begin showing signs of stress by changes in foliage color, they can be differentiated from healthy trees by remote sensing methods.

**b) Disease:** Most visible symptoms of forest disease are evident only when the disease is far advanced in the host tree. As with insect damage, manifestations of disease show as discolorations and thinness of foliage. Oak was affected by fungus which occludes the water conducting tissues of oak. The symtoms show up as dying back of the top and discoloration of wilting oaks. Damages caused by cronartium ribicola Fischer on Pinus strobes are easy to detect on medium scale color and color infrared photos.

**c) Deforestation:** Since deforestation is a continuing process, efforts to inventory and monitor changes are very closely related. There are many uncertainties about actual rates of deforestation (Sader et al.1990), hence the need for accurate, up-to-date monitoring schemes. Techniques used to inventory these areas also can be applied in their systematic monitoring to create a time-serie sof data describing rates and magnitudes of deforestation. In Rondonia Brazil, for example, Landsat MSS (1980) and TM (1986) imagery were used to define the area and deforestation rates for a study area of approximately 30,000 square kilometers (Stone et al. 1991). The researchers found that 3168 square kilometers (528 squarekm/year) of new clearing occurred between 1980 and 1986. Earlier research (Woodwell et al.1987) had revealed a rate of clearing of 14 square km/year from 1972 - 1978 and 79 square km/year from 1978 - 1980. Historical records have also been used in GIS to identify changes in forest cover. Between 1979and 1984, a land resource inventory project was completed in the Jhikhu Khola watershed in Nepal (see Schreier et al. 1989). Land use information was digitized using 1:50,000 scale topographic maps as the base for information collected by surveying 1980. Land use data that had been divided into three broad categories in the original 1950 topographic map were also digitized. The area of each land use type was calculated in the GIS and then the two layers were subtracted. “Although somewhat crude, this information was found to be very useful in producing a land use change overview map” (Schreier et al. 1989). The thirty-year interval revealed that about 50 percent of the forestland has been lost to shrub and agriculture. A second three-year project was initiated in 1988 to "examine processes relating to soil erosion, sediment transport, soil fertility changes and land use changes in a quantitative way" in the Jhikhu Khola watershed (Schmidt and Schreier 1991). Forest and agricultural land uses were mapped and digitized using 1:20,000 scale and aerial photographs taken in 1972 and 1989. Changes in the area of four land uses were calculated for each date: forest, grassland, irrigated agriculture and sloping terraces. In this case, using a larger scale and a different land cover scheme, the researchers found that the forest area had not decreased substantially (only 1 percent) during these 17 years.

d) **Forest Fires:** Fire is one of the disasters causing threats to the forests and the ecosystem throughout the world. Fires have adverse effects on soil, forests and humans. During the process of burning, the soil nutrients are reduced and the soil is left bare making it more susceptible to both soil and water erosion. The forest cover is drastically reduced through the death of fire intolerant tree species. Fire also leads to an increase in greenhouse gas emissions. Air pollution due to smoke causes prolonged effects on human health such as respiratory and cardiovascular problems. Mongolia has a serious increase in forest fires.

Figure 1. Forest fire in California (sep,2008)
Source: https://en.wikipedia.org/wiki/Wildfire

Giglio et al. (2003) presented an enhanced contextual fire detection algorithm in order to identify smaller, cooler fires with a significantly lower false alarm rate, and promising results were obtained. Lentile et al. (2006) reviewed "current and potential remote sensing methods used to assess fire behavior and effects and ecological responses to fire". Urban forest Jensen et al. (2003) investigated the relationship between urban forest leaf area index (LAI) and household energy usage in a mid-size city, and concluded that the increase of LAI resulted in the less energy usage. Zhang et al. (2007) applied remote sensing to map the distribution, classification and ecological significance of urban forest in Jinan city

## 14.8 Application of remote sensing in wildlife mapping

Human induced undesirable changes such as land encroachments leading to wildlife habitat loss, pollution and introduction of invasive species pose serious threat to wildlife health and richness. Hence in order to restore wildlife habitat, fragmentation and to prevent further local and global extinction of any species, it is imperative to understand and carry out comprehensive study of the wildlife population and pattern. But most of the wildlife habitats are located in those areas where accessibility is not easy because of difficult terrain. Also the study of wildlife conservation and management including wildlife densities, living pattern, population and habitat with the help of conventional methods happens to be tough, time taking, risky and requires lot of resources. Also expressing and measuring biodiversity including study of organisms and their biotic and abiotic components happens to be intricate because of the versatile nature of biodiversity. Remote sensing can answer these problems as the number of strategies for wildlife studies including investigation of biodiversity, wildlife habitation mapping and animal movement modeling can be executed with the help of remote sensing and inventory database.

Remote sensing is a computer based software application which obtains and processes geographic information from satellite or air born sensors. Remote sensing measures the reflected and emitted electromagnetic radiations from the objects. The spatial coverage provided by the remote sensing occurs across wide range of electromagnetic wavelength.

Remote sensing is capable of providing uniform consistent spatial observation data at wide scale domain. The images and photographs obtained from the remote sensing helps greatly in the investigation of physical conditions. It can be further enhanced for better accuracy using remotely sensed data and field study (multi stage approach). Remote sensing can be classified based on either direct approach or indirect approach (Chambers et al., 2009). The direct approach suggests direct observation of spatial features, objects or communities using satellites or air born sensors using high resolution spatial sensors and hyperspectral sensors (Turner et al., 2003). The indirect parameters are dependent on the environmental parameters such as land use, land cover, species composition etc., obtained from remotely sensed data as surrogate for precise measurement of the potential species verities and patterns (Collingwood et al., 2009).

Satellite Remote Sensing offers information on vegetation type, forest cover, and their changes at global, regional, national, or micro level studies (Roy et al. 1987, Unni at al. 1985, Porwal and Pant, 1986). Remote Sensing plays an important role in forest management with reference to wildlife management, fire control, grazing land management, soil and water conservation, mapping of sites suitable for social forestry and afforestation programmes.

Some of the areas where remote sensing can be useful for wildlife studies are:

- Revision and updating of stock maps
- Fire risk Zonation o Planning response routes
- Protected area management
- Site suitability analysis for Afforestation
- Soil and water conservation
- Mapping wildlife corridors
- Habitat suitability Mapping
- Prediction Analysis
- Change Detection Analysis
- Mapping Required Resources for Wildlife
- Real time tracking o Population Mapping
- Developing and updating Web Portal of particular Wildlife

Wide varieties of satellite data sets are available commercially including digital data sets obtained from LANDSAT-5 (Land Observation Satellite), TM (Thematic Mapper), LISS-3 (Linear Imaging and Self Scanning Sensor), IRSID (Indian Remote Sensing Satellite Series 1D), SPOT (Système Probatoire Pour l'Observation de la Terre) and

XS (Multi-Spectra). TM sensors helps in availability of multi temporal data with replicated coverage of 16 days for examining temporal changes occurring in the wildlife habitat and communities. Latest series of Indian Remote Sensing Satellites and SPOT series (French satellites) come with the advantages of stereo data acquisition competence with ±26° off-nadir viewing potential of and higher spatial resolutions of 6 (IRS1C/IRSID PAN data) to 10m (SPOT PAN data). The sensors LISS-3 on board IRS1C/D satellites give multi-spectral data obtained in four bands of visible and the near infrared (VNIR) and short wave infrared (SWIR) zone. LISS-3 images contain region of 124/141 km for the VNIR bands (B2, B3, B4) and 133/148 km for the SWIR band (B5) perceived from an altitude of 817 km (IRS1C) to 780 km (IRS1D) with recurring coverage of 25 days. The VNIR bands have spatial resolution of 24m and SWIR has nearly 71m of resolution. The spatial resolution of LISS-3 of the IRS satellite series and XS of the SPOT satellite series are superior to LANDSAT- TM.

In order to conserve and manage wildlife system, many countries maintain an inclusive forest account databases of protected areas. These vegetation inventory databases are important for the wildlife studies as they are extensive at comparatively larger spatial scales (example, 1:20,000), reduce the cost of production and they are generally allocated in convenient GIS format (McDermid et al., 2009). Generally different management and conservation strategies cover only particular species and protected areas, which happens to be only 5.19% (7.74 million km2 ) of the total earth's land surface (WCMC 1992). Many of these biological reserves and protected areas are designed for aesthetic purpose and tourist attraction, rather than wildlife conservation purpose. In these areas, sometimes wildlife is exposed to unsuitable land use practices such as grazing livestock, agriculture, mining etc. Poaching of some species makes them vulnerable and sometimes some deceases and invasive species invade wildlife population (Prins 1996). Therefore thriving wildlife resource require up keeping of optimal conditions within wildlife reserve as well as outside it. The successful management and conservation of wildlife reserve can be carried out well if there is complete availability of information and relevant knowledge about the spatial and temporal distribution of wildlife population. The successful mapping of wildlife distribution can be accomplished using satellite remote sensing.

Coral reef mapping of 9 reef classes was done with 37% accuracy with LANDSAT TM, 67% with aerial photography and 81% with an airborn CASI hyperspectral scanner by Mumby and his coworkers (1998a). Thermal scanners have been used to measure the population of deer, elk, bison and moose in Canada by comparing ground counts with aerial count, as thermal scanners are known to determine the presence or absence of those species which are not easily observable during certain climatic conditions (Intera Environmental Consultants, 1976). Error can sometimes occur during thermal scanning because of sunlight heated objects and presence of non- target animals. Many of the species like earthworms and termites are known to cause interference because of the roughness caused either by their exoskeleton or by their impact to the soil surface. Certain species which readily modify their environment hamper the applicability of remote sensing satellite as the sensors are incapable to capture the impact of such species on the environment. In such conditions radar can be helpful to map such animals as it is sensitive to micro topography (Weeks et al. 1996; Van Zyl et al. 1991).In the figure 2, GPS satellites and radio tags provide key data on animal location and movement of Merriam's Turkey. This data would be useful to derive statistical models of space and resource use.

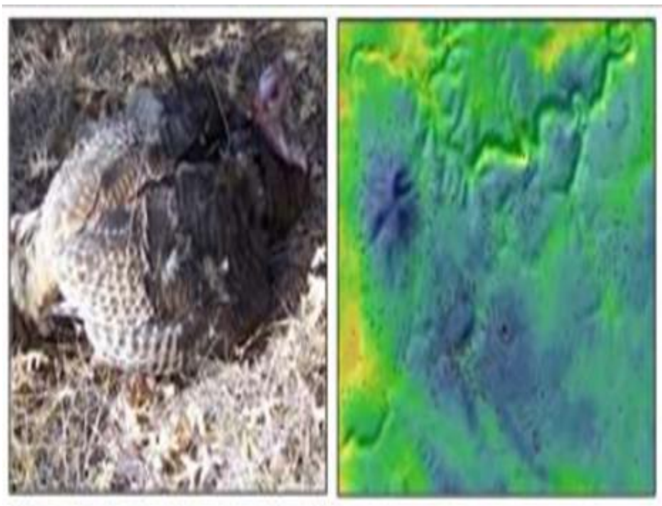

**Figure 2: Statistical Model to Predict Animal Location and Movement for Merriam's Turkey**
(Source: https://nau.edu/LCI/LLECB/Wildlife-Habitat-Modeling/ )

Integrated Normalized Difference Vegetation Index (NDVI) or 'greenness index' was reported to be associated with biome averages of net primary productivity (Goward et al., 1985). It has also been demonstrated that there exist sharp linear relationship between vegetation indices observed from the satellite and seasonal primary production (Prince, 1991). Similarly several studies have been carried out which demonstrate relationship between NDVI and biomass production but fewer studies have been carried out to show the linkage between NDVI and wildlife (Muchoki, 1995;

Omullo, 1996; Oindo, 1998). Since more than three decades remote sensing has been widely used to confine the distribution of zones appropriate for the specific wildlife habitat. Landsat MSS was used for mapping suitable areas for prairie chicken (Cannon et al., 1982) and Wiersema (1983) used it to map snow cover to detect south facing snow free slopes which forms winter habitat of alpine ibex. Landsat TM was used to map wetland suitable for foraging wood stork by Hodgson et al., (1987) and it was used by Congalton et al., (1993) for mapping suitability of land for deer identification. Landsat TM was used to evaluate availability of habitat for wood thrush (Rappole et al., 1994). These studies relied on the vegetation map acquired from the remote sensing as the sole explanatory variable but land suitability for the wildlife may be found out using more than one factor for better representation.

## 14.9 Application of Geographic Information System (GIS) in wildlife mapping

GIS is computer based system designed for capturing, managing, manipulating, analyzing, modeling and displaying spatially geo-referenced data and for solving complex management problems. GIS helps in easy management of natural and man-made resources at wider scales extending from local to global scale. GIS is capable of overlaying information from different thematic maps depending on user specific logic and derived map outputs. Because of the wide array of GIS application, task defined systems have been created which include engineering specific, land based information, generic thematic, statistical and property lot mapping, environmental planning systems and image processing systems related with remotely sensed data and landsat. In GIS, the attribute data are stored in relational database and geospatial data are saved in map layers, map themes and map coverages. These layers geographically referenced to one another happen to be the foundation of GIS. The gist of map layers refers to spatial as well as attributes data. GIS database sourced map coverages and GIS analysis based results can be displayed and printed in maps, tables and figures and shared various GIS software packages.

The increasing use of geospatial technology that involves the use of remote sensing, GIS and GPS have helped vastly in research pertaining to ecological domain. In the context of wildlife management, GIS is used for mapping, monitoring, analysing and modelling the nesting behaviour and habitats of wildlife populations; wildlife distributions; movement patterns; and to identify potential nesting habitats (Lawler & Edwards 2002; Harvey & Hill 2003; Gibson et al. 2004). which can provide valuable information for the development of management strategies (Lawler & Edwards 2002; Harvey & Hill 2003; Fornes 2004; Gibson et al. 2004; Greaves et al. 2006; Shanahan et al. 2007; McLennan 1998; Maktav et al. 2000; Fornes 2004; Beggs 2005).

GIS easily helps in creating maps that cannot be created by using traditional cartographic method. Moreover GIS software packages offering modeling tools can easily create measurements and analyze attribute data. The information in GIS is stored digitally hence it is easily accessible for evaluation and analysis making it easy to be shared among wildlife managers and public.

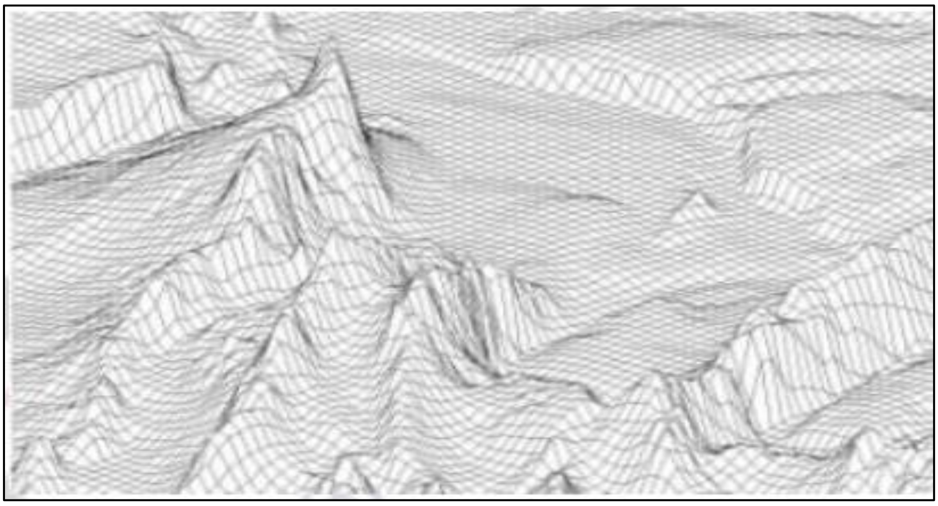

**Figure 3: A Digital Elevation Model showing continuous coverage of slope, aspect, and elevation in a raster grid across an entire area. This area is the east side of the Cascade Mountains in west-central Washington State. Each regular grid cell is 1 km on a side. Figure developed and provided by Steve Brown at the University of Montana**

GIS particularly offer potential to enhance the accuracy and precision and long term inexpensive basic actions of wildlife management and conservation such as inventorying, analysis, monitoring, planning and communication. Wildlife management actions are ideally based on intimate information of natural landscape, land use and mass of interior and exterior threats to it. GIS and similar type of computer based technologies such as remote sensing provide means to acquire huge amount of geospatial data and offer powerful analysis tools for understanding linkages between different types of data and help in manipulating these data over larger areas for various development goals for wildlife. Geographic information on the population scattering of wildlife forms a basic source of data in wildlife management. Usually the distribution is derivative from observations on the ground. Radiotelemetry and satellite pathway have been used to evidence the distribution of a diversity of animal species (Thouless and Dyer 1992).

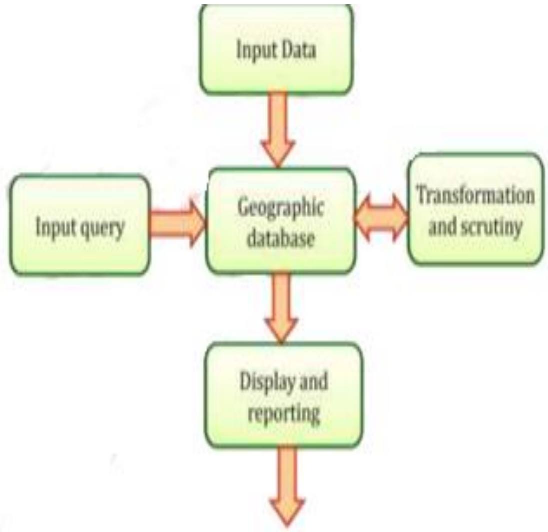


Figure 4: Mechanism of GIS

Aerial inspection process based on direct observation increased by use of photography have been used to map the distribution of a range mammals (Norton-Griffiths 1978), birds (Drewien et al. 1996; Butler et al. 1995) and sea turtles and marine mammals (Wamukoya et al. 1995).


**Figure 5: Sketch for GIS based suitability mapping**

GIS mapping is progressively being used for wildlife density mapping and dispersion mapping derived from ground observation or aerial survey. Habitat studies based on GIS commonly merge information on vegetation type or different area descriptor, with other land feature reflecting the reserve base factors and other significant factors. A model for Florida scrub jay developed included vegetation type and soil drainage to differentiate primary habitation, secondary habitation and unsuitable areas (Breiniger et al., 1991). A GIs-based model was developed to categorize prospective nesting habitation for cranes in Minnesota (Herr and Queen, 1993).

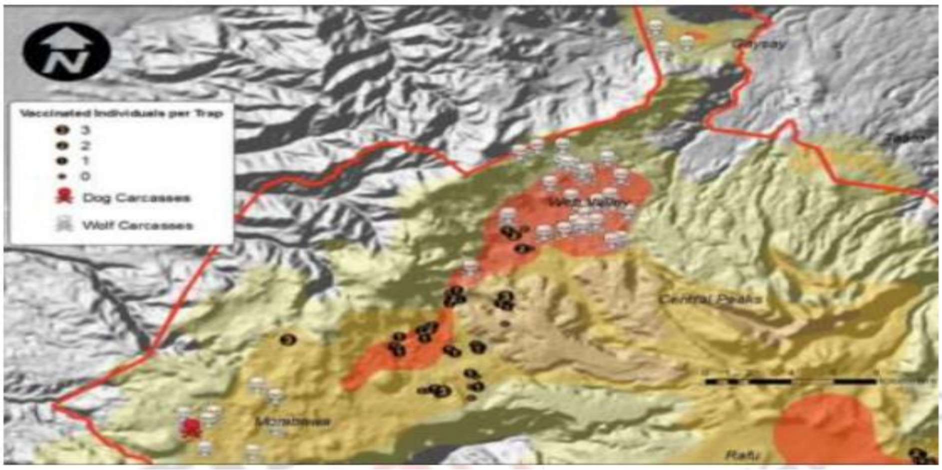


**Figure 6: An overview of the Web Valley and Morebawa, showing wolf deaths caused by rabies, and the ensuing vaccination effort. The circled numbers represent the number of wolves vaccinated at each trapping location. The carcasses found to the south of the vaccination points were caused by a second rabies outbreak.**

GIS sometimes faces basic issues such as in case of determining if GIS is suitable for given situation, finding which data layer is essential and adequate to achieve the planned task. These basic problems need to be resolved before taking any action. constrictions and limitations of GIS applicability consist of the simplification of data for mixed areas due to inadequate scale resolution, data incoherence from integrating data from different sources without due regard to reliability of each source, and lack of quality data.

In Bale Mountains National Park (BMNP) in south central Ethiopia, most wolves were split into three linked subpopulations, Sanetti Plateau, Morebawa, and the Web Valley.

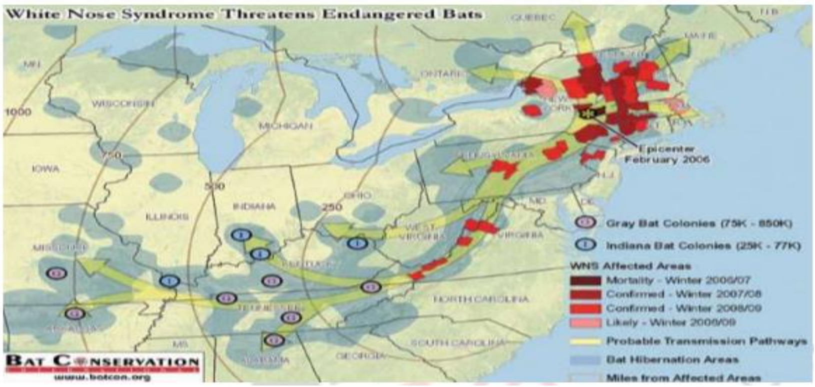


**Figure 7: Map showing the future impact of White nose syndrome (WNS) on gray bat and Indiana bat hibernation sites**

***Map sources:*** *Bat Conservation International, National Atlas, Natural Earth, North American Atlas, Ontario Ministry of Natural Resources, Pennsylvania Game Commission, U.S. Fish and Wildlife Service, and West Virginia Division of Natural Resources*

In late August 2008, researchers in the Web Valley found dead Ethiopian wolves and the laboratory tests confirmed rabies cases. It was then added to a rapidly rising GIS layer of the area, in order to understand the likely origin of the outbreak and the direction of its dispersal through the population.

Bat Conservation International (BCI) created a geodatabase of critical hibernation sites and mapped the likely spread of the disease using GIS. A few past projects had focused on developing geospatial datasets, but no long-term plan was in place for setting GIS as part of customary operations. Now, GIS technology is helping biologists to improve understanding the threats prevailing in the wildlife communities. Spatial analysis of the affected areas and possible future spread is essential for focusing efforts to increase awareness and endorse vigilance.

## Summary

Forest resources play a vital role in maintaining ecological balance; and contribute to the multifaceted processes that are accountable for recycling water and carbon. However, forest resource scarcity may affect their future roles in sustaining taxonomic as well as genetic variation, ecosystem functions and environmental services. Deforestation (forest fragmentation and degradation), population growth, urbanization, pollution and climate change are all having adverse effect on forest biodiversity. Forest loss will threaten the process and system of environment. Understanding the spatial variation in forest change status and the root causes leading to such variations at regional and global level, there is an immediate need to work towards their sustainable development goals.

Wildlife habitat and species around the world are facing a crisis. It is estimated that global warming may cause the extinction of 15–37% of species by 2050. India has launched an extensive protected area network of research institutions in which legislation, socio-economic factors, and wildlife research are playing a great role. Planned research activities include studies on disease diagnosis, site suitability, animal behavior, as well as tracking the animal movement in its habitat by means of GPS. The future depends on interaction between habitat and wild animals as well as preservation of genetic diversity and biodiversity. The potential of RS and GIS tools in mapping wildlife, planning natural resource and management are indeed huge. These technologies at present fully developed and they are progressively being useful in natural resource mapping, planning and management. However, their application, mainly in developing countries, is still lacking because of the shortage of suitable scale of data, software, hardware and expertise. Future research in wildlife modeling should focus designing more practical dynamic models of wildlife.

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# Unit 15: Watersheds Measurement

**Unit Structure**



## 15.0 Learning objectives

After studying this unit you will be able to explain:

- To understand watershed and its characteristics
- To study the importance of integrated watershed management
- How does application of Remote sensing and GIS helps in watershed management

## 15.1 Introduction

A watershed is a hydrological unit where all the water from precipitation in the form of rain and snowfall are drained into a common area and from where it is drained off to a common outlet. The mechanism of watershed displays a basin topography which can be as small as a footprint or large enough to encompass all the land that drains water into a river and finally enters sea and ocean. The watershed comprises of one large river or streams

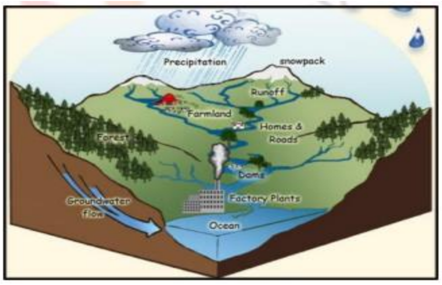

**Figure 01: Watershed basin**
**Source: terrainworks.com**

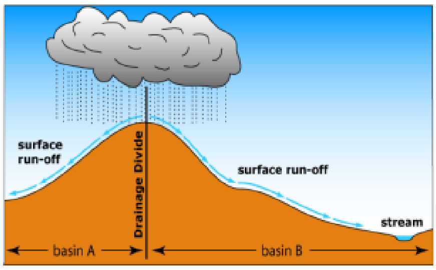

**Figure 02: Drainage divides**
**Source: studyblue.com**

that would be connected with several other smaller streams or tributaries. The large stream or river get its source of water from all the smaller streams as all the surrounding water flows to accumulate in the larger stream under the influence of slope and gravity. The picture no.1 shows watershed and the catchment areas.

There are several watershed represented by their location and the topographic feature in a particular region. Two watershed basins (Fig 02) are separated by ridges and hills that are called as the drainage divide. It depends on the slope of basin that from different watershed in a particular area. The drainage divide is responsible for draining surface run-off water under the influence of slope thereby creating basin topography. The surface water flows to meet another stream and tributaries and finally making a watershed of the particular place. The watershed consists of surface water like, lakes, streams, reservoirs, and wetlands as well as all the underlying ground water.

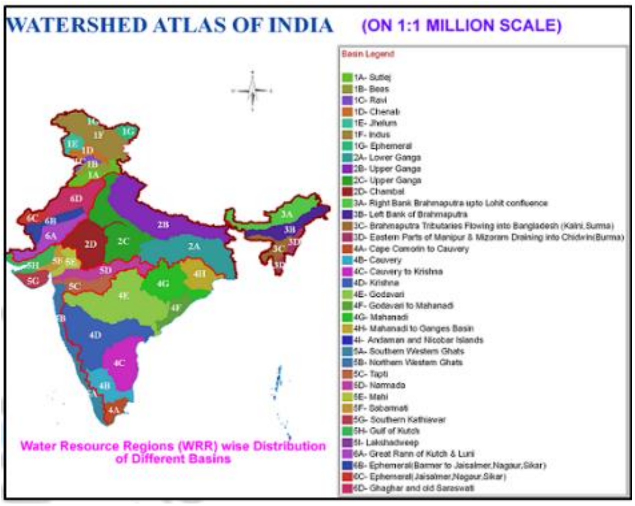


**Figure 3: Watershed of India**
**Source: http://slusi.dacnet.nic.in/watershedatlas/indexnew.html**

A watershed is a precipitation collector and feeds the river life. It is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people. The watershed in India (Fig 03) shows the area demarcation of watershed and in relation the river basin of India (Fig 04) that displays the river and stream where

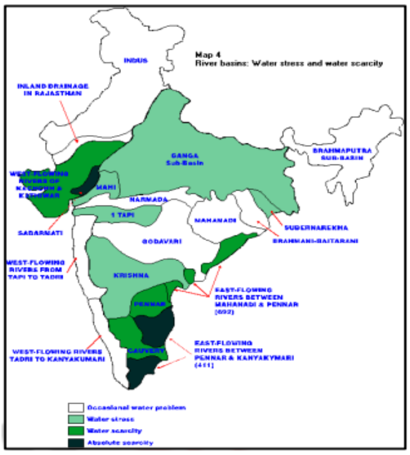

**Figure 4: river basin of India**
**Source:http://www.history.upenn.edu/coursepages/hist086/material/IndiaRiverBasins.gif**

the particular watershed is the source for the water. So the relationship between watershed and drainage basin is inter-related and the study of watershed is integral in drainage pattern and its basin.

## 15.2. Factors that determine the geomorphologic characteristics of a watershed

**1) Precipitation:** The greatest factor controlling stream flow is the amount of precipitation that is in the form of rain or snow. This fed the river and the streams down flow along the path, serving as the main source. Thus the change in the amount of precipitation will affect the characteristics of watershed.

**2) Infiltration:** The amount of water that soaks or seeps inside the soil also determines the watershed. When rain water soaks in (other than surface run off) and infiltrates the soil it remain in the shallow soil layer, where it will gradually move downhill, through the soil, and eventually enters the stream by seepage into the stream bank. Water that infiltrate enters much deeper, recharging groundwater aquifers. Water may travel long distances or remain in storage for long periods before returning to the surface.

**3) Soil characteristics:** The type of soil characteristics also determines the watershed as clayey and rocky soils absorb less water at a slower rate than sandy soils. Soil saturation happens where like wet sponge, soil already saturated from previous rainfall cannot absorb water and result in surface runoff.

**4) Land cover:** Land covers have a great impact on infiltration and rainfall runoff affecting the watershed where impervious surfaces leads to flooding of areas.

Slope of the land: The angle of the surface determines the amount of runoff where water falling on steeply-sloped land runs off more quickly than water falling on flat land.

**5) Evaporation:** The watershed also depends on the amount of evaporation determined by temperature, solar radiation, wind, atmospheric pressure, and other factors.

**6) Water use by people:** Anthropogenic factor plays an important role as water resource is usage varies from one place to the other. This greatly have an impact on the characteristic of watershed that varies accordingly from upper stream and lower stream river flow.

## 15.3 Scale delineating the watershed

A watershed is a basin where water flows across or through on its way to a common stream, river, or lake. A watershed can be very large (e.g. draining thousands of square miles to a major river or lake or the ocean), or very small, such as a 20-acre watershed that drains to a pond and sometimes a small watershed nests inside of a larger watershed which is sometimes referred to as a sub watershed. Thus identification of watershed largely depends on the area it covers depending on the numbers of channels. A larger stream would create a larger basin in corresponding to the smaller stream with a smaller basin. Fig. 5 & 6 shows the demarcation of larger watershed and smaller or sub watershed looking at the numbers of streams flowing in an area. The topography is greatly influenced by the river flowing on the particular area. Thus maintaining a healthy watershed requires a systematic approach for sustainable development. Application of Remote Sensing and GIS (Geographic Information System) becomes a very important tool in delineating stream flow and demarcation of watershed and sub watershed. It helps in analyzing the various techniques that could be implemented in carrying research for maintaining watershed management.

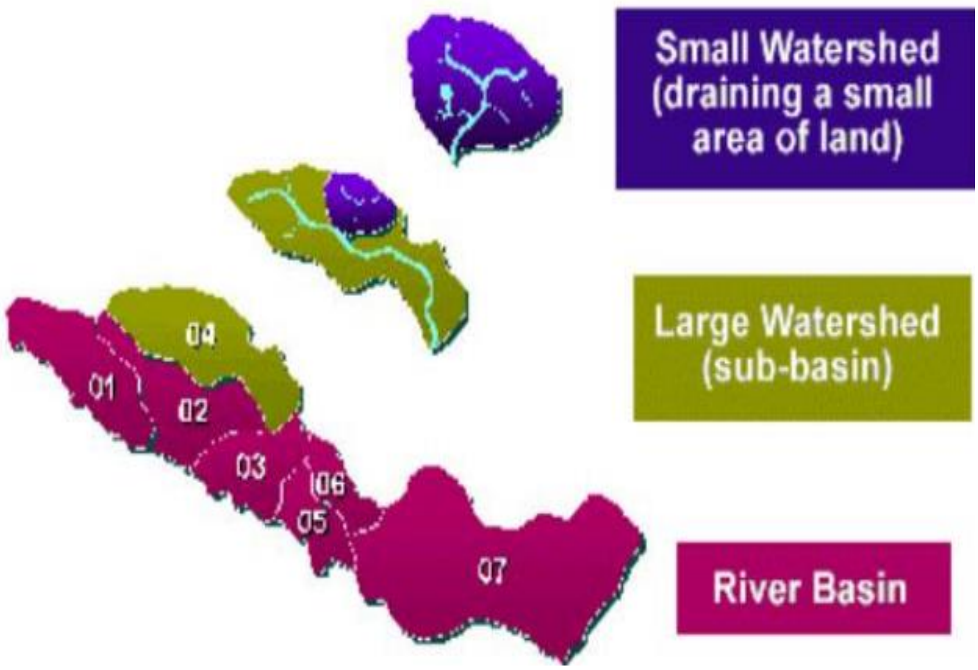


**Figure 05: River basin, large watershed & small watershed**
**Source: swcd.net**

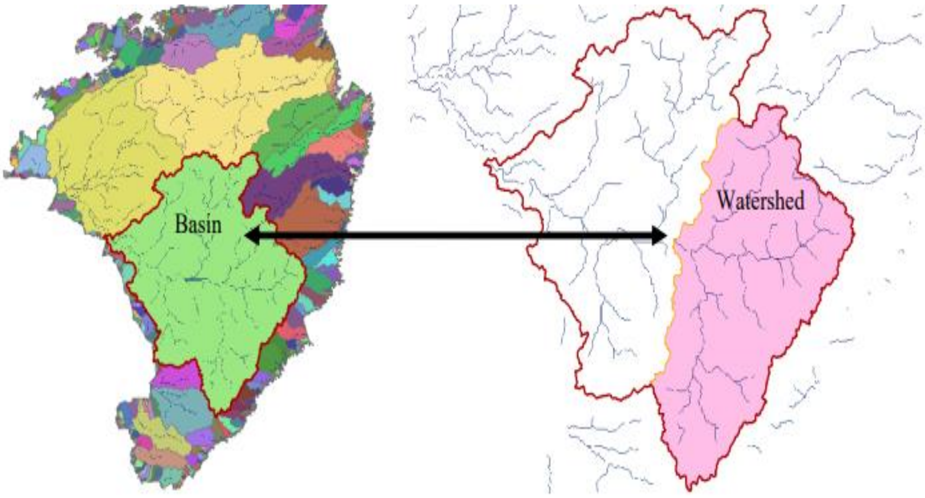


**Figure 6: Delineating River basin & watershed (KarbiAnglong district, Assam, India). Source: Geoinformatics (NEHU, Shillong)**

## 15.4. Concept of watersheds measurement

Remote Sensing (RS) and Geographic Information Systems (GIS) technology plays very important role in watershed management in assessing watershed conditions through various modeling. Through the use of computer aided software and availability of huge resources of digital data, mapping of watershed have proven tremendously much easier for a researcher in the field of GIS technology. Due to this fact, the use of RS and GIS in the application of watershed management has changed from operational support (e.g., inventory management and descriptive mapping) to prescriptive modeling and tactical or strategic decision support system. The application has enabled mapping giving accurate information through many multi resolution data that has helped in delineation of ridge line, stream flow, erosion prone areas, etc. Some of the features of remote sensing and GIS in the study of watershed are as follows;

a) **Watershed Characterization and Assessment:** The available Digital Elevation Model (DEM) and USGS's National Hydrography Dataset (NHD) and EPA (environment protection agency) BASIN database provides enormous water quality data relating to watershed that helps in demarcation of watershed boundary, drainage network system, flow accumulation, and drainage density.

b) **Management Planning:** The analysis of characterization and assessment studies could generate understanding of the complex relationships between natural and human systems by looking at water quality. Many factors like drought, flood and water degradation could be studied through proper planning and utilization of resource. Thus GIS provide a common framework for watershed management by providing a platform for assessment of data for analyzing spatial dimensions that are important for understanding impacts of human activities.

c) **Watershed Restoration (Analysis of Alternative Management Strategies):** GIS helps in water assessment programs that include total maximum daily load (TMDL). The watershed ranging from small rural watersheds to heavily urbanized landscapes GIS provide framework for restoration the watershed is studied by creating digital maps showing the existing conditions of drainage pattern and thereby comparing to maps that could possibly represent alternative scenarios. It acts as a platform by integrating the complexities of a real world system within the confine of a digital world accurately and efficiently, thus providing a platform for collaborative functions among researchers, watershed stakeholders, and policy makers.

## 15.5 Application of Watershed modeling

Watershed modeling is considered as an important objective to study in hydrology. Modeling of a particular watershed assesses the health of a particular watershed for further implementation of different management plans. In watershed modeling one needs to consider every possible aspect that can directly or indirectly influenced the particular watershed. Some of the important considerations are;

a) **Soil:** The soil survey geographic data base provides analysis while studying factors of erodibility, agricultural capacity, development suitability, dwellings, small commercial buildings, local roads and tress.

b) **Geology:** The geology of the surface plays an important role in hydrology. Especially geology is a determining factor in shifting of bank lines or we can say watershed boundary. This data is taken from geological survey, and by creating a separate vector file it use to compile in GIS.

c) **Impervious surface:** The NEMO (Nonpoint Education for Municipal Officials) project developed an analytical methodology to correlates the amount of impervious surface in the watershed and study the impact on stream quality.

d) **Land use/land cover:** Shows the change over a period of time relating to urban land, agricultural land, forest, water, wetland, barren land. Land use and land cover analysis is very much important as it shows the present and past conditions of a particular surface.

e) **Ground water:** The ground water data use to take from the secondary sources like district ground water board and potential areas of ground water used to assess with the help multi criteria analysis by giving weight to every factors that is taken in to consideration.

f) **Rainfall:** rainfall is most important in watershed modeling. The amount of rain fall in a watershed determines its future applicability in management. The rainfall data can be taken from meteorological departments as well as from TRMM (Tropical rainfall measuring mission).

g) **Sediment yield:** it is estimation of sediment transported by water in a particular cross section. It is a manual process. It also includes bed and bank samples of sediment. It compile with other layers by joining the data.

h) **Chemical prosperity:** Analysis of chemical prosperities of water also collected and tested by manually at number of cross-sections and added by creating separate vector layer

i) **Social data:** the present status of the utilization of the particular watershed, local dependency on it and associated problems are collected by manual data collection. By creating different vector layer is use to relate with other layers.

## 15.6 Factors influenced the watershed modeling

a) **Ground water flow:** the flow of ground water is considered as a complicating factor in watershed modeling. The ground water flow is not controlled or limited by the topography that above the ground. It may flow across the demarcated watershed. In this condition assessing the ground water potentiality and accumulation needs multi criteria analysis.

b) **Time factor:** the watershed boundaries may change over the time. It may shift due to natural causes as erosion and flooding or due to man induced interventions such as construction of dam, culverts, roads etc. Watershed demarcation needs updates and new technologies that can capture very minute change above the ground, surface elevation and subsequent water routing.

## 15.7 Integrated watershed management

The study of watershed is important because the stream flow and the water quality depend on many activities in the area through which it flows. Many of such activities included anthropogenic factors like river pollution, construction of dams, and growth of settlement etc. happening in the land area "above" the river-outflow point. The management of watershed is a sustainable way to use water resource. In understanding the natural resources, the concept of sustainability envisage the smarter way in using resources so as to secure the requirement for the future needs. The watershed management reflects the conservation of water and its usage practices in the light of sustaining the river life particularly in the upper reaches so as to maintain the quality in the downstream.

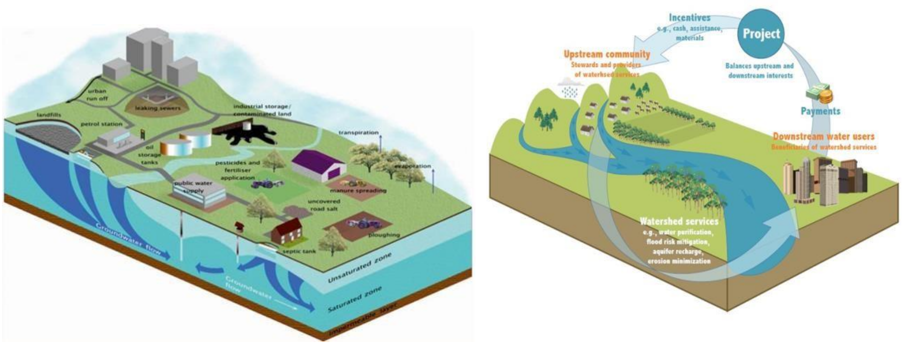


Fig 07: Watershed management.
Source: pinterest.com

This is the process of guiding and organizing the usage of land and other resources in watershed ensuring sustenance of environment. The main focus in watershed management is how various human activities affect the relationship between water and other natural resources. It aims to provide a basis for actions concerning the development and conservation. The watershed Management Concerns agendas like; Preventing deterioration of existing relationships between the use of natural resources within a watershed, restoration of sustainable relationships which had been destroyed due to actions in the past and ensuring the best use of resource in watershed. Watershed Development Approach is an Integrated and multi-disciplinary approach thereby suggesting possible exploitation of resources within the limits of tolerance. The conservation of Soil and Water, improved ability of land to hold water, maintaining adequate vegetative cover for controlling soil erosion and rain water harvesting and ground water recharging would reflect some initiatives carried out in the path of achieving the management strategies.

The resultant factors are highly depicted in proper managerial of resource in physical as well as social. Some of which can be mentioned like; promotes economic and social development of community, employment generation and other income generation, ecological balance, the crop yield has increased in dry land farming, soil loss due to erosion was brought down, large extent of barren hill slope were covered by vegetation, large tract of marginal lands brought under dry land horticulture, development of agro-horti and agro forestry system, water resource were harvested through nala bund, farm pond, regeneration of grassland for more fodder and grass.

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# Unit 16: Disaster Management

## Unit Structure



## 16.0 Learning objectives

After studying this unit you will be able to explain:

- Disasters and application of geospatial technology.
- Remote sensing and geographical information system in disaster management.

## 16.1 Introduction

For mankind, disasters are unavoidable in nature and have been recurrent events despite problematic ever since time immortal. The disasters mostly natural likely to hit without warning and are supposed to have high magnitude, frequency, complexity and economic impact worldwide. The disasters cause threats to humans, settlements, economic assets and are supposed to have high risk proportions in areas of dense population. It is for the reason that most of the world's nastiest disasters tend to occur between the Tropic of Cancer and the Tropic of Capricorn (Sharma, 2014). This vast belt from both sides of equator is inhabited by the developing countries of the world, where the problems of disaster management are exclusive due to the apparently competing needs between basic requirements for people and economic growth (Sharma, 2014).

In 2015, Asia-Pacific belt remained as the world's most disaster prone region. Around 160 disasters out of world's 344 recorded ones were reported in the region, which account 47% of that total. The total population affected by such calamities was about 59.3 million with a total of more than 16,046 deaths in the region. South Asia went through highest percentage of fatalities with a total of 14,647 deaths (around 64% of the total) due to 52 disasters that took place in the year 2015 and out of which the maximum deaths (around 8,790) were reported from Nepal earthquake tragedy. The total economic loss in Asia and the Pacific was more than US$ 45.1 billion in the year 2015, besides much more losses indirectly. About 90 storms were recorded worldwide that took place in 2015, out of which half of the storms occurred in Asia-Pacific, affecting 9 million inhabitants with a loss of US$ 11.8 billion. Two-fifth of all disasters was related to floods, responsible for 37% damage to human lives and 25% economic loss. (ESCAP, 2015)

## 16.2 Concept of Disaster Management

Disaster Management can be defined as the organization and management of resources and responsibilities (activities) while dealing with emergency situations with all humanitarian aspects during different stages viz., preparedness, response and recovery in order to reduce the impact and damage caused during disasters. In this process, the objectives of the concerned experts are to monitor the condition, simulate the disaster occurrence to have better models for prediction, propose suitable contingency plans and finally preparation of spatial databases.

The management of calamities either natural or man-made requires both manual as well as technological efforts. So far as technological aspect is concerned, the management of disasters can be done using technology like remote sensing (RS) and geographical information system (GIS). A large amount of multi -temporal spatial data is required for the management of natural disasters. RS and GIS are very effective tools in management of disasters. These techniques can be used effectively for the assessment of disaster severity and subsequent impact of destruction. Together with the growing applications of RS, the use of GIS has become equally important for the purpose of cartography (map composition) and enumeration tasks. In disaster management, the satellite data can be used during various phases of the management, such as preparedness, prevention, preparedness, relief and reconstruction; mostly used for monitoring and warning tasks. During the past few decades the RS technique has been an effective operational tool in preparedness and warning phases for floods, droughts and cyclones. In preventive phase, the GIS are used in assessing the severity and impact of destruction due to disasters. Integrated with global positioning system (GPS), the GIS in disaster relief stage, is very useful in search and rescue operations in areas devastated by calamity. And in preventive phase, the GIS can be used to manage large amount of data needed for the assessment of vulnerability of the hazard. It can also be used for better planning, emergency operations designing, evacuation means during preparedness stage and for the incorporation of satellite data with other significant data in proper design of warning system. This technology can also be used in search and rescue operations during relief stage. The GIS can be used to organize the information related to damage due to disaster and after disaster for census report preparation during rehabilitation phase.

## 16.3. Indian Scenario

As is well documented, the Indian subcontinent is susceptible to various natural disasters such as droughts, cyclones, tsunamis, floods, earthquakes, forest fire, landslides and avalanches. Out of 35 total states/ Union Territories in the country, 25 are prone to disasters. In the country, on an average, about 50 million people are affected by disasters every year, besides million dollars loss to property (Sharma, 2014).

Literally, a disaster is a sudden accident or a natural calamity that leads to serious damage to property or lives of living beings. According to World Health Organization (W.H.O), a disaster can be defined and health services on a scale, sufficient to warrant an extraordinary response from outside that affected community or area". A natural disaster owes its origin to the natural processes occurring on A disaster is a major adverse event or disruption, occurring over a relatively short time, resulting from natural or human induced activities, causing heavy damage to human lives, material, environment or economy, thus, making it difficult to combat such losses. During such calamity developing countries go through much more costs compared to developed ones, more than 95% of all deaths caused by calamities in developing countries, and losses due to natural events are 20 times greater (as GDP %) in developing countries than in developed countries (Sharma, 2014).

## 16.4. Types of Disasters

Broadly, disasters can be natural or man-made which occur in many different forms with different magnitude of destruction and range of time duration.

**A natural disaster** is a type of that happens due to natural process or phenomenon, causing damage to lives, health, property, environment and economy of the region. This type of disaster includes earthquakes, volcanoes, landslides, floods, storms (hurricanes and tornadoes), tsunamis, and cyclones, killing people on large scale and costs billion of dollars damage to property and the environment every year worldwide. Today, however, due to population explosion and urbanization, there is a sharp increase in severity of damage due to frequent disasters. There are some disasters that happen without any warning such as earthquakes and tornadoes, causing much more damage unexpectedly to infrastructure and other productive capacity (Sharma, 2014). Storms like hurricanes and typhoons are considered as one of the most seriously damaging natural calamities because of their size and magnitude. Disasters like floods and cyclones cause damage to a larger extent to both infrastructure and agriculture (Sharma, 2014).

**Man- made disasters** are the end results of technological hazards or human error. Fires, stampedes, industrial accidents, oil spills, transport accidents, war and nuclear explosions/radiation are some of the examples of man-made disasters. Like natural disasters, these events also cause serious damage to human lives, property and economy of the state.

Disasters have also been categorized into different sub-groups depending on their source/ origin (Sharma, 2014). These five subgroups are as follows:

**Sub-Group I- Water and Climate Related Disasters**

This sub-group includes cyclones, tornadoes and hurricanes, heat wave and cold wave, avalanches, floods, droughts, hailstorm, sea erosion, thunder, cloud burst and lightning.

**Sub-Group II- Geologically related disasters**

This includes landslides, mudflows, dam failures/ dam bursts, mine fires and earthquakes.

**Sub-Group III- Chemical, Industrial & Nuclear related disasters**

In this sub-group the chemical, industrial and nuclear disasters have been accounted.

**Sub-Group IV- Accident related disasters**

This category includes oil spill, building collapse, bomb blasts, festival related disasters, electrical disasters and fires, forest fires, urban fires and transport related accidents.

**Sub-Group V – Biologically related disasters**

This sub-group includes pest attacks, biological disasters and epidemics, cattle epidemics and food poisoning.

## 16.5. Disaster Management and application of Geospatial Technology

Disaster Management can be defined as the organization and management of resources and responsibilities (activities) while dealing with emergency situations with all humanitarian aspects during different stages viz., preparedness, response and recovery in order to reduce the impact and damage caused during disasters. In this process, the objectives of the concerned experts are to monitor the condition, simulate the disaster occurrence to have better models for prediction, propose suitable contingency plans and finally preparation of spatial databases.

The management of calamities either natural or man-made requires both manual as well as technological efforts. So far as technological aspect is concerned, the management of disasters can be done using technology like remote sensing (RS) and geographical information system (GIS). A large amount of multi -temporal spatial data is required for the management of natural disasters. RS and GIS are very effective tools in management of disasters. These techniques can be used effectively for the assessment of disaster severity and subsequent impact of destruction. Together with the growing applications of RS, the use of GIS has become equally important for the purpose of cartography (map composition) and enumeration tasks. In disaster management, the satellite data can be used during various phases of the management, such as preparedness, prevention, preparedness, relief and reconstruction; mostly used for monitoring and warning tasks. During the past few decades the RS technique has been an effective operational tool in preparedness and warning phases for floods, droughts and cyclones. In preventive phase, the GIS are used in assessing the severity and impact of destruction due to disasters. Integrated with global positioning system (GPS), the GIS in disaster relief stage, is very useful in search and rescue operations in areas devastated by calamity. And in preventive phase, the GIS can be used to manage large amount of data needed for the assessment of vulnerability of the hazard. It can also be used for better planning, emergency operations designing, evacuation means during preparedness stage and for the incorporation of satellite data with other significant data in proper design of warning system. This technology can also be used in search and rescue operations during relief stage. The GIS can be used to organize the information related to damage due to disaster and after disaster for census report preparation during rehabilitation phase.

## 16.6 Principles of Disaster Management

- The management of disasters is the duty of all spheres of government.
- Resources should be used efficiently that are available for daily purpose.
- All related organizations should work as an extension from their core business.
- Each individual is responsible for his/her safety during disaster.
- A better planning should focus on large scale events during management practices. The planning should significantly recognize the differences between disasters and incidents.
- The planning should take into account the type of physical environment and the population structure.

- The arrangements should recognize the cordial role of non-government organizations.

## 16.7 Phases of Disaster Management

a) **Disaster Preparedness**: All those actions that are implemented before the occurrence of a disaster. For example: Preparedness plans; emergency exercises/training; warning systems.

b) **Disaster Impact:** This phase includes all the damages and negative consequences on human lives, property, environment and their economy.

c) **Disaster Response:** This phase includes activities during the occurrence of a disaster. For example: Public warning systems; emergency operations; search and rescue.

d) **Rehabilitation:** All those actions that are meant to rebuild lives and livelihoods during disaster for long term sustainable development. It accounts all those measures which assist in increasing the resilience of food, water systems and other resources in case of future disasters and emergencies.

e) **Mitigation**: It includes those activities that reduce the effects of disasters. For example: building codes and zoning; vulnerability analysis; public education.

## 16.8 Management of Disasters

The UN General Assembly Resolution declared the period of 1990- 2000 as International Decade for Natural Disaster Reduction. In response to this, the Government of India has undertaken several initiatives, shifting the focus from post-disaster approach to pre-disaster preparedness, including preparation of Vulnerability Atlas of India; to minimize the loss to life and property as a result of these disasters. Besides, the Disaster Management Act, 2005 lays down institutional and coordination mechanism at national, state and district level.

### 16.8.1 Management of EARTHQUAKE using geospatial technologies (remote sensing and geographical information system)

To provide rapid and reliable assessment report of the destruction caused by earthquakes, the analysis of RS imagery in particular high-resolution aerial imagery has been a very effective technology. The techniques like Photogrammetry and GIS are considered as modern tools in exploring the earthquake and other associated phenomena (Altan, 2005). The methods like terrestrial photogrammetry was first time used to document and report the earthquake damages caused in Friaul, Italy. There are several efforts to use RS, photogrammetry, and other information sciences and systems in the areas damaged by earthquake. Some of them are associated with long term and short term prediction, and some are linked with recording and assessment of the damage caused (Altan, 2005). The maps related to epicentre of the earthquake are being used to generate seismic hazard maps. The seismic zoning map happens to be a basic informative tool in the code for designing resistant structures related to earthquake. Figure 1 describes the seismic zones of India.

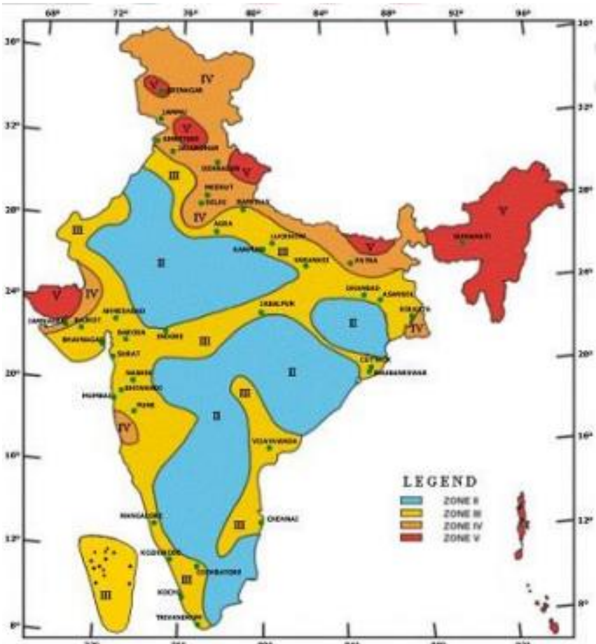


**Figure 1: Seismic zones map of India**
**(Source: www.isr.gujarat.gov.in)**

Along with the data associated with earthquake, structural design, geological factors, soil data etc., are very useful for the preparation of building codes which aid in designing earthquake resistant structures. The Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation, Government of India, collaborates with national and international agencies/organizations for vulnerability analysis and mitigation practices.

## 16.8.2. Management of LANDSLIDES using geospatial technologies (remote sensing and geographical information system)

Landslides occur in a wide range, depending on speed of movement, type of movement (slide, fall, flow, spread, topple), material involved (debris, rock, soil), and also the triggering mechanism (rainfall, earthquake). The use of satellite data, aerial photos and RS techniques helps in the data collection during the disaster. The computerized techniques and other systems would help in storage, retrieval and analysis of the data. In the preventive phase of disaster, satellite imagery can be used for landslide inventory and the mapping of factors related landslide occurrence, such as faults, lithology, geo-morphological setting, slope, land use and vegetation. The dimension of the landslide features relative to the ground resolution of the RS data, landslide inventory mapping has been very essential. Satellite imagery with better spatial resolution and stereo capability (SPOT, IRS) are very helpful in recording and documentation of the past landslides. In future, it is expected that Very High Resolution (VHR) imagery, such as from IKONOS-2, might be very useful for landslide inventory. The imagery of satellite data can also be used to have data on the parameters (soils, geology, slope, geomorphology, land use, hydrology, rainfall, faults etc.) related to landslide assessment. For the classification of lithology, land use and vegetation, multispectral images are significantly important. Also for geomorphological mapping or terrain classification, Stereo SPOT imagery has been widely used (Soeters et al., 1991). SPOT or IRS images can be used to prepare digital elevation models (DEM). The techniques like GPS, photogrammetry and Radar interferometry have been essential during disaster preparedness stage. Landslide hazard zonation map included a map separating the draw out varying degrees of predictable slope stability. The landslide hazard zonation map has an inbuilt factor of

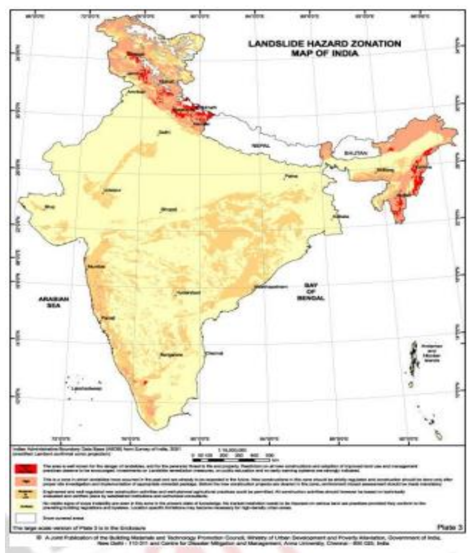


**Figure 2: Landslide zonation map of India (Source: http://www.bmtpc.org)**

forecasting, consists of map showing varying degree of slope stability and therefore, probabilistic in nature. A landslide hazard zonation map has ability to aid in some of the following individual factor maps based on methodology and input data: Landslide location, Slope steepness, Land use/ land cover, Geology, Density of drainages and Rainfall.

There is a wide range of applications of the hazard zonation maps which include preparation of development plans for dams, roads, cities etc., master plan and land use plans, decision making in rescue and relief operations.

### 16.8.3 Management of FLOODS using geospatial technologies (remote sensing and geographical information system)

Floods are considered to be most devastating hazard among all natural hazards worldwide, causing more deaths and property damage than any other. It may be defined as any relatively high water flow that overflows the banks in any portion of a river or stream beyond it capacity to hold. Different types of flooding (e.g. river floods, flash floods, dam-break floods or coastal floods) have different characteristics with respect to the time of occurrence, the magnitude, frequency, duration, flow velocity and the areal extension. Many factors play a role in the occurrence of flooding, such as the intensity and duration of rainfall, snowmelt, deforestation, land use practices, sedimentation in riverbeds, and natural or man-made obstructions. Figure 3 represents the flood hazard zonation map of India.


**Figure 3: Flood Hazard Zonation map of India**

**(Source: [www.mapsofIndia.com](http://www.mapsofIndia.com))**

In flood evaluation procedure, there are certain parameters that need to be taken into consideration which include depth of flood water, the rate of rise and decline, the duration, the flow velocity and the frequency of occurrence. During the stages of preparedness/warning and response/monitoring the earth observation satellites are widely used. These earth observation satellites provide data for mapping geomorphologic elements, historical events and sequential inundation phases, including depth, duration, and direction of current during prevention stage of disaster. The monitoring of flood is carried out by using RS satellite imagery from global scale to storm scale. In most of the disaster management phases, the satellite data has been effectively and operationally used (CEOS, 1999). It is frequently used in the storm scale to monitor the movement, intensity and precipitation spread to determine how much, when, and where the heavy precipitation is going to shift during the next zero to three hours (called NOWCASTING) through hydrodynamic models. Synthetic Aperture Radar (SAR) has been regularly observing the earth's surface, even in a bad weather situation or thick cloud cover. The mapping and monitoring of flood can also be done by using NOAA AHVRR, in near real time. From GOES and POES satellites, the multi channel and multi sensor data are used for meteorological evaluation, interpretation, validation, and assimilation into numerical prediction models to assess hydro-geological risks (Barrett, 1996).

For flood forecasting and subsequent warning, the Quantitative precipitation estimates (QPE) and forecasts (QPF) use satellite data as informative source. For the mapping of flood inundated areas, the Synthetic Aperture Radar (SAR) from ERS and RADARSAT have been verified as very effective even in bad weather conditions. In India since 1993, ERS-SAR has been used effectively in flood monitoring besides Radarsat since 1998 (Chakraborti, 1999). For the management of floods, the RS should always be associated with other data in a GIS, especially the integration of a large number of hydrological and hydraulic factors on the local scale. The GIS technique can contribute in generation of topographic information using digital elevation model (DEM), obtained from SPOT, aerial photography, geodetic surveys, LiDAR (Light detection And Ranging) or SAR (Corr, 1983 ). All these data incorporated in 2D or 3D finite element models, have been very useful in flood prediction in floodplains and river channels (Gee et al., 1990).

## Conclusions

At the end of the module, the reader would have gained an insight into the types of disaster, principle of disaster management and the role played by remote sensing and

GIS in managing the disasters, especially in terms of preparedness and mitigation measures.

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http://www.bmtpc.org www.isr.gujarat.gov.in www.mapsofIndia.com

# Unit 17: Human settlements

**Unit Structure**



## 17.0. Learning objectives

After completing this unit, you should be able to understand about:

- Human settlements
- Describe various components that make up a human settlements
- Analyze the evolution of settlements over time; and
- In this unit, we will learn about how human settlements came into being, and what principles are followed by human beings while choosing sites for settlements and on what basis are human settlements classified and related issues.

### 17.1. Introduction

Humans reside in structures we refer to as homes. The unfortunate people who don't have a house are referred to as the homeless. While many people live in permanent homes, which are referred to as dwellings, certain others, such as the nomadic population, live in temporary residences as they migrate from one place to another. The word "dwelling" refers to a person's home. Human settlements or habitations are any collection of houses, whether they tiny or large, in a hamlet, village, or town. Settlement geography is a crucial subfield of human geography that studies human settlements, including their structure, population, purposes, and interrelationships. Therefore, the study of settlement geography focuses on the earth's inhabited regions.

One significant aspect of the link between humans and their environment is human habitations or settlements. Humans gradually alter the natural landscape as they settle down in a location to suit their needs. In addition to developing fields for farming, they also build water channels to irrigate their fields, as well as streets, roads, places of worship, stores, hospitals, theatres, factories, offices, parks, and other public spaces that are significant from an economic, social, cultural, and political standpoint. Because of this, human settlements are one of the main examples of human culture and civilization.

## 17.2 What Is Human Settlement?

We must first identify human settlements before we can analyze the many characteristics of human habitation. A group of residential buildings built with the purpose of or for habitation, along with other social and economic uses, can be referred to as a "human settlement" and together constitute a space for social interaction. In order to achieve a variety of socio-economic, cultural, and political goals, people who live in a location depend on and interact with one other as well as those who live elsewhere in other habitations, whether they be close by or far away. Interaction between and among habitations creates spatial relations that connect residents of one locale, site, or region with both their close neighbors and those who reside in other locations. The settlement system is made up of the spatial interactions that exist between and within settlements.

Human settlements are defined as "the entirety of the human community, whether city, town, or village, with all the social, material, organizational, spiritual, and cultural elements that sustain it" in the United Nations Declaration on Human Settlements (1976).

**Settlement System:** Human habitations or the system of human habitations can be thought of as a complex whole made up of both physical and non-physical components. Consequently, the subsystems consist of people, society, the government, the built environment, and the natural environment. Because of changes in these five subsystems, human settlement systems are constantly changing.

"Ekistics," or the science of human settlements, was created by **C. A. Doxiadis** and examines both the principles used in settlement construction and the development of human settlements across time. The topic is a very complex system made up of five components: shells (also known as structures or houses), networks, society, human beings, and nature (Fig. 1). It is a system made up of both natural and man-made components, and it may be viewed from the perspectives of the economy, society, politics, technology, and culture.

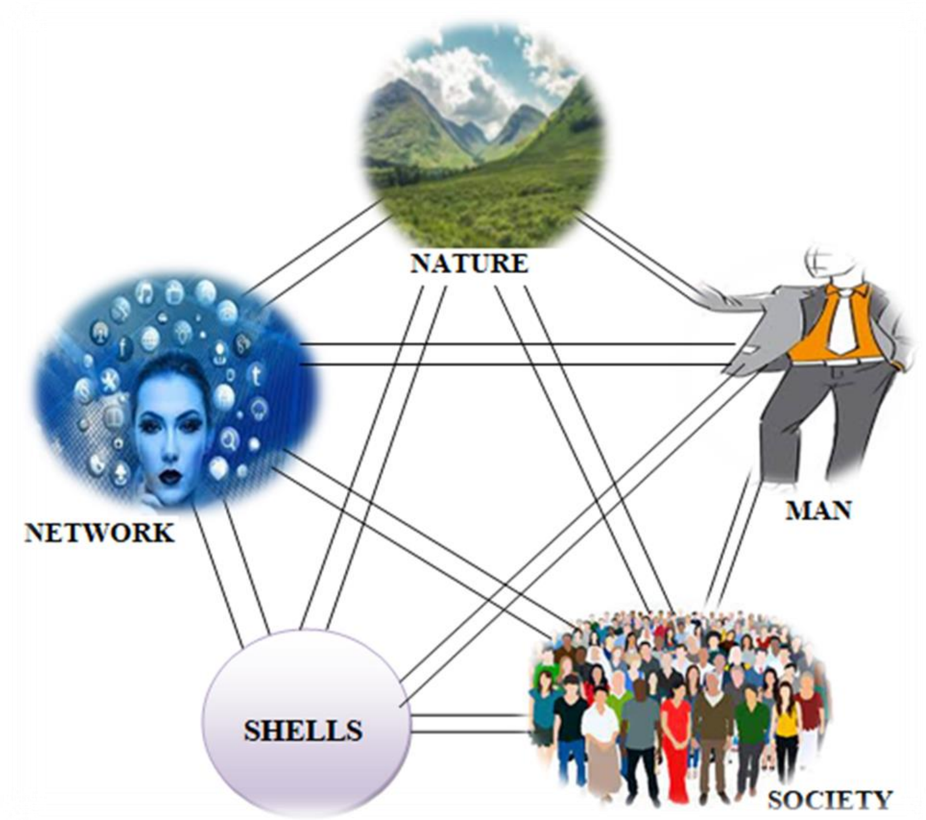



Figure 1: Doxiadis' Concept of Human Settlement.

When constructing homes and villages, humans take into account a number of factors, including safety, security, survival, and the spread of their racial group. These turn into guiding principles. The following is a list of some of these ideas.

I. The First Principle calls for maximizing human contact with other people, with other living things, and with man-made structures like buildings and highways.

II. The Second Principle calls for minimizing the amount of work necessary to establish actual and potential human interactions. They choose the least-effort-required approach or give structures their shape.

III. The third principle focuses on optimizing the protective area around humans, which entails choosing a location that puts them at a comfortable distance from other people, animals, and objects.

IV. The fourth principle, which promotes physiological and aesthetic order, is the optimization of the quality of a human being's relationship with his or her environment, which includes nature, society, shells (all kinds of buildings and houses), and networks (roads and telecommunications).

V. The fifth principle is that humans organize their cities in an effort to produce the best possible synthesis of the other four principles. This synthesis depends on time, space, and the human ability to construct it.

As a result, theories of settlement systems can be either normative or behavioral. The behavioral theories make an effort to explain the current regional settlement trends. On the other hand, normative settlement theories try to identify an ideal system of settlements rather than being concerned with the current patterns. The Zipf's Rank Size Rule is an example of a behavioral theory, while Central Place Theory is an example of a normative theory of settlement systems. Behavioral theories are based on empirical observations of comparable settlement patterns from different countries. In the lesson on urban settlements, you will discover more about these theories.

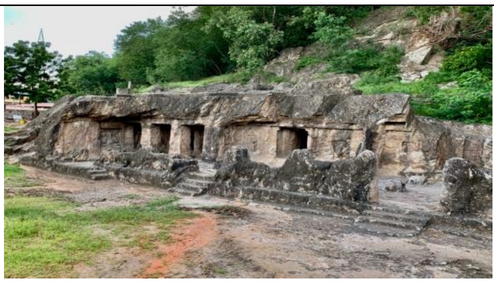
## 17.3 Evolution of Settlements

### 17.3.1 Origin and Growth of Settlements

The inclination of both men and women to live in big communal buildings with their families and a number of interrelated families is a reflection of the social character of people. Humans' reliance on bonds of kindred and family expanded as they started to create a way of life that was not only reliant on the gifts of nature. Settlements had to be established due to interactions between and among people and groups.

Although it is still debatable when and where the first settlements took place, archaeological evidence suggests that they did so during the Neolithic era. The earliest humans were nomadic, moving from place to place in quest of sustenance. They lived in caves since they lacked the building construction abilities. They occasionally sought safety in trees to avoid being attacked by wild creatures.

Humans inhabited caves (Fig. 2) and areas near rivers, lakes, and springs up to 10,000 BC. They valued locations that were elevated or protected by river marshes. They never made caves their permanent home because they would relocate whenever there was a food shortage. Also employed as homes were the tree houses, or "machaans," as they are known in India. Some tribes in the Andaman and Nicobar Islands continue to live in these structures.



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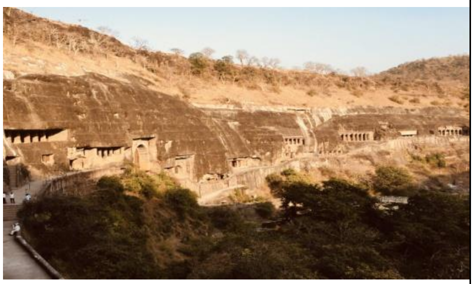

b: https://pixahive.com/photo/ajanta-caves-in-maharashtra/

c: https://greg-willis.com/2021/naupa-iglesia-cave-shrine-of-the-inca/

d. https://commons.wikimedia.org/wiki/File:Davidareja_monastery_and_caves_21.jpg

Figure 2: Human settlements around the world a: Andhra Pradesh b: Maharastra c: iglesia cave d: Davidraj cave

Between 10,000 and 5,000 BC, humans developed the skill of plant cultivation. It was simple for them to stay put and generate food thanks to land cultivation. They started to build settlements close to the fields they farmed. They constructed huts out of materials that were readily available nearby, such as mud, bamboo, and thatch, and liked to dwell close to fertile areas with abundant of water. The earliest communities started to take shape between 5,000 and 1,000 BC when clusters of homes were constructed next to agricultural fields along with a shrine and a burial site. Additionally, people started to group themselves into communities led by capable individuals, sowing the seeds of civilization. However, as the agricultural land's productivity decreased with succeeding crops, people tended to abandon their towns and move to newer locations. People stopped practicing shifting once they figured out how to cultivate their fields by rotating, and they began to settle down in one location.

The ability to prepare manure would allow humans to increase their food production. As there was more food available, people's health improved, birth rates increased, and death rates decreased. Due to the natural expansion of populations, this caused population to increase. All of these circumstances made it possible for people to live continuously close to the land they farmed. In order to determine the probable factors that influenced the choice of locations for permanent colonies, the following can be noted:

1. The environmental conditions had to be favourable for human existence and survival.
2. Climate had to be moderate and not harsh.
3. The region/area should be free from frequent epidemics.
4. Fertility of the soil had to be high to support cultivation of crops.
5. Potable water found in abundance.

Since they offered fertile soil, soft clay for building habitations, and the river could be used as a method of transportation, river valleys were seen to be the finest places for settlement. Thus, the first settlements were discovered in the Fertile Crescent (modern-day Iraq, Syria, Jordan, and Israel), China, India, and Egypt near river valleys.

The oldest settlements emerged in the later Neolithic era when early farmers were able to produce surplus food, freeing some members of the community from labor-intensive land work. From 4000 BC onward, a portion of the population began working in non-agricultural occupations wherever there was water for irrigation, such as Egypt, Mesopotamia, and the Indus Valley. They engaged in handcrafting, trading, and community organisation as non-agricultural occupations. Specialised guilds of craftspeople, traders, officials, and priests began to form.

These groups grouped together in compact societies that later came to be known as early towns, together with a portion of the agricultural community. To enable the development of transport infrastructure, suitable geographic regions were selected as the sites. Wheeled vehicles liked flat terrain, and sailing was done on rivers. Memphis and Thebes in the Nile Valley, Harappa and Mohenjo-Daro in the Indus Valley, Lagash, Kish Ur, and Nippur in the Tigris and Euphrates Valley are a few examples of such towns. These towns had temples, pyramids, and palaces and were largely walled for defense. These communities had trade connections with distant locations in addition to trading with the nearby farms and towns for goods like copper and supplies for creating paper.

New commerce hubs arose during the Bronze Age. These towns benefited from sea trade passing via the Mediterranean Sea. A few caravan centers (such as Damascus) were built in Syria's oases in the desert near the Fertile Crescent. New settlements also arose in the Wei Ho Valley in Northern China, and the idea of the city spread throughout China's middle and southern regions. Greek and Roman city-states first developed between 2000 and 1000 BC. The city served as the centre of the city states, and the surrounding rural area served as its supply source. These city states had dense urbanization but little population.

They were situated atop hills and had a direct connection to the ocean. From the Atlantic coast of Iberia to the Pacific coast of China, instances of urban settlement patterns based on the rectangular grid layout discovered in Harappa were also present by 500 BC. Due to the usage of iron tools, ships, and land vehicles, it was now easier to conduct business with other countries. The drop in city expansion was caused by the fall of the Roman Empire, the invasion of the Barbarians, and the onset of the Dark Ages in Europe.

Many cities in the previously urbanized regions of Europe had significant capital expansion between 1500 and 1750 AD as a result of the Renaissance voyages and the rising reputation of their rulers. At this time, a few strong cities started to dominate the others as a few powerful kings took control of expanding trade and vast swaths of land. Cities like Versailles, Nancy, and Potsdam expanded with wide, straight boulevards, magnificent palaces, meticulously landscaped parks, and theatres and art galleries.

Due to the expansion of sea trade, ports like Antwerp, Lisbon, and Amsterdam that allowed for trade with the Atlantic and Asia replaced Mediterranean ports like Venice and Genoa.

London had the most residents since it was the capital of a large state and a significant commercial hub. By the year 1700 AD, London had a population of 700,000, surpassing that of Moscow, Paris, and Vienna. Wherever water for irrigation was accessible after the Industrial Revolution, a greater number of towns were established, such as in Egypt, Mesopotamia, and the Indus Valley, and a portion of the population began working in non-agricultural jobs. They engaged in handcrafting, trading, and community organization as non-agricultural occupations. Specialized guilds of craftspeople, traders, officials, and priests began to form. These groups grouped together in compact societies that later came to be known as early towns, together with a portion of the agricultural community.

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Greek and Roman city-states first developed between 2000 and 1000 BC. The city served as the centre of the city states, and the surrounding rural area served as its supply source. These city states had dense urbanization but little population. Rarely did they provide for more than 50,000 individuals. They were situated atop hills and had a direct connection to the ocean.

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**INDIA**

In India, one comes across settlements that are more like cultural entities than straightforward settlements because they not only occupy the physical space but have a place in mythological and historical realms. The'story' of their origins must therefore be approached with a greater awareness of the place's spirit as it manifests in the minds of its residents.

Each settlement associated with the sacred geography that is a component of the imagined landscape has a "story" and is connected to the manifest eruptions of Divinity, such as the svayambhu sites like Thiruvannmalai in Tamil Nadu, or the settlement sites sanctified by pratishtha or adhesion of deities to those predetermined places from which the deity would not move away. The settlement grew as a result of this. Nathadwara in Rajasthan, Gokarna in Karnataka, and Vaidyanath in Bihar are a few examples of such villages.

The terms "fords" or "crossings" are also used to refer to places known as tirthas, or pilgrimage sites. These settlements include Tirupati, Gaya, Kashi, and Prayaga, for instance. The four dhams, which are found in each of the country's four cardinal directions, are thought to be where divinity resides. These towns are Rameshwaram in the south, Rameshwaram in the east, Puri in the north, and Dwarka in the west.

Settlements also provide a sense of community and a social identity for their residents. In both North and South India, names of one's birthplace appear as a prefix to one's name, such as Madurai Shanmukhavadivu Subbulakshmi, and one sees surnames of individuals bearing the names of their towns, such as Junjhunwalas from Jhunjhunu.

## 17.4 Classifications of Settlements

Each community is distinct and develops an own identity. Villages frequently occupy similar sites, have the same form and function, and occasionally occupy comparable landscapes. Cities and towns both share certain characteristics, such as distinct structures made of comparable materials. As a result, it is possible to compare settlements and then look for commonalities among them in order to classify settlements. Because size, form, and function are interdependent, it is crucial to consider all three while studying settlements. Let's go over a few of these qualities one at a time.

### 17.4.1 Classification on the Basis of Size

A village's size is influenced by its social, economic, and environmental circumstances. Compared to locations where the land is undulating and the soil is thin and unproductive, flat areas with suitable soil for farming have larger villages. In close proximity to desert regions with little natural resources, village sizes are minimal. The size of the village will increase more than the ones around it if the locals are adept at making use of the available resources.

The function of the urban core is the most significant factor influencing the size of urban settlements, but there are many other complex factors as well. The biggest business and financial centers are located in the biggest urban areas.

### 17.4.2 Classification on the Basis of Forms

Settlements may develop taking up different shapes, forms and patterns. It may be broadly classified into three categories on the basis of their form-Compact Settlements, Semi Clustered Settlements and Dispersed Settlements.

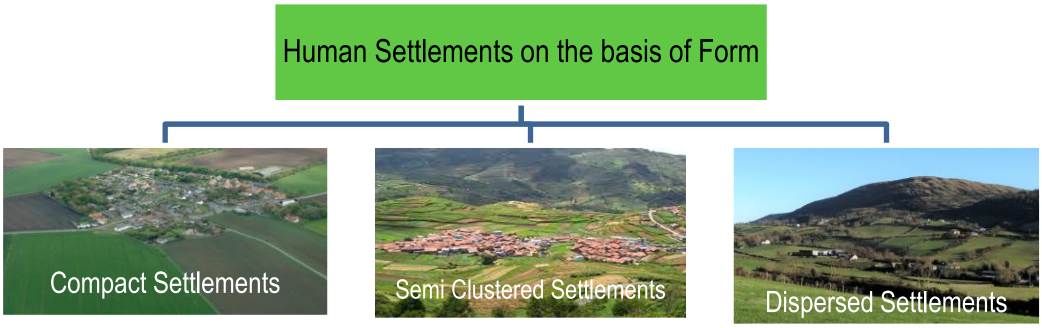


**Figure 3: Types of human settlements**

**(i) Compact settlement:** Homes are situated closely together in this form of settlement. The areas between buildings are small. They are referred to as clustered, compact, or nucleated settlements. These towns, where sizable hunting and gathering communities live, are typically found in highly productive alluvial plains.

**ii) Semi clustered or semi nucleated settlements:** These are areas that are transitioning from being scattered settlements to compact communities. The causes of this may vary depending on the environment, but in productive places, the number of homes increases as the population grows in modest, loosely clustered settlements with no discernible pattern. The semi-compact village is shaped like a compact settlement, and these new homes fill the open spaces.

iii) **Dispersed settlements:** A compact settlement site is absent from dispersed communities (see iii). Buildings are dispersed throughout a vast area, and there are substantial spaces between them. These towns can be found in regions with harsh weather, hilly terrain, dense woods, grasslands, and regions with intensive farming.

A number of elements, some topographical (such as a community's location in relation to relief, rivers, and roadways), some historical (such as the early necessity for defence), and some economic (such as the type of agricultural system used when the hamlet was originally created), affect how a village looks. The majority of villages are clustered communities; however some contain buildings that are significantly closer together than others.

**Urban settlements'** initial forms may be influenced by the surrounding environment, but as they develop, their forms and structures are shaped by social structures and ways of production.

### 17.4.3 Classification on the Basis of Functions

Functional classification attempts to categorize settlements on the basis of their economic function. Most functional classifications use employment and occupational data for this purpose.

In the villages, the inhabitants are engaged and dependent on various primary occupations, such as agriculture, dairying, cattle keeping, fisheries, forestry and mining. Of all these, agriculture is the main occupation. In towns and cities, one common function is trading and business. Towns also perform additional functions of trade, transport, industrial production, administration, defense, and entertainment. Towns and villages may change their functions in the course of time, and this may mean that the present function of a town may be unrelated to the function which led to its origin.

The main settlement system split occurs along the rural-urban division. Although there is general agreement that there are two types of communities, it is difficult to tell rural from urban areas.

**i) Rural**: Rural settlements are those where the locals rely on the exploitation of the region's natural resources for a living. Utilizing natural resources include mining, forestry, fishing, and agriculture. It is inextricably linked to the land that its residents occupy. Frequently, rural settlements are described as having characteristics that are absent from urban towns.

The majority of rural communities around the world are established and long-lasting. The open landscape dominates the rural districts. Administrative demarcation and identification are more objective since administrators may acknowledge a cluster as a unit even though it is deemed a settlement by the inhabitants. Numerous criteria can be used to define rural villages. We've highlighted a handful of them below.

**1. The existence of local deities:** In many regions of India, the sphere of influence of the village deity delineates the boundaries of a rural community. Rural communities in

North India have Khetrapals as protector deities, and in the south, Kaval-Deivams, who are related deities, are in charge of maintaining watch over rural villages.

**2. Revenue Village:** The administrative boundary for tax collection delineates the boundaries of rural communities.

**3. Census Village:** The boundaries of rural settlements are determined by how the Census activities map out the village boundaries.

**4. Villages in the Panchayati Raj System:** The Panchayati Raj System uses villages as the basis for delineating rural settlements.

**5. Resettlement Villages:** Following natural disasters and development initiatives, the inhabitants of the first destroyed settlements are frequently relocated. In Uttar Pradesh's Sitapur district, where roughly 800 destitute families have been living along the roadside for the past two years, Reusa block is a recent example of such a village. After the River Sharda altered its course by seven km, flooding and destroying the villages, these family were forced to leave their homes.

The Rural Resettlement Colonies in the Uttarakhand region, near Haridwar and Dehradun, are examples of where villages that were drowned by the Tehri Dam Project were relocated.

**6. Displaced/Abandoned Villages:** The village of Kuldhara in Rajasthan's Jaisalmer area is incredibly fascinating. It has been abandoned since the early 1800s, and it is thought that the villagers who fled elsewhere were cursed. The villagers still avoid entering the village due to their dread of the curse.

**7. Migratory/Transhumance Villages**: Tribes who engage in transhumance also live in rural communities, whether they are in the lowlands during the winter, which remain uninhabited during the summer, or on the mountains during the summer, which remain deserted during the winter.

In the Pitthoragarh district of Uttarakhand, the Bhotia tribe travels to the Milam glacier in the summer and returns to Munshiyari in the winter. In the Chamoli district of Uttarakhand, the Bhotia tribe travels to Gamshali in the winter and returns to Chhinka in the summer.

**ii) Urban:** Urban settlements are ones where the majority of residents rely on non-primary sources of income. These include manufacturing, management and service roles, retailing, wholesale distribution, banking, operations at regional and national headquarters, as well as a wide range of other personal and professional services.

According to the 1971 Census of India, an urban area is defined as follows:

All locations that have a municipality, corporation, cantonment, or notifiable town area

b) All additional locations that met the following requirements:

i) A population of at least 5,000 people.

ii) At least 75% of working-age men did not work in agriculture.

iii) A population density of at least 400 square kilometres, or 1,000 people per square mile.

However, in some marginal circumstances, the Director of Census of each State/Union Territory was allowed some latitude to include select locations that had other distinctive urban characteristics and to reject unworthy cases in consultation with the State Government.

## 17.5. Concept of Urbanization

Urbanization is the process of a city's population growing. The United Nations defines urbanization as the movement of individuals from rural to urban regions. The following is Mishra's (1998) definition of urbanization: Urbanization is a work in progress. It is a process by which a population shifts from widely dispersed rural communities to towns and cities dominated by industrial and service functionaries. It involves increasing the size of cities or urban regions. The increase in the urban population is one sign of urbanization. Famous demographer Kingsley Davis split the urbanization process into three phases.

**Stage I:** The initial stage, or Stage I, is distinguished by a typical rural civilization with a focus on agriculture and a dispersed pattern of settlement.

**Stage II:** In stage II, the percentage of urban population gradually increases from 25% to 40%, 50%, 60%, and so on. This stage is sometimes referred to as the "stage of acceleration," and it is where investments in social overhead capital, including transportation and communication, as well as fundamental economic transformation, happen.

**Stage III:** This stage is referred to as the terminal stage when the urban population reaches 70% or more.

The Census of India has broadly categorized urban areas in into following types:

i) **Statutory towns:** All locations with a municipality, corporation, cantonment board, notified town area committees, etc. are considered statutory towns.

**ii) Census towns:** All villages with at least 5000 people in the most recent census, at least 75% of the male primary working population employed in non-agricultural activities, and at least 400 people per square kilometre.

iii**) Urban agglomerations (UAs): These areas** include one or more towns, are continuous urban spreads.

**iv) Urban Growths (OGs**): Outlying districts of a main city or town, including well-known locations like railway colonies, university campuses, port areas, etc.

Table 1.1: Number of Urban Agglomerations/Towns and Out Growths in India

| **Types of Urban Units** | | | | **2001 Census** | **2011 Census** |
|---|---|---|---|---|---|
| 1. | Towns | | | 5161 | 7935 |
| | Statutory Towns | | | 3799 | 4041 |
| | Census Towns | | | 1362 | 3894 |
| 2. | Urban Agglomerations | N 1 | 1 | 384 4111 R | 475 |
| 3. | Out Growth (OGs) | | | 953 s | 981 |

Source: Census - 2011

However, in India, the Municipal Law classification of urban areas is different to that of the Census one. The categories according to the Municipal Laws are as follows:

(i) The Municipal Corporation having population about 3 lakh;

(ii) Municipal Council with 1 to 3 lakh population and

(iii) Nagar Panchayats having 5000 — 10,000 population. The Municipal Council are further subdivided on the basis of their population which is as follows:

| Type | Population |
|---|---|
| A or Class-I | 1 to 3 lakh |
| B or Class-II | 50,000 to 1 lakh |
| C or Class-III | 25,000 to 50,000 |
| D or Class-IV | 10,000 to 25,000 |

Source: Census — 2011

## 17.6. Rural Development

Rural development is a vast, multidimensional notion. It comprises, among other things, the development of human resources in rural areas, as well as cottage and village industries, craft industries, socioeconomic infrastructure, and services and facilities for the local populace. Numerous institutional, social, cultural, technological, economic, and physical factors interact to create the phenomena of rural development. It is a method for enhancing the social and economic well-being of a specific demographic, the rural poor. It is a multidisciplinary field that blends agriculture with the domains of engineering, management, social science, and behavioural science.

Rural development is a method used to make rural communities self-sufficient. The concept of rural development encompasses the expansion of the industry, agriculture, and socioeconomic infrastructure in rural areas. In conclusion, the transformation of a social structure from a "unsatisfactory" condition of living to one that is financially and spiritually better is encompassed by the process of rural development. Raising the level of living of rural populations while being fair, environmentally conscious, and socially responsible is the aim of rural development. better access to services and resources (including natural, physical, human, technological, and social capital), as well as through political and financial control over the capital required for production. by enhancing access to resources (natural, physical, human, technological, and social capital) and services, as well as by exercising political and monetary control over the capital required for production. The fundamental objectives of rural development schemes have been to employ marginal farmers and provide training for young people who are unemployed in rural regions, as well as to alleviate poverty and unemployment through building vital social and economic infrastructure.

## 17.7. Rural Development in India

The welfare of India's millions of residents has been the primary objective of all governmental endeavors ever since the country gained its freedom. Planning has been a cornerstone of Indian foreign policy ever since it attained independence, and it is planning's triumphs that give India its influence. The policies and programmes have been developed with the objective of eliminating rural poverty, which is one of the primary goals of planned development in India. It was realized that the core of any long-term strategy for eliminating poverty is expanding the number of opportunities for meaningful employment during the boom phase itself. The elimination of poverty, ignorance, disease, and opportunity inequity as well as the provision of a better and higher standard of living were the essential concepts on which all development plans and blueprints were founded.

Rural areas are where the majority of the world's poor and malnourished children, women, and men reside, with India having the biggest population. Due to this, since India's independence, policymakers in the nation have always placed a high priority on the development of rural areas. India began a magnificent effort for rural development that is extremely challenging to duplicate elsewhere due to its distinctiveness in terms of scale, variety, and dynamism. Agricultural development and rural development were once used synonymously. Shriram Maheshari (1995) claimed that India's agricultural development was the context in which the concept of rural development developed and that the two coexisted for a very long time.

However, this notion experienced a remarkable transition through time, and as a result, the terms "rural development" and "poverty reduction" are now frequently used synonymously. India's rural development problems, strategies, and tactics have changed over time as a result of incorporating new information and learning from past mistakes. Different methods have been employed to define and conceptualize rural development. Generally speaking, rural development is a complicated topic that includes a range of programmes intended to enhance the quality of life for those who live in rural areas. In order to give rural populations better possibilities for economic development, decentralized planning, improved enforcement of land reforms, and more access to funding are all envisaged. The World Bank (1992) compared economic and social uplift of the rural poor to rural development.

Because of this, the rural development programmes that were first implemented in India were always designed to ensure a sustained increase in per capita output and income, an expansion of productive employment, and greater equity in the distribution of the benefits of growth, in addition to ensuring that the rural poor have access to an adequate minimum of food, clothing, shelter, education, and health. Therefore, for rural development, social and economic infrastructure development is required. Rural development also entails transforming rural lifestyles and enhancing spatial and social ties, revitalizing institutional and organizational frameworks, introducing appropriate technology with the primary objective of generating employment, and creating programmes to support environmental sustainability, gender equality, self-sufficiency, and self-sustenance.

## 17.8 Summary

Human settlements mean the totality of the human community with all the social, material, organizational, spiritual and cultural elements that sustain it. C. A. Doxiadis developed "Ekistics" or the science of human settlements which takes into consideration the principles human takes into consideration while building his settlements, as well as the evolution of human settlements through history. The subject is a very complex system of five elements — nature, human, society, shells and networks. Theories related to settlement systems may be broadly grouped under behavioural or normative.

If we trace the evolution of settlements, when and where the first settlements had developed is still a matter of dispute. Through archaeological evidences, one can say that the first settlements developed in the Neolithic period. During 5,000 to 1,000 BC, earliest settlements began to take shape with groups of houses being built near the agricultural fields, with a shrine and a burial ground. The earliest towns came into existence in the later part of the Neolithic period when the early farmers were able to produce surplus food, and thus allowing a part of the society to be free from tilling of the land. It is therefore possible to look at the similarities between settlements for a comparative treatment and then to arrive at some classification of settlements. In the study of settlements, it is important to take all aspects of size, form and function because they are closely dependent on one another. Settlements may be broadly classified into three categories on the basis of their form-compact settlements; semi clustered settlements and dispersed settlements. On the basis of functions, settlements are broadly classified as rural and urban.

**Fill in the blanks with suitable words:**

a) Bigger villages are found in areas.

b) Most common function of towns is

c) Open country sides are a feature of Settlements.

d) In India, settlements should have a density of persons per sq. km to be qualified as an urban settlement.

## 13.6 Terminal Questions

1. What are the various components that make up settlements?

2. Briefly trace the evolution of settlements from the Neolithic period to the present times.

3. What are Dispersed Settlements? In which geographical conditions are these settlements found?

4. Write short notes on (a) Rural Settlements; (b) Urban Settlements.

**13.7 ANSWERS**

**Self-Assessment Questions**

1. a) A collection of human-made structures, put up with the intention of habitation, establishment of shelter or social/economic use, which forms a spatial unit for human interaction.

b). Maximization of human contact with elements of nature, other people and human-made structures; minimization of the effort to reach them, optimizing the zone of safety or the protective space around the settlement and optimization of the quality of human being's relationship with his/her environment.

2. a) Permanent Settlements were located where the environmental conditions are favourable for human existence and survival like moderate climate; high fertility of the soil which can support cultivation of crops; abundance of potable water; and a region free from frequent epidemics.

b) A Metropolis is a large city dominating a number of small towns and villages. Such a settlement is commonly occupied by cosmopolitan population, following many specialized occupations, and has a very wide sphere of influence.

3. a) Flat

b) Trading and business

c) Rural

d) 400 97

**Terminal Questions**

1. Human settlements or the system of human settlements could be conceived as a complex whole consisting of physical as well as non¬physical subsystems, besides human being. Human, society, government, built environment and natural environment are the subsystems

2. Historically, the first settlements came up in the Neolithic Period and natural shelters were converted into dwellings. During 10000 to 5000 BC, with growth of cultivation, huts were built close to fields. As food became abundant, earliest towns came into existence with non¬agricultural activities such as trading and manufacturing gained importance. Between 1500 and 1750 AD, many great cities dominated over other cities and in the post Industrial Revolution period, improvement of communication led to multiplication of urban centres —a trend which continues till the present times.

3. In a Dispersed Settlement, buildings are spread over a large area, and inter building spaces are large. These settlements are found in areas of extreme climates, hilly tracts, thick forests, grasslands and in areas of extensive cultivation.

4. a. Rural settlements are those where the inhabitants of the settlement, depend on exploitation of the natural resources for their livelihood. Exploitation of natural resources means engaging in agriculture, fishing, forestry and mining. It cannot be separated from the land, the inhabitants use for their occupation.

b. Urban settlements are those where the inhabitants of the settlement, depend on non-primary activities for their livelihood. These activities range from manufacturing, service and management function, retailing, wholesaling, banking, regional and national headquarter office activity and a host of other personal and professional services.

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