Remote sensing: An overview with fundamentals and applications

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Introduction:

A simple statement can derive the broad concept of remote sensing, namely, the acquisition of information from a specific distance. It is the study of measuring emitted and reflected radiation to get information about an object and phenomenon (Ray, 2013). According to Lillesand et al. (2015), The science and techniques of acquiring information about an object, land area, phenomena, or ecosystem process using a technology that is not in direct touch with the object, region, or phenomenon under research are known as remote sensing. The data collection is done remotely using various sensors, which may be further analyzed to obtain information about the objects, areas or phenomenon. Variations in force distributions, acoustic wave and electromagnetic energy distributions are only some of the types of data that may be gathered. Modern remote sensing, according to Joseph (2005), is an extension of the natural phenomena of visual perception of things. Apart from visible spectrum, the electromagnetic radiation from the ultraviolet to far infrared and the microwave regions is used for remote sensing. The observations, which are directly inferred through electromagnetic radiation (EMR) from the sun or self-emitted radiance, is called passive remote sensing. Active remote sensing, on the other hand, uses electromagnetic radiations of a given wavelength or band of wavelengths to illuminate objects and records reflected or back-scattered EMR to obtain information, such as LiDAR, RADAR, and SAR.Remote sensing is described as the process of detecting the earth's surface from space using the qualities of electromagnetic waves generated, reflected, or diffracted by detected objects in order to improve natural resource management, land use, and environmental protection. The classification of remote sensing is further based on the selection of EMR (e.g. microwave and optical) Navalgund et al. (2007). Optical remote sensing uses interference and polarization concepts with electromagnetic energy to detect the scattered energy returning from the terrain and records it as an image. Microwave remote sensing uses interference and polarization concepts with electromagnetic energy to detect the scattered energy returning from the terrain and records it as an image. The basic goal of remote sensing is to collect information about two or three dimensions of actual things in an orderly, systematic, and large-scale manner.

Through various earth observation satellite sensors, one can obtain large and broad, global coverage and repeatability of data to obtain multipurpose information, which helps in detecting things that are normally absent in visible spectra, such as land-surface temperature, underground or sub-surface water, and so on.There are several Earth Observation (EO) Satellites namely, Cartosat series, Landsat series, Sentinel 1, 2, MODIS, RISAT 1 and RADARSAT 2, Resourcesat, Envisat, Oceansat 2, IRS-1A, and many more.

Electromagnetic Spectrum:

The term "electromagnetic radiation" (EMR) refers to all of the numerous forms of energy emitted by electromagnetic processes. Electromagnetic energy comes in various forms, including visible light. Electromagnetic radiation includes radio waves, infrared light, and X-rays. The vibrations of electric and magnetic fields, which change in amplitude in a direction perpendicular to the direction of propagation of radiations at a constant speed of light (c = 3*108 m/s), generate electromagnetic waves. Figure 1 depicts a broad definition of EMR. These vary from mechanical waves in that they do not require a medium to propagate, therefore they may move through air, solid materials, and even the vacuum of space. Thus, to define the EMR scientifically, it can be said as a form of energy emitted or absorbed by charged particles which exhibits wave-like behavior as it travels through space.

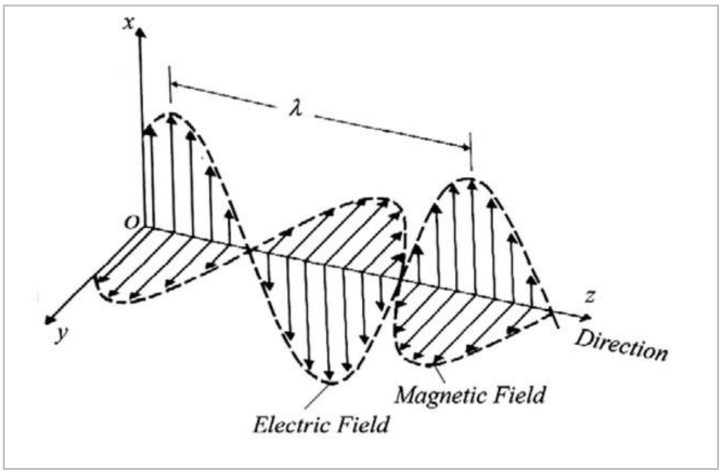


Figure 1. Illustration on the concept of EMR in which propagation of electric and magnetic field is shown

Source - http://www.fao.org/3/t0355e/T0355E02.HTM, accessed on 25th April, 2021.

The electromagnetic spectrum is the entire range of all possible frequencies of electromagnetic radiation (Figure 2). This contains electromagnetic radiation ranging from Gamma rays to radio waves, with the intensity and frequency generally decreasing as the wavelength lengthens. There are four kinds of resolution that are described from the EMR spectrum are as follows:

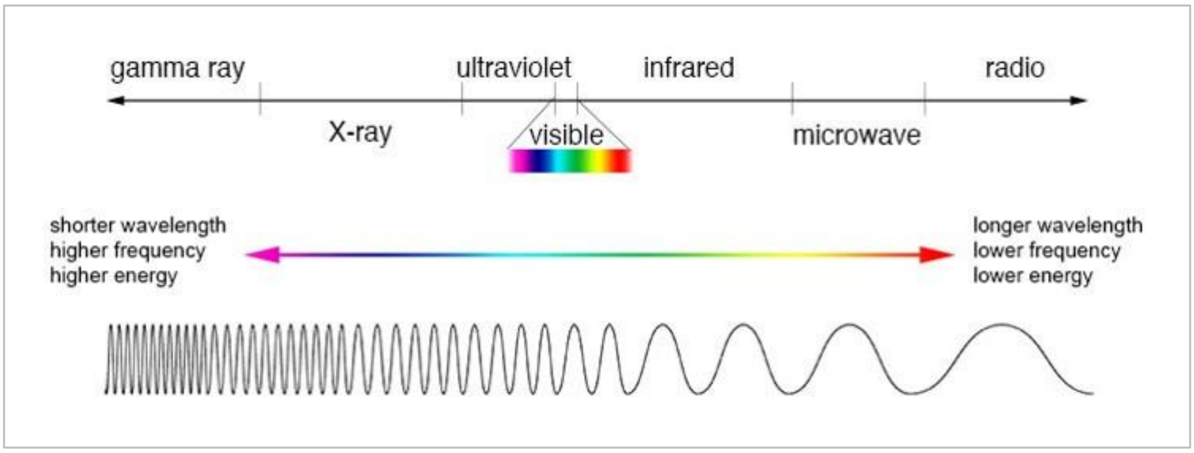


Figure 2: Electromagnetic spectrum showing waves and the radiations with respect to wavelength and frequency *Source -http://gsp.humboldt.edu, accessed on 8th April, 2021.*

1. Spectral resolution – It is the variation in the reflectance/emittance as a function of wavelength. Spectral responses are recorded by separate spectral bands such as Red, Blue, Green, Thermal, NIR, etc. A reflectance curve in Figure 3 demonstrates the spectral resolution. It is further subdivided into four classes:

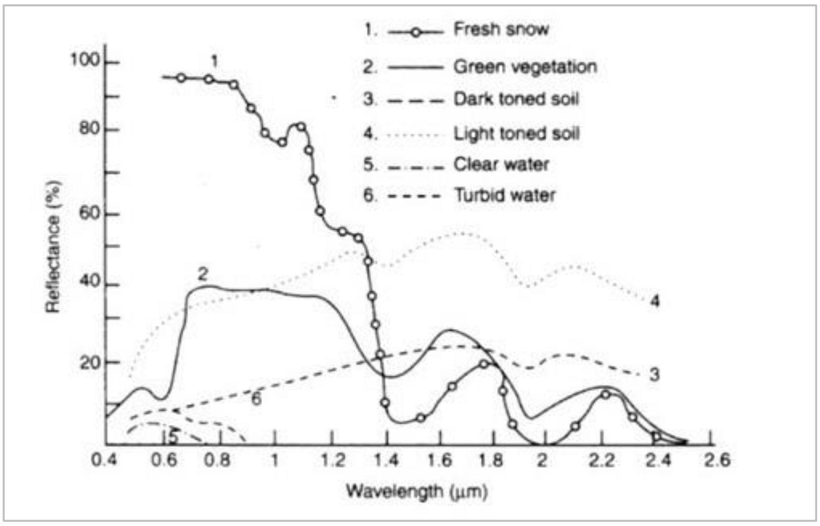


Figure 3: Spectral reflectance curve to determine spectral resolution *Source –Lillesand et al. (2015). Remote sensing and Image interpretation. 7e.*

a. Panchromatic - There is just one band (B/W) in this type of image.

b. Colour — It is made up of combinations of three visible spectrum hues (RGB)

c. Multispectral – consists of 3 to 10 bands and offers Medium level spectral resolution (Feng et al., 2020)

d. Hyperspectral – consists of 100s of band and offers higher spectral resolution (Feng et al., 2020)

Spectral indices are combinations of spectral reflectance from two or more wavelengths that show the relative abundance of a feature of interest. Vegetation indices are the most popular type, but other indices are available for burned area, built-up features, hydrologic and geologic features. The band combinations for formulating spectral indices varies from satellite to satellite. Some of the most common spectral indices are listed in Table 1.

Table 1: Different kinds of Spectral indices with respect to their formulations of band combinations:

No	Spectral indices	Formulation (Band combinations)
1.	NDVI (Normalised Difference Vegetation Index)	NIR – Red / NIR + Red (Where, NIR is Near-infrared band)
2.	NDWI (Normalised Difference Water Index) NDMI (Normalised Difference Moisture Index)	NIR - SWIR / NIR + SWIR
3.	AVI (Advanced Vegetation Index)	[NIR * (1-Red) * (NIR-Red)] $^{1/3}$
4.	NDSI (Normalised Difference Snow Index)	Green – SWIR / Green + SWIR
5.	SAVI (Soil Adjusted Vegetation Index)	((NIR – R) / (NIR + R + L)) * (1 + L) Where, L is soil brightness correction factor
6.	MSI (Moisture Stress Index)	MIR / NIR Where, MIR is Middle-wave Infrared
7.	NDGI (Normalised Difference Glacier Index)	NIR – Green / NIR + Green
8.	NDBI (Normalised Difference Built-up Index)	SWIR – NIR / SWIR + NIR
9.	BSI (Bare Soil Index)	((Red + SWIR) – (NIR + Blue)) / ((Red + SWIR) + (NIR + Blue))

Source -https://giscrack.com/list-of-spectral-indices

2. Spatial resolution–As discussed in the book Advance Remote Sensing, 2012, it is defined as the smallest item that the sensor can resolve, or the ground area photographed by the ground sensor's instantaneous field of view (IFOV), or the linear dimension on the ground indicated by each pixel, in the reflectance/emittance determined by the shape, size, and texture of the target. It is measured in metres, for example (250m, 80m, 10m, 1m resolutions, etc). Figure 4 is an example of spatial resolution.

10 m resolution

(a)

30 m resolution

(b)

Figure 4: Example of Spatial Resolution by imagery acquired from Sentinel (a) and Landsat (b) satellite sensors

3. Temporal resolution – Temporal resolution refers to the amount of time it takes to revisit and gather data for the same place. For example, Landsat's revisit time period is 16 days, whereas Sentinel's is 10 days. The processed temporal resolution is shown in Figure 5.

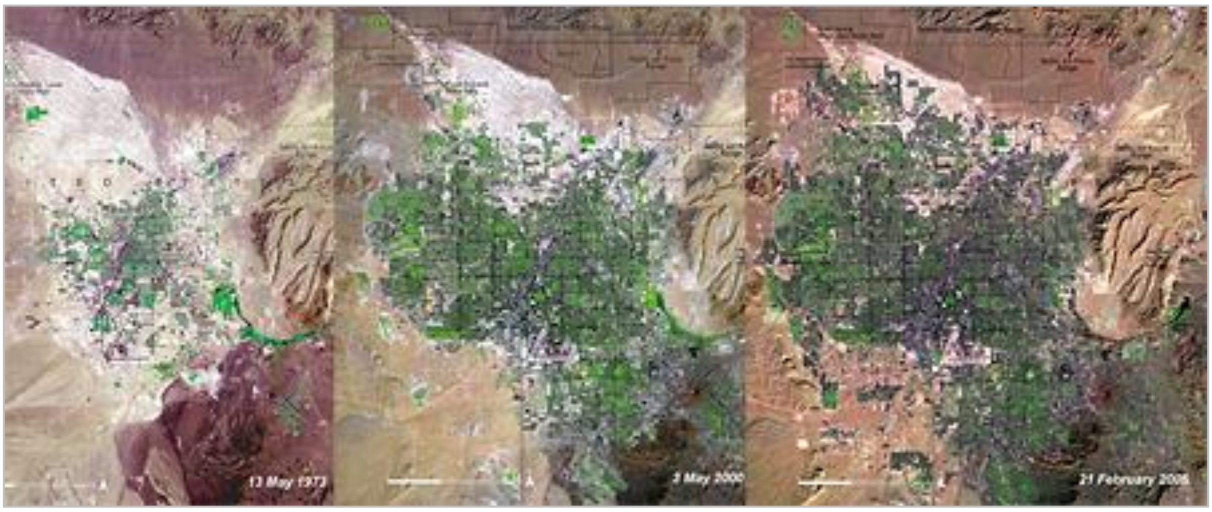


Figure 5: Example of Temporal resolution of Las Vegas over time in 1973, 2000 and 2006

Source- https://seos-project.eu/remotesensing

4. Radiometric resolution – The radiometric resolution of a picture captured by a sensor is determined by its sensitivity to the magnitude of electromagnetic radiation. The finer a sensor's radiometric resolution is, the more sensitive it is to minute variations in reflected or emitted energy it may detect.

Components and process of remote sensing:

The process of remote sensing is depicted in Figure 6. Despite the fact that the techniques for collecting, processing, and interpreting remotely sensed data vary, imaging systems must have the following components:

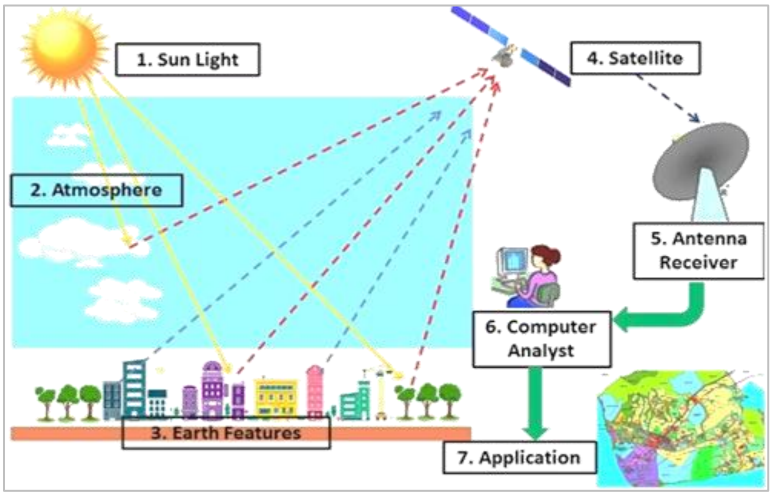


Figure 6: A generalized process components of remote sensing technology

Source - https://www.gisoutlook.com/2019, accessed on 8th April, 2021.

1. Energy source or illumination:

This is the most basic prerequisite for the remote sensing procedure, to have a source of energy that illuminates electromagnetic energy to the target of interest, for example, Active and passive sensors. Mostly the sensors are passive which tends to measure the solar radiation reflected from the target.

2. Interaction with the atmosphere:

Electromagnetic radiation must travel a certain distance through the Earth's atmosphere before reaching the surface. Particles and gases in the environment can alter incoming light and radiation, and these affects are caused via scattering and absorption processes (Figure 7).

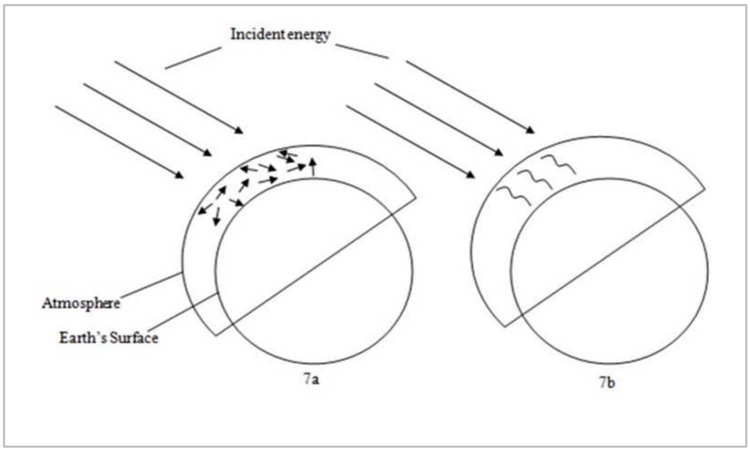


Figure 7: Interaction of EMR with atmosphere (a) Scattering and (b) Absorption

Electromagnetic radiation is diverted from its intended path when particles or large gas molecules interact in the environment. The wavelength of the radiation, the number of particles or gases, and the distance the radiation travels through the atmosphere are all considerations. There are three 3 types of scattering which take place, are described in Table 2, All the different types of scattering with examples are briefly shown in figure 8.

Table 2: Different types of scattering occurs when EMR interacts with the atmosphere:

No.	Types of Scattering	Particle size (µm)	Examples
1.	Rayleigh	< 0.1 µm	Small specks of Dust, N_2, O_2 molecules.
2.	Mie	~ 1 to 10 µm	Pollen, Smoke, Water vapour
3.	Non – Selective	> 10 µm	Water droplets and large dust particles

Source: https://www.nrcan.gc.ca/maps-tools-publications

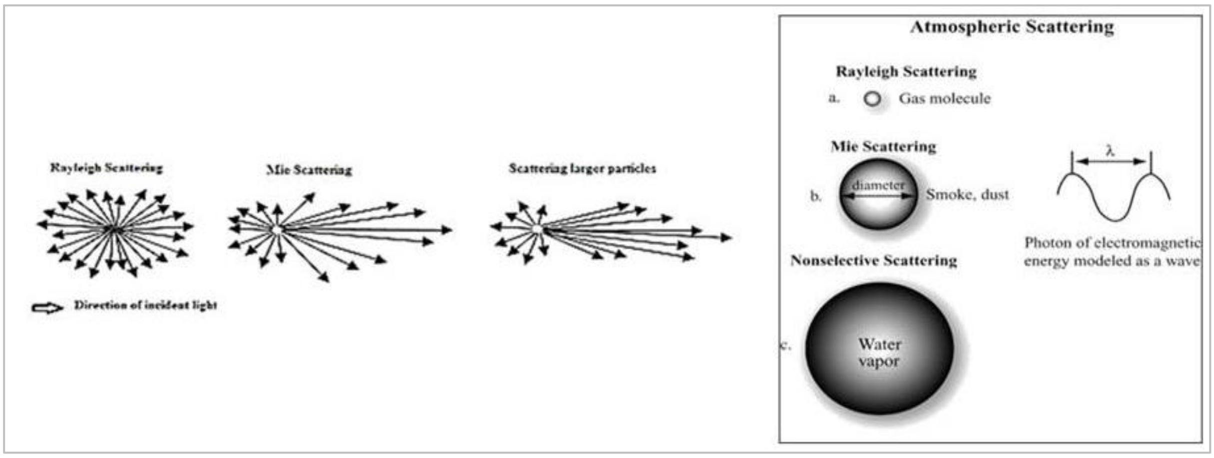


Figure 8: Different types of scattering when EMR interacts in the atmosphere or with the Earth's surface *Source - http://www.geo.oregonstate.edu/ , accessed on 8th April, 2021.*

When EMR interacts with the atmosphere, one of the key mechanisms is absorption.It causes molecules in the atmosphere to absorb a certain quantity of energy at various wavelengths, as opposed to scattering. The three primary atmospheric elements that absorb radiation are oxygen, carbon dioxide, and water vapour. Atmospheric windows are portions of the EMR spectrum that are not heavily impacted by atmospheric absorption and hence ideal for distant sensors (Figure 9). The visible portion of the spectrum, to which our eyes are most sensitive, corresponds to both, the atmospheric window and the peak energy level of the sun.

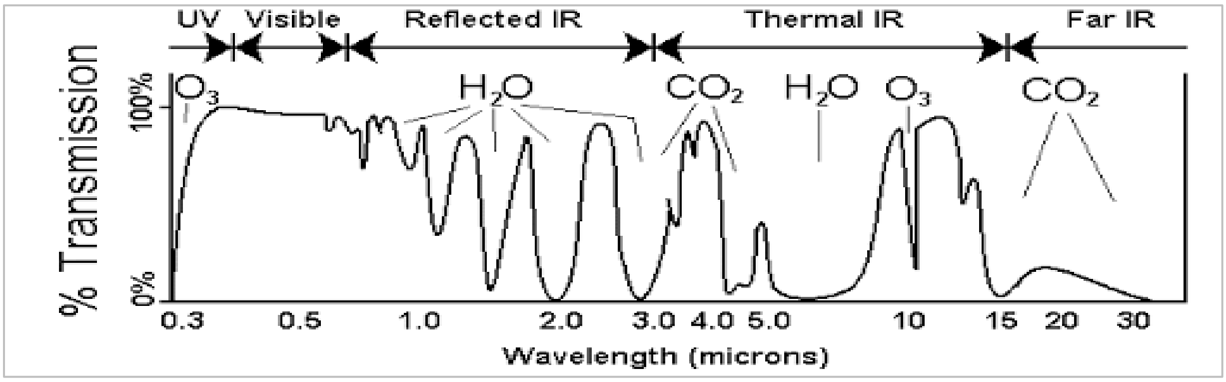


Figure 9: Atmospheric window showing the transmission of molecules at different wavelength with respect to different radiations *Source - http://www.sarracenia.com/astronomy, accessed on 8th April, 2021.*

3. Interaction with the target:

After passing through the atmosphere, the energy interacts with the target, depending on the qualities of both the target and the radiation. Figure 10 depicts some of these interactions. As the energy travels back from the target to the sensor, this might happen a second time. When electromagnetic energy collides with matter, whether solid, liquid, or gas, the following interactions are possible:

- Radiation can pass through or be transferred through the substance.
- It may be absorbed and give up its energy largely to heating the substance.
- It may be emitted as a function of its emissivityand temperature.
- It can be reflected in two different ways: specular and diffuse (Scattered).

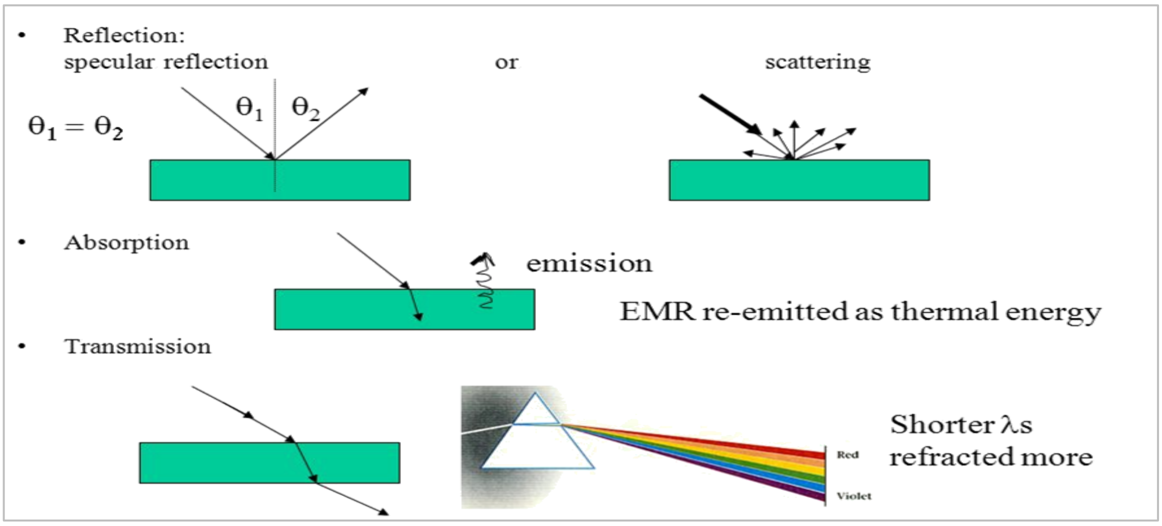


Figure 10: EMR interaction with the Earth's Surface

Source: https://www.slideserve.com/portia © Rick Lathrop, accessed on 25th April, 2021.

4. Recording of Energy by the sensor:

After the energy has been scattered by, or emitted from the earth's surface, there is a need for a sensor which is mounted on a satellite, to collect and record the EMR. The sensors are well-known for the EMR area they detect. Optical and microwave remote sensing, as well as active and passive remote sensing, are elaborated by Navalgund et al., (2007); Feng et al., (2020); Ray, (2013).The sensors that will be used to collect data must be put on a platform. This might be on the ground (e.g., portable radiometers), in the air (e.g., NASA's AVIRIS sensor on board aeroplanes), or in space (i.e., satellite based).

5. Transmission, Reception, and Processing:

The sensor's energy must be sent, usually in electronic form, to a receiving and processing station on the ground, where the data is processed and stored in digital form.

6. Interpretation and analysis:

Furthermore, this processed data is visually and digitally evaluated to derive information about the lit target. There are numerous specialised instruments or hardware and software used that are commonly known as image processing tools which involves four basic steps viz. image correction/restoration, image enhancement, image transformation and image classification.

7. Application:

When we use the extracted and processed information to solve a specific issue, this is meant as a completion of the final step of remote sensing process. This task may be performed and completed by specialists who work in each application subject.

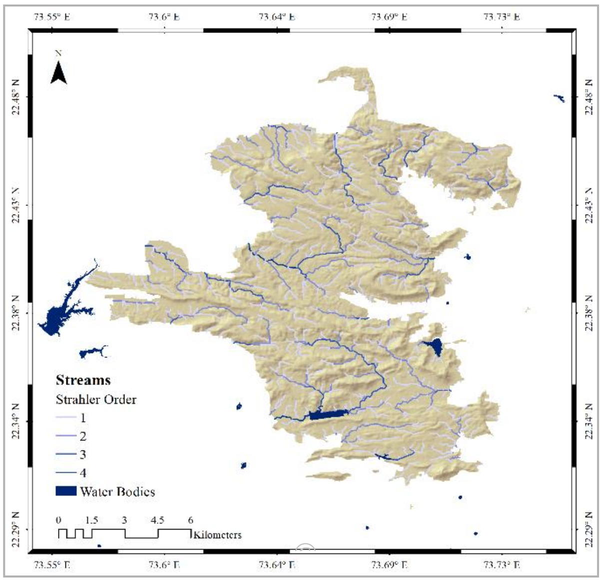
Applications of remote sensing:

Every application itself has some specific demands for spectral, spatial, radiometric and temporal resolution of the satellite sensor (Shandilya et al., 2013). Remote sensing has shown to be quite useful in understanding and resolving issues in practically all sectors in the contemporary period. In this article, we'll look at a handful of its most common applications in the modern day.

1. Geology:

In the field of geosciences, the remote sensing techniques are applied to interpret and analyse the bedrock, lithological, structural formations, sedimentation, (Merritt et al., 2014; Stead et al., 2019) planetary, surface monitoring, (Clark et al., 2003; Des Marais et al., 2002; Shepard et al., 2001) geo-hazards and mineral exploration through observation and modelling techniques.

2. Hydrology:



Some examples of applications of remote sensing in hydrological science include, soil moisture estimation, flood and wetland monitoring, watershed and drainage modelling, river delta change detection, and many. Figure 11 and 12 are an example of one of the studies undertaken for hydrological modelling and mapping of wetlands, respectively (Dharaiya, 2020a; Dharaiya et al., 2021).

Figure 11: Drainage modelling in Jambughoda Wildlife sanctuary, Gujarat (after Dharaiya, 2020a)

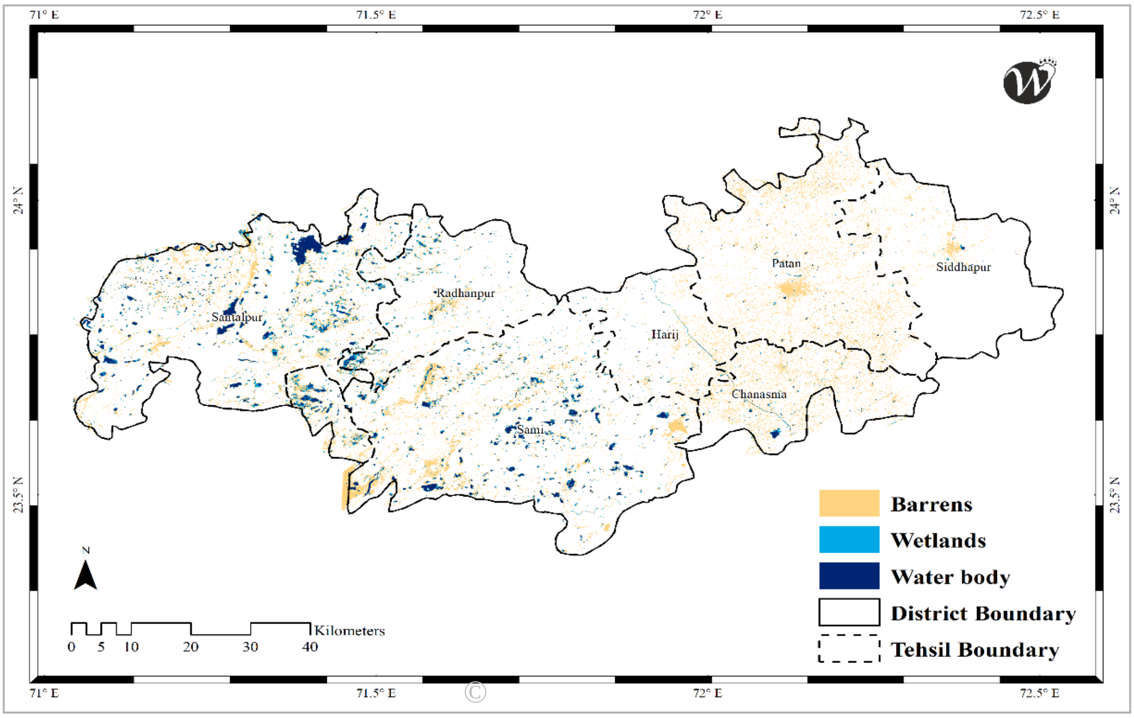


***Figure 12: Mapping of wetlands in Patan district, Gujarat (Dharaiya et* al., 2021)**

3. Glaciology:

By means of remote sensing, one can acquire information and map the ice concentration, ice type or motion (Frey et al., 2014; Jiyang Chen & Ohmura, 1990), iceberg detection, glacier dynamics (Pratibha & Kulkarni, 2018; Remya et al., 2019), snow thickness monitoring (Gantayat et al., 2014; Kulkarni et al., 2002), meteorological change research, snow-water equivalence, snowmelt run-off estimation and many more.

4. Agriculture:

Remote sensing is commonly utilised as a decision-making tool in agriculture, such as for crop type classification, crop condition evaluation, crop yield estimation, soil characteristics, soil management methods, and compliance monitoring (Zheng et al., 2014).

5. Forestry:

Forestry is one of the major sectors where remote sensing has proved as very effective tool. Some of the purposes that can be reached include reconnaissance mapping, commercial forestry, and environmental monitoring, all of which contribute in the management and conservation of natural resources. Figure 13 is an example of mapping the forest coverat Ratanmahal wildlife sanctuary, Gujarat, using spectral indices.

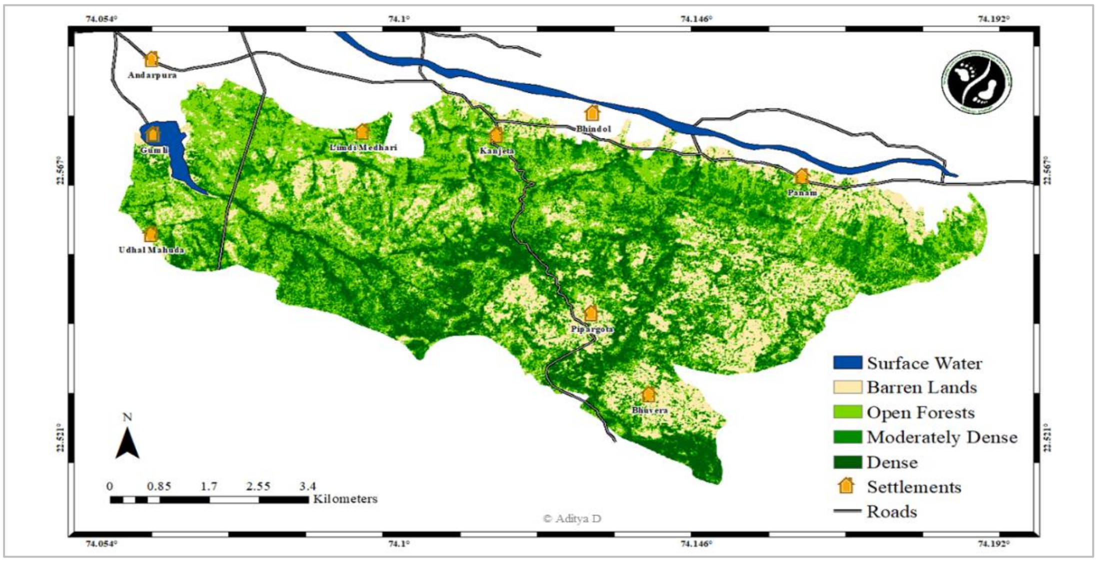


Figure 13: Forest cover map of Ratanmahal wildlife sanctuary, Gujarat *© A. Dharaiya*

6. Land use Land cover (LULC):

Yacouba et al. (2010) examined the LULC using two terms: "land use," which refers to the purpose for which the land is used, and "land cover," which refers to the natural surface cover on the ground. It's commonly utilised in habitat and natural resource management, urban development, baseline mapping, risk assessment, legal borders for tax appraisal, and change detection, among other applications. Figures 14 and 15 show the LULC categorization and wetlands change detection, respectively (Dharaiya, 2020b; Dharaiya et al., 2021).

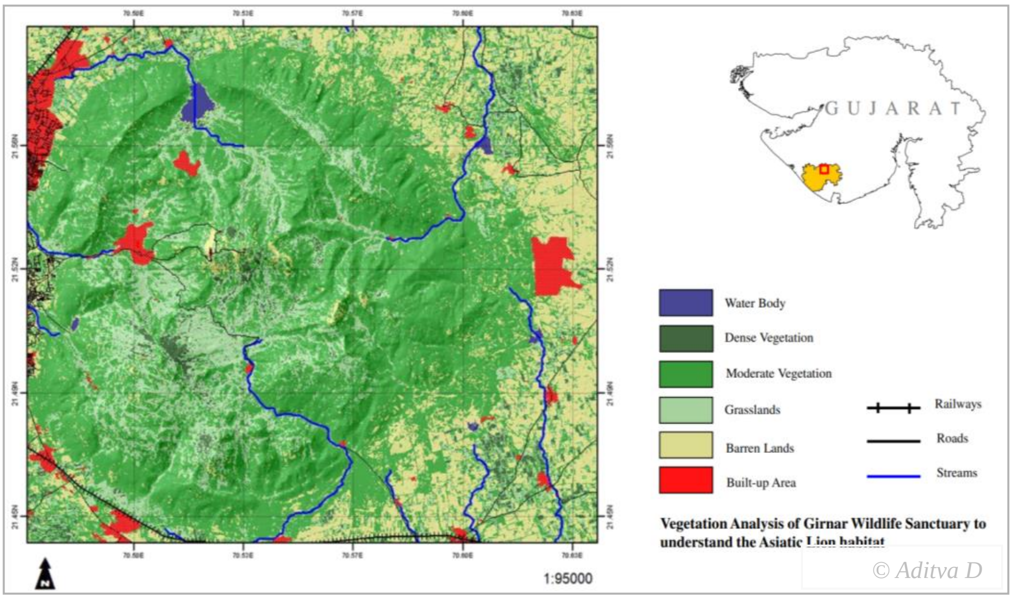


Figure 14: LULC classification with vegetation cover in Girnar Wildlife sanctuary, Gujarat (Dharaiya, 2020b)

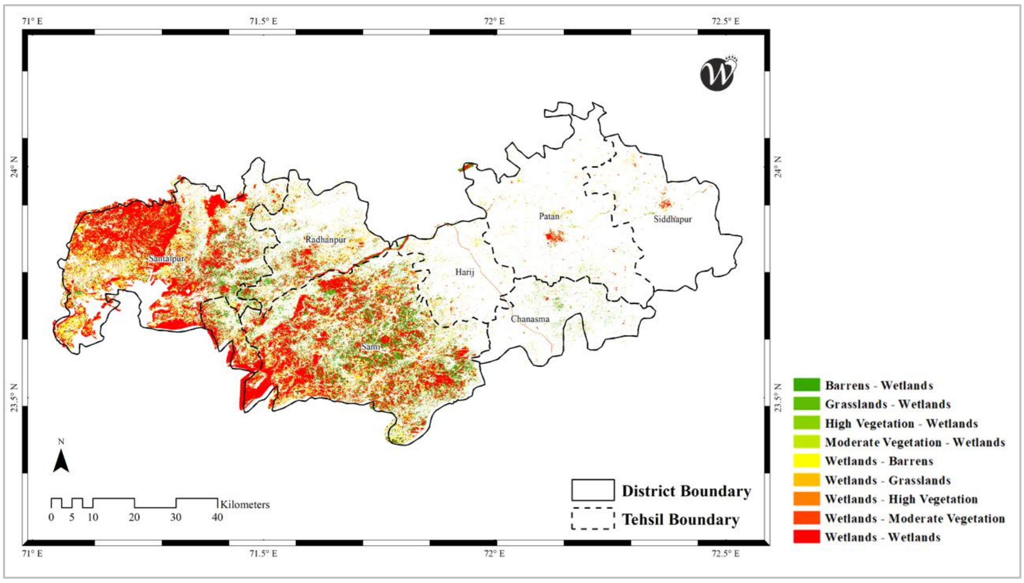


Figure 15: Change detection of wetlands in Patan district, Gujarat using Landsat 8 OLI (Dharaiya et al., 2021)

7. Coastal monitoring:

Remote sensing can be used to gather information about oceanic processes (physical and biological), oil spill (Alesheikh et al., 1997; Fingas & Brown, 1997), and shipping by means of remote sensing.

Several other applications according to Shandilya et al., (2013) include planimetry or land surveying using very high spatial resolution satellites (30cm). Using radar interferometry, radargrammetry, and photogrammetry, elevation profiles are generated by creating Digital Elevation Models (DEMs) using remote sensing data. Base map imagery gives a priori information about the regions that may be used to derive planimetric details about mineral exploration activities, topographic mapping, and surface monitoring.

Conclusion:

Remote sensing is a new method that may be used to monitor the Earth's surface. Its applications have grown in scope, allowing users to gather, evaluate, and edit data over large areas. Multi-temporal satellite data helps in the delineation of changes to the earth's surface, making it a valuable and practical tool for all users, since it improves the precision, efficiency, and quality of the analysis, making it beneficial in the decision-making process. Furthermore, the products may be utilised by other scientists, even if they are unfamiliar with the technique, to extract the highest amount of detail possible.

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