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1. Introduction

Conventional geological and other field expeditions will always remain the best methods of data collection. However, modern geospatial tools like remote sensing can make such investigations rapid and more comprehensive. In the last four decades, remote sensing and GIS tools have been extensively used for better mapping, monitoring and decision-making tasks in many disciplines. Therefore, a systematic study is needed to understand the physical principles behind remote sensing technology to efficiently use it for different earth resources applications. In this module, the basic concepts, advantages, historical developments and structure of a typical remote sensing program is discussed.

2. Definition of Remote Sensing

As the name suggests, remote sensing is a method of collecting information about any ground object under investigation from a distance without being in contact. There are many definitions found in the literature, however, the most accepted definition was given by the American Society for Photogrammetry and Remote Sensing in 1988. Accordingly, Remote Sensing can be defined as *"The art, science and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems."*

3. Advantages and Limitations of Remote Sensing

Remote Sensing techniques have several advantages over the conventional field-based investigations. These are -

a) **Synoptic Overview:** The remote sensing images provide a synoptic overview or bird's eye view of a larger area, enabling us to study the relationship among different ground objects and delineation of regional features/trends.

b) **Feasibility Aspects:** Due to inaccessibility to ground survey in many parts of the terrain, remote sensing is the only scientific method for data collection.

c) **Time Saving:** Remote sensing saves time and manpower as larger area can be covered by this technique.

d) **Unobtrusiveness:** If the remote sensors collect the information passively by recording the electromagnetic energy reflected or emitted by the ground object, the area of interest is not disturbed. It also ensures collection of information in its natural state.

e) **Systematic Data Collection:** Remote Sensing devices collect the information of the ground surface in a systematic manner with a specific time interval, removing the sampling bias introduced in some in situ investigations.

f) **Derivation of Biophysical Data:** Under controlled conditions, remote sensing can provide fundamental biophysical information, e.g., location, elevation, temperature, moisture content, etc.

g) **Multi-disciplinary Applications:** The same remote sensing data may be used by researchers or workers from different disciplines, e.g., geology, forestry, agriculture, hydrology, planning, defense, etc. and therefore, increase the overall benefit-to-cost ratio.

Although, there are many advantages making the technique an enormously popular tool, it has some limitations, too.

a) **Understanding limit of application:** The greatest limitation of this technique is that its utility is often oversold. Remote Sensing alone cannot provide all the information needed for any scientific study. The applicability of these tools and techniques are limited to selection of appropriate sensors, its resolutions, time of data collection and appropriate post-processing operations.

b) **Expensive technique:** The collection and interpretation of remote sensing data is expensive, as it requires specific instrumentation and skills. However, the enormous advantages of this technique overrule this limitation.

4. History of Development

Although, the first space photography of the Earth was carried out by Explorer-6 in 1959, the background of remote sensing expeditions started long before, perhaps through Aristotle's (Circa 336-323 BC) philosophy about the nature of light and Sir Isaac Newton's Principia summarizing basic laws of mechanics. In 1826, Joseph Nicephore Niepce took the first photographic image; however, the first aerial photograph from balloon was taken by G F Tournachon in 1958. With the invention of airplane by Wright Brothers (1903), aerial photography received a new pair of wings. Photoreconnaissance survey was widely used during World War I (1914-18) and II (1939-45). During this period, the aerial photography and photogrammetric techniques had advanced manifold and paved the way for civilian use. Meanwhile, several space photography missions were successfully launched by the US and Russia in the 60's viz. Mercury program (1960), Gemini Mission (1965), Apollo Program (1961), Corona (1960-72). In this period, sensors were also developed for Earth Observations for meteorological purposes (TIROS-1, ITOS, NOAA, etc.). The payload of NOAA satellites were modified and the first-ever Earth Resources Technology Satellite (ETRS-1) was launched in 1972, later renamed as Landsat-I, and thus, began a new era in the history of remote sensing. During the 1980's, with successive launces of Landsat Series with Multi-spectral Scanner (MSS) and Thematic Mapper (TM), extremely valuable data about land surface were collected worldwide and spectral behavior of rock, mineral and vegetation were thoroughly studied. At the same time, space shuttle programs were initiated for radar imaging and applications (SIR-A, SIR-B etc.). Hyperspectral sensing systems were also introduced with potential of lithological mapping. With improvement of electronic technology, many other countries including Germany (MOMS), French (SPOT series), Japan (MOS) and China-Brazil series joined hands with USA in space remote sensing experiments. In 1988, India also joined the league with IRS – 1A satellite and the legacy continued. In the 1990's, many improvements of sensor technology were seen with better spatial, spectral, radiometric and temporal resolutions. In 1995, IRS-1C was launched with 5 m spatial resolution. By the end of the decade, private agencies entered the race with better spatial (Ikonos 1m; Quickbird 60cm) and radiometric resolution, increasing the potential of remote sensing applications.

Table 1: Major Milestones in Remote Sensing

Year	Events
1687	Newton's Principia – Basic Laws of Mechanics
1826	Niepce's first photograph
1958	Tournachon's aerial photograph from balloon
1903	Wright Brother's Airplane
1914-18	World War I photo-reconnaissance
1926	Goddard's liquid powered rocket
1939-45	World War I photo-reconnaissance advances
1959	First Space photography by Explorer-6
1972	Earth Resource Technology Satellite / Landsat-1
1982	Landsat Thematic Mapper
1988	IRS-1A launched
1991	European ERS-1 launched
1995	IRS-1C launched with 5.8 m panchromatic band
1998	SPOT-4 launched
1999	IKONOS with 1 m spatial resolution
1999	EOS - ASTER launched
2000	Shuttle Radar Topography Mission (SRTM) for global DEM
2001	Quickbird2 with 60cm panchromatic and 2.4m multispectral data
2005	IRS Cartosat-1 for DEM generation
2007	IRS Cartosat-2 with 80cm panchromatic band
2013	Landsat-8 OLI/TIRS with 11 bands (freely downloadable)
2014	WorldView-3 – 30 cm resolution

In the last decade, further improvements in space technology were seen. Some of the important missions/sensors in this decade are ASTER, MODIS, Resourcesat LISS-IV, SRTM, Landsat ETM+, WorldView, Cartosat, etc. Most recently in 2013, Landsat-8 was launched with availability of multispectral data available free-of-cost with high potential of earth resource mapping applications. Although, it is not possible to sum up the complete history within the scope of this module, some of the important events are further listed in Table 1.

5. Basic Principles of Remote Sensing

All objects of the earth's surface (at 300 Kelvin) like, soil, rock, vegetation, etc. above absolute zero (-273° Centigrade or 0 Kelvin) emit electromagnetic energy. And so does the Sun (at 6000 Kelvin). Sun is the major source of energy required for remote sensing purpose (except radar and sonar). The energy is transferred by electromagnetic radiation through the vacuum between the Sun and the Earth at the speed of light. It interacts with the atmosphere before coming into contact with the earth's surface. While returning, it interacts with the atmosphere once again and finally reaches the remote sensor. The detectors or photographic film system on-board records this reflected or emitted energy in analogue or digital form (Figure 1).

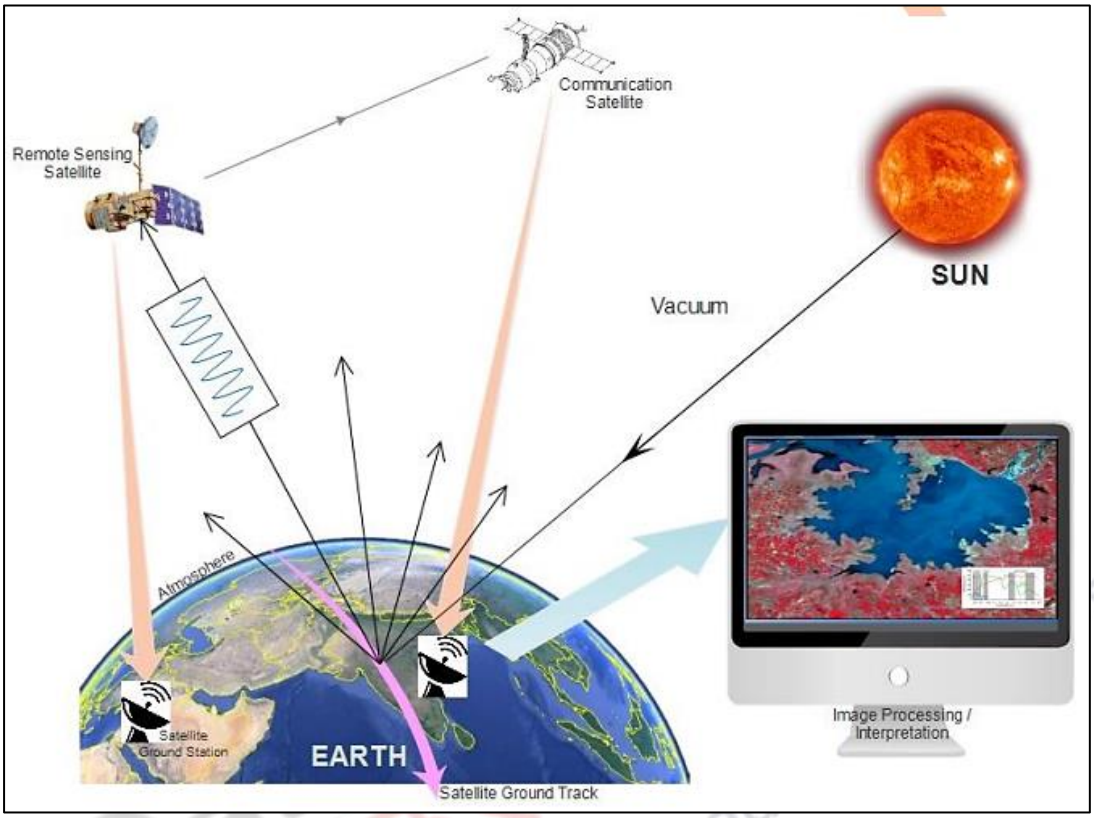

Figure 1: Overview of Remote Sensing Data Collection.

The electromagnetic radiation principle conceptualized by James Clerk Maxwell in 1960, refers to all energy that moves with the velocity of light (300,000 km per second) in a harmonic wave pattern. The electromagnetic wave consists of two fluctuation fields – one electrical and the other magnetic at the right angle to one another. Both are also perpendicular to the direction of travel (Figure 2). The electromagnetic waves are characterized by its wavelength (i.e. the distance from any point on one cycle or wave to the same position on the next cycle or wave measured in micrometer, µm) and frequency (number of cycles or waves pass through a point per second). The frequency is inversely proportional to the wavelength.

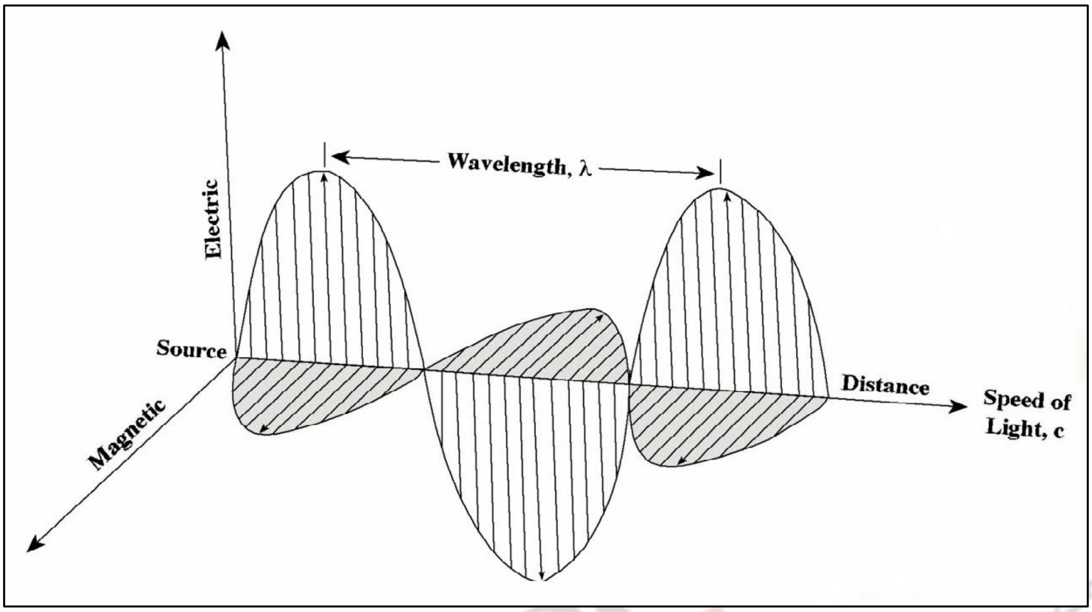

Figure 2: Components of Electromagnetic wave.

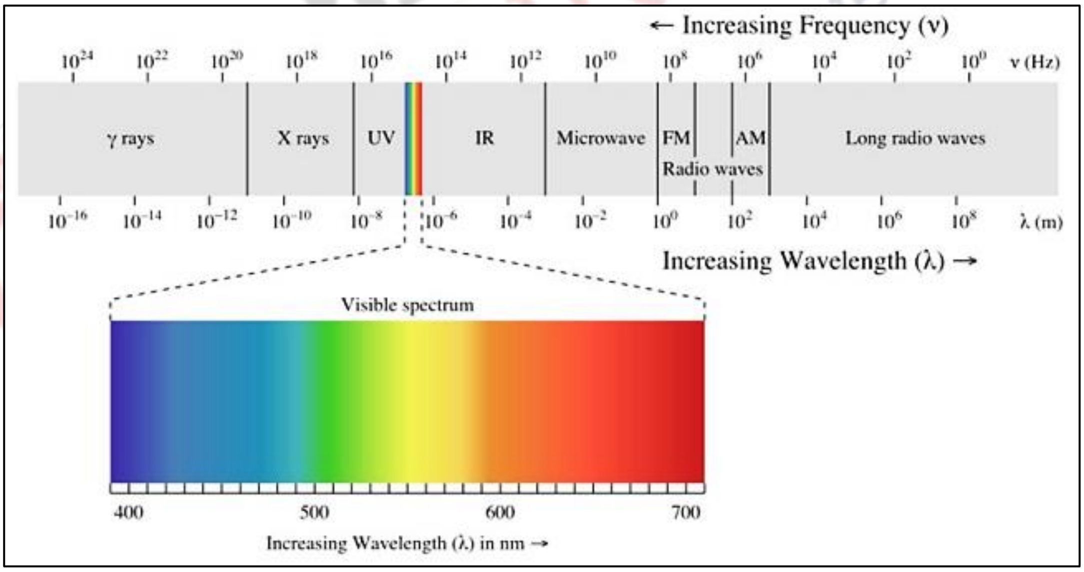

Figure 3: Wavelength ranges in electromagnetic spectrum.

The basic principle involved in remote sensing methods is that in different wavelength ranges of the electromagnetic spectrum (Figure 3), each type of object reflects or emits a certain intensity of light, which is dependent upon the physical or compositional attributes of the object. Hence, the spectral behavior (i.e. the intensity of light emitted or reflected by the objects) of same ground object in different wavelength ranges may be studied through Spectral Signature Curves (Figure 4). Such curves may help to differentiate different types of objects, e.g., soil, vegetation, waterbody, settlements, etc. and map their distribution on the ground (Figure 5). The remote sensing missions are, thus, a process of collection of spectral information of the ground objects, enhancement and interpretation for different applications.

Further discussion on the electromagnetic energy and its interaction with earth surface features is discussed in the next module.

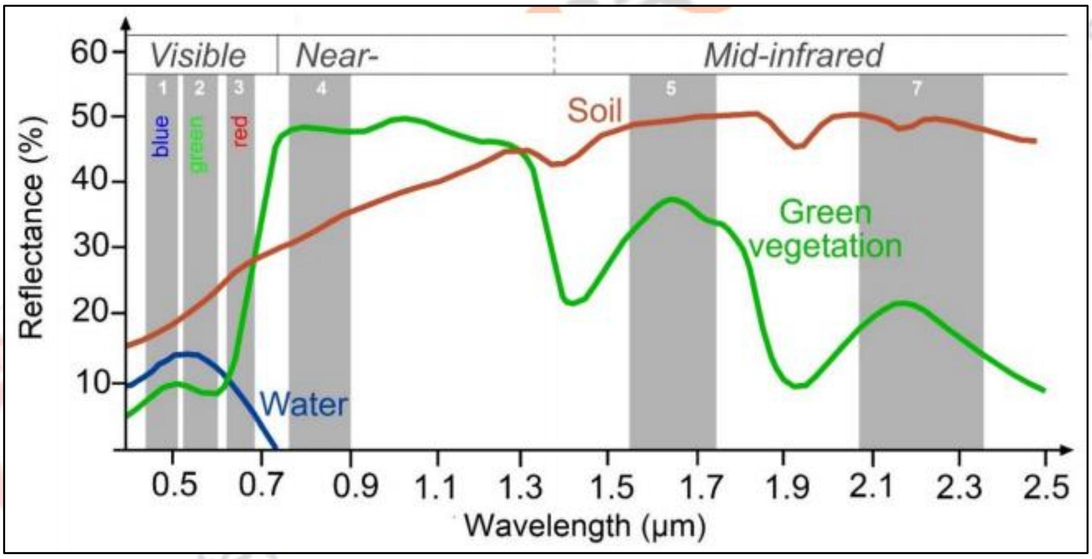

Figure 4: Spectral Signature Curves of common ground objects. Spectral bands of Landsat-7 are shown in the background (1 µm = 1000 nanometers = 10-6 meters).

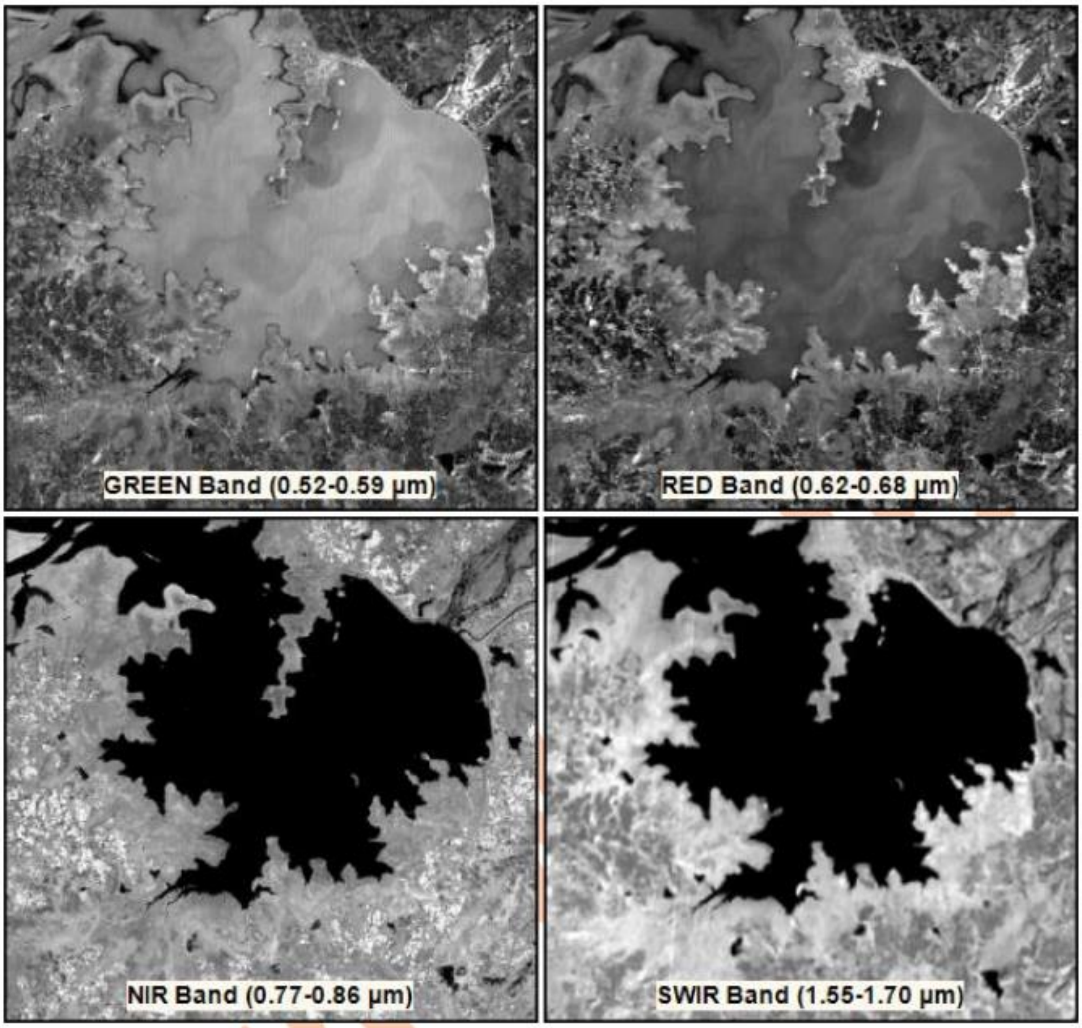

Figure 5: Four bands of IRS LISS-3 multi-spectral image showing different spectral characteristics of various ground objects.

6. A Typical Remote Sensing Process

A typical remote sensing-based application process involves the following steps (Figure 6):

6.1 Statement of Problem: Remote sensing can provide information on various biophysical (viz. location, elevation, chlorophyll concentration, biomass density, surface temperature, soil moisture, evapotranspiration, snow/ice cover, etc.) and hybrid (viz. land use, vegetation stress, etc.) variables. Depending upon the nature of problem, a scientist should identify the potential use of remote sensing. Scale of mapping and accuracy specification should be given the priority during selection of appropriate sensor and methodology

6.2 Data Acquisition: Remote sensing data may be collected using either passive or active remote sensing systems. Passive sensors record naturally occurring electromagnetic radiation that is reflected or emitted from the terrain. Remote sensing in the day light under the influence of solar energy falls under this category. When man-made electromagnetic energy is used to illuminate the ground and backscatters are recorded by the sensor (e.g. in microwave radar), such sensors are called passive sensors.

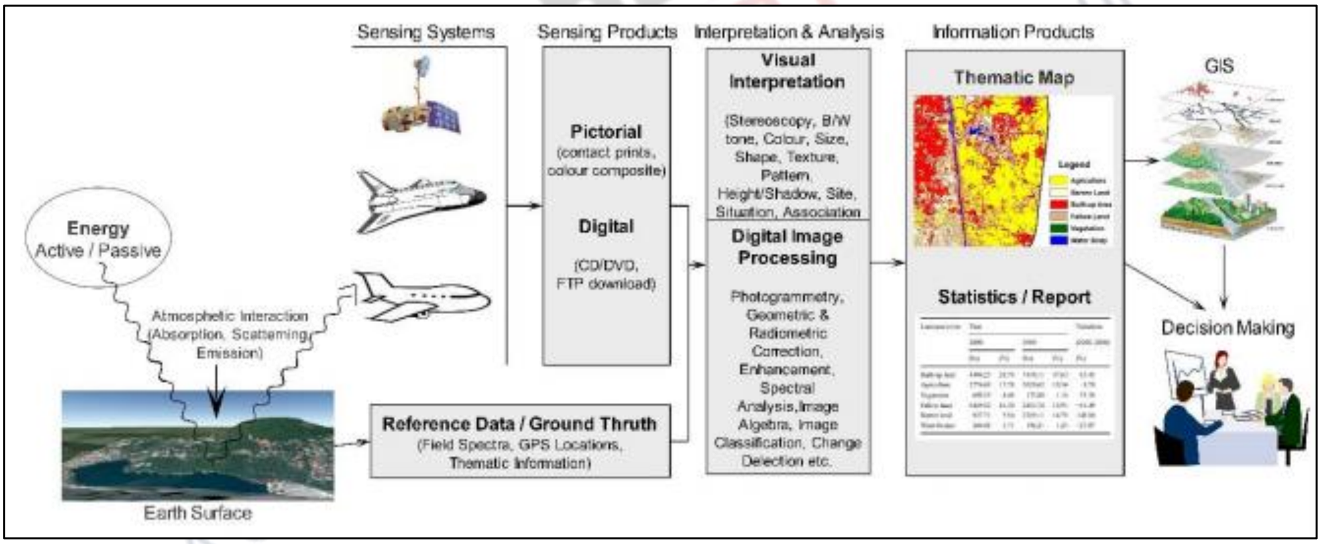

Figure 6: A typical Remote Sensing Program

Remote sensing images are collected from suitable platforms located at various altitudes (Figure 7) e.g. aerial (balloons, helicopters and aircraft) and space-borne (rockets, manned and unmanned satellites). Hydraulic platforms and handheld spectroradiometers are used to generate ground truth data. Each remote sensing system is characterized by four types of resolutions e.g. spectral, spatial, temporal and radiometric. Thorough understanding of these resolutions are needed to extract meaningful information from remote sensing data (Figures 8).

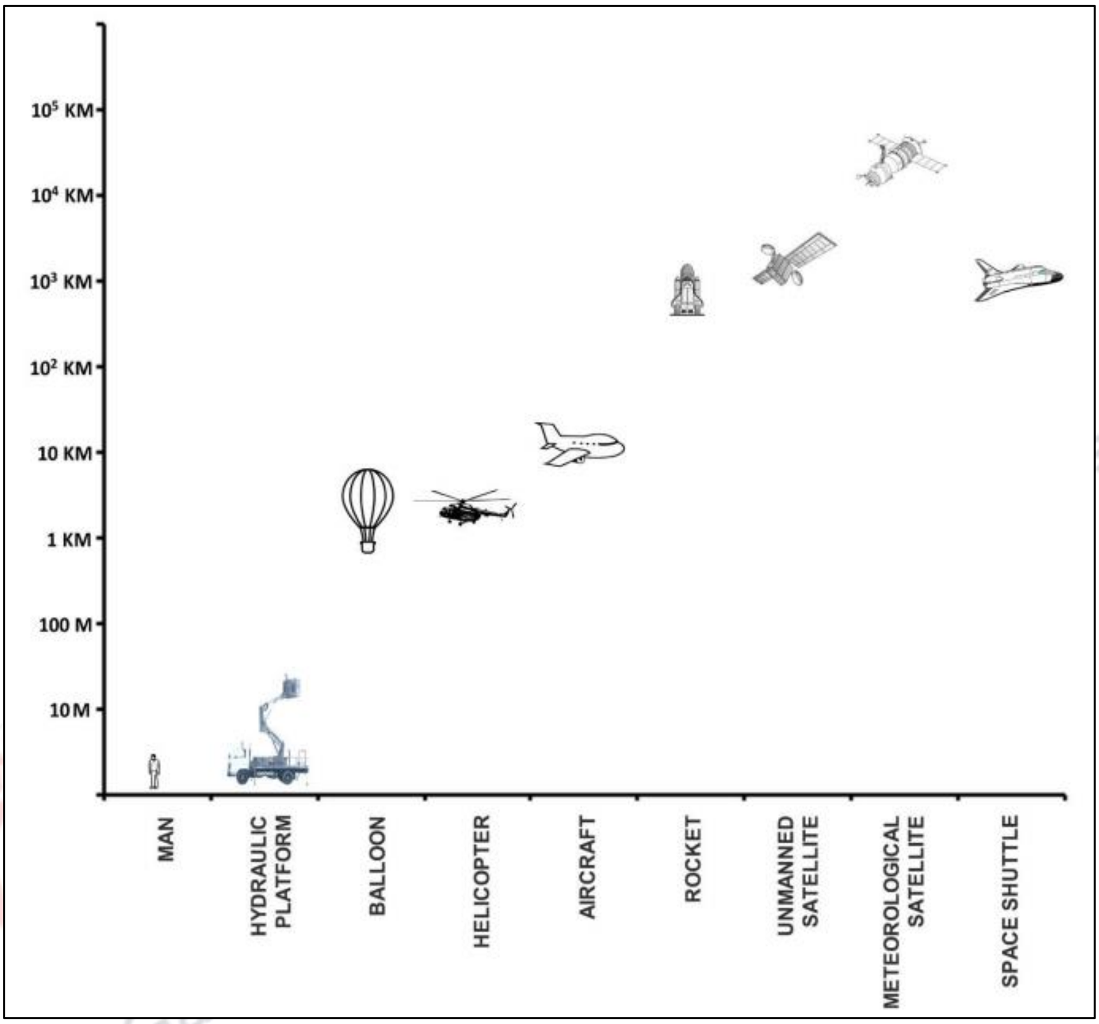

Figure 7: Remote Sensing Platforms.

BOX 1

SENSOR RESOLUTION

Spectral Resolution: The number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive.

Panchromatic data with single broad spectral band (e.g. 0.5-0.7 µm) has low spectral resolution in comparison to a multispectral data with more than two narrow spectral bands (e.g. Blue: 0.45-0.52 µm, Green: 0.52-0.60 µm, Red: 0.63-0.69 µm and Near Infra-red: 0.76-0.90 µm)

Spatial Resolution: It is a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor.

In broad sense, the ground distance (e.g. 0.8 m of IRS Cartosat-2) represented by the smallest unit 'pixel' of a digital image is its spatial resolution. More number of pixels of dimension 60cm x 60cm are needed to cover 1 km x 1 km area than of pixel dimension 30m x 30m, hence the earlier data has high spatial resolution.

Temporal Resolution: It is a measure of frequency of data collection of a particular area by the sensor.

Satellites have fixed revisit schedule for each geographic area, e.g. 5 days, 24 days, etc.

Radiometric Resolution: It is defined by the number of discriminable signal levels the sensor can record the radiant flux from the terrain.

12-bit data (2^{12} or 0-4095) helps to discriminate variation of greenness in vegetation more than 8-bit data (2^{8} or 0-255) with same spatial and spectral resolution.

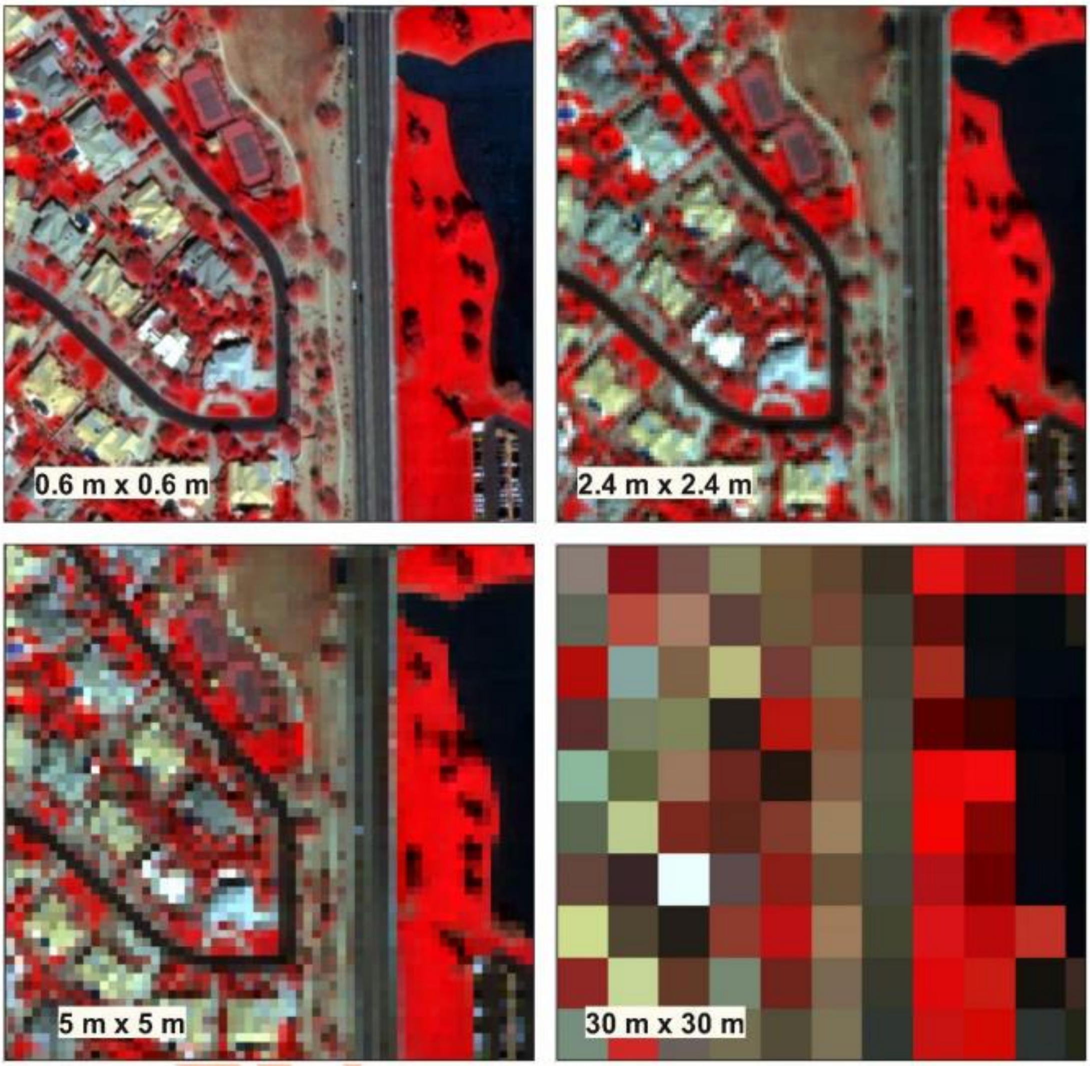

Figure 8a: Spatial Resolution.

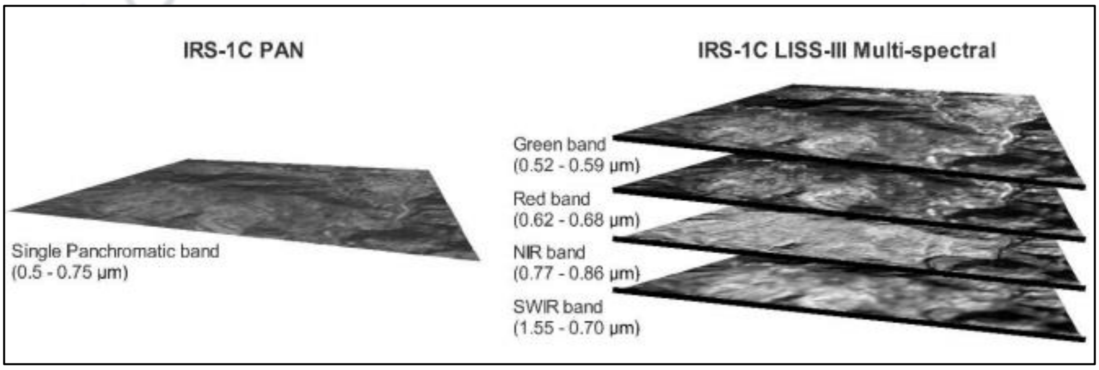

Figure 8b: Spectral Resolution.

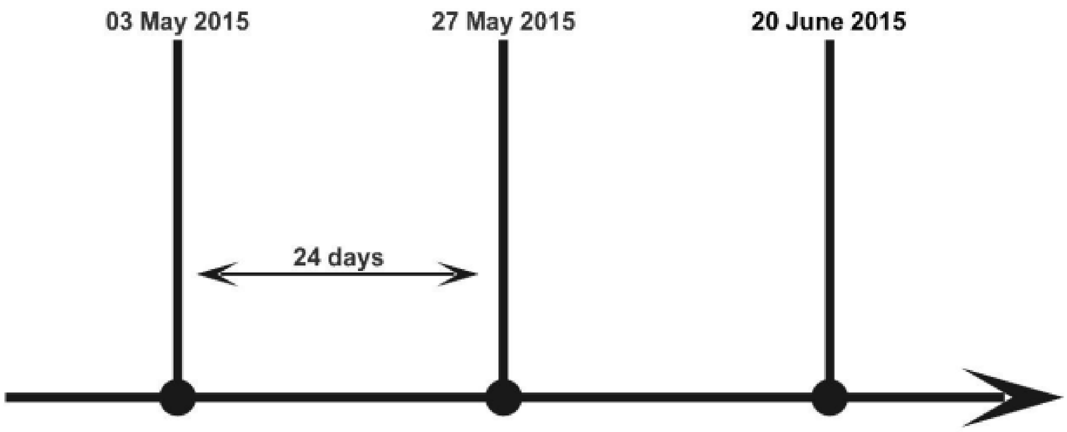

Figure 8c: Temporal Resolution.

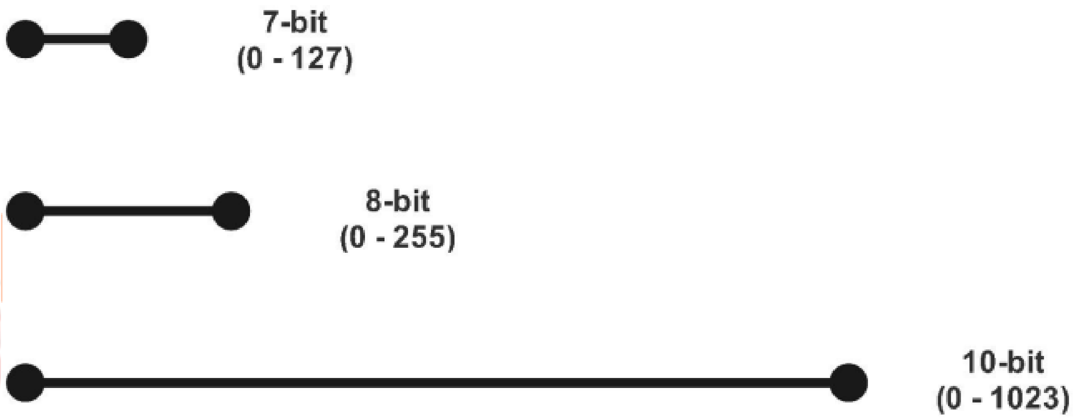

Figure 8d: Radiometric Resolution.

6.3 Data Processing, Analysis and Interpretation: Remote Sensing data acquired through various sensors and platforms are processed to enhance the quality for better analysis and interpretation. Aerial photographs mostly available in analogue form are meant for visual interpretation (through tone, texture, pattern, association, etc.) and photogrammetric measurements. However, the satellite remote sensing data collected in digital form can be used for quality enhancement, statistical and syntactical pattern recognition, photogrammetric processing, expert system and neural network image analysis. The image processing tasks are carried out in computer workstations with the help of specific image processing software (e.g., Erdas Imagine, ENVI, eCognition, Idrisi/TerrSet). Through these processes, various thematic information may be extracted e.g. land cover, lithology, structure, soil, vegetation cover, etc.

6.4 **Field/Ground Validation:** Field data or ground truth play very important roles in remote sensing. These are –

(i) Calibration of remote sensor

(ii) Data correction, analysis and interpretation

(iii) Accuracy assessment of thematic maps generated from remote sensing data

Timing of field data collection should be decided based on the nature of application. The time-stable parameters, such as, spectral emissivity, rock type, structure, etc. may be collected any time, however, time-variant parameters (viz. temperature, rain, condition of crop, phonological cycle) must be measured during the remote sensing overpass. In case of archival data analysis, fieldwork is usually carried out in the same season for identical weather or phonological condition. In most of the cases, purposive sampling strategy is adopted utilizing skills and local knowledge of the field worker. In the field, thematic information e.g., lithology, structures, landform, plant species, soil types, water bodies, etc. are collected that help to verify the remote sensing image interpretations. Location information for observation points are collected through GPS instruments. In specific cases, field spectroradiometers are also used to generate spectral signature curves of ground objects that may be used to identify similar objects in the remote sensing data. Recently, very high spatial resolution Google Earth images have also been used as reference data for interpreting relatively low resolution remote sensing data for regional scale applications (e.g., Land use / land cover mapping, etc.).

6.5 Presentation for Decision Making: The outputs are presented as analogue or digital thematic maps, spatial database file, statistic or graphs. The final outputs often become an important data source for GIS-based decision support system. Most recently, integrated approaches of GIS and remote sensing have become more effective tools than using remote sensing interpretation alone.

7. Important application areas of Remote Sensing

Remote Sensing data has been used successfully in many application areas. Some of the important Earth Resources applications are listed in Table 2.

Table 2: Earth Resource Applications

Broad Area	**Key Applications**
Geology	Landform characterization, Structural mapping, identification of fold, fault, etc., Lithological Mapping, Soil Characteristics, Mineral and hydrocarbon exploration, Hydrothermal alteration, Engineering Geology, Geothermal anomaly
Hydrology	Groundwater exploration, Paleo-channels, recharge site selection, Glacial retreat/progress
Terrain Mapping	Digital Elevation Model, 3-D Terrain Visualization
Forestry	Species identification, Biomass estimation, Deforestation
Land Use/ Land Cover	Mapping and change detection
Urban Planning	Cadastral Mapping
Environmental Monitoring	Coal and forest fires, Landfill, Soil Erosion, Atmospheric Pollution, Environmental Impact Assessment, Urban Heat Islands
Agriculture	Crop yield estimation, Soil moisture
Disaster Management	Earthquake, flood, landslide damage assessment Land subsidence
Utility, Transportation	Route Planning, identification of road/trails
Social Science	Archaeological site, Population Density Estimation
Ocean/ Coastal Monitoring	Ocean color / phytoplankton concertation, Potential fishing zones, Sea Surface Temperature, Oil Spill
Defense Application	Terrain Evaluation, 3-D visualization

8. Summary

Remote Sensing is obtaining information about an object without touching the object. The objects under investigation behave uniquely in different wavelengths of electromagnetic radiation incident upon it, enabling us to differentiate one object from another. Remote sensing has been advantageous over the conventional field data collection in respect to synoptic overview, time saving, systematic and multi-disciplinary applications. Since its beginning, the tool has been used for many application areas from meteorology to earth resources mapping, monitoring and conservation. A typical remote sensing program involves collection of surface reflections or emissions of electromagnetic energy using sensor system on-board a specific platform, calibration, distribution, pre-processing, enhancement, visual interpretation and / or digital image processing for automatic/semi-automatic thematic information generation. Selection of appropriate remote sensing data with specific spectral, spatial, temporal and radiometric resolution depends upon the nature of application. The resultant thematic information may also be used as a prime source of input data for GIS-based modelling and decision-making tasks.

Frequently Asked Questions-

Q1. Does clicking a picture using handheld camera qualify to be a remote sensing system?

Ans: Such photography may also be called remote sensing as the information about a phenomenon is collected from a distance without direct contact with the objects. However, in conventional remote sensing, the information is collected from the top and there is a basic difference in perspective of observation. Worth to mention, traditional photography is also considered to be an important tool in time series analysis for many environmental applications.

Q2. What do you mean by "Synoptic Overview"?

Ans: Synoptic overview is synonymous with Bird's eye view where the larger section of the study area can be seen within one frame, enabling us to study the relationship of any object with its neighbor for better interpretation and analysis. For a geologist, synoptic overview through aerial photographs or digital image may help to extrapolate regional fault or fold exposures on ground, and prepare a geological map more efficiently.

Q3. Why "Spectral Signature Curve" of a ground object is unique?

Ans: Spectral response of any object is related to its physical and chemical composition, which varies in different electromagnetic wave length. These curves are derived through spectrometers under ideal illumination condition for a standard object. However, the actual field spectra of similar object may vary depending upon surface coating, leaching, moisture content, etc., on it.

Q4. What is reflectance?

Ans: Reflectance of the surface of a material is its effectiveness in reflecting radiant energy. In other words, it is the ratio of the intensity of reflected radiation to that of the radiation incident on a surface, usually represented in percentage.

Q5. What is the best sampling strategy of ground truth data collection for remote sensing applications?

Ans: Purposive sampling for selected sampling points based on local knowledge of the expert as well as interpretation of the photographs/images are considered to be the best method.

Multiple Choice Questions-

1. Which was the first Indian Remote Sensing Satellite for Earth Resources Application

(a) INSAT-1A
(b) IRS-1A
(c) ERTS-1

2. What is the ambient temperature of the Sun

(a) 6000 K
(b) 3000 K
(c) 300 K

3. What is the wavelength range of visible part of EM spectrum

(a) 0.4-0.7 µm
(b) 0.7- 1.1 µm
(c) 1 mm- 1m

4. How many spectral bands are present in Landsat-8 mission

(a) 4
(b) 8
(c) 11

5. What is the ideal resolution combination for lithological mapping

(a) Low Spectral and Low Radiometric
(b) High Spectral and Low Radiometric
(c) High Spectral and High Radiometric

6. What is the approximate altitude of unmanned earth resources satellite platforms

(a) 10-15 Km
(b) 600-800 Km
(c) 36,000 Km

Suggested Readings:

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