Remote sensing: An overview with fundamentals and applications

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Introduction:

The general concept of remote sensing can be inferred by a simple statement, i.e., the acquisition of information from a specific distance. Scientifically, it is the science of acquiring information about an object or phenomenon by measuring emitted and reflected radiation (Ray, 2013). According to Lillesand et al. (2015), remote sensing is defined as the science and techniques of obtaining information about an object, land area, phenomenon, or ecosystem process acquired by a device that is not in direct contact with the object, area, or phenomenon under investigation. The data collection is done remotely using various sensors, which may be further analyzed to obtain information about the objects, areas or phenomenon. These acquired data can be of many forms, such as variations in force distributions, acoustic wave and electromagnetic energy distributions. Joseph, (2005) has discussed modern remote sensing as an extension of the natural phenomenon of visual perception of objects. 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. Whereas, in active remote sensing, the electromagnetic radiations of a specific wavelength or band of wavelengths are generated to illuminate the targets and reflected or back-scattered EMR are recorded to gain information, for example LiDAR, RADAR, SAR, etc. Based on its applicability, remote sensing is defined as sensing of the earth's surface from the space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and environmental protection. The classification of remote sensing is further based on the selection of EMR (e.g. optical and microwave, Navalgund et al. (2007)). When the sensors detect the solar radiation in the visible, and infrared wavelength regions, reflected/scattered or emitted from the earth is said as optical remote sensing and in microwave remote sensing uses interference and polarization concepts with electromagnetic energy that detects the scattered energy returning from the terrain and records it as an image. The main purpose of remote sensing is to have an organized systematic and large amount of data collection in order to acquire information about 2 or 3 dimensions of real objects. One can get large and broad, global coverage and repeatability of data to obtain a multipurpose information through various earth observation satellite sensors which helps in detecting things that are normally absent in visible spectra such as, Land-surface temperature, Underground or sub-surface water, etc., There are several Earth Observation (EO) Satellites namely, Cartosat series, Landsat series, Sentinel 1, 2, MODIS, RISAT 1 and RADARSAT 2, Resourcesat, Envisat, IRS 1A, Oceansat 2, and many more.

Electromagnetic Spectrum:

Electromagnetic radiation or EMR is the term used to describe all of the different types of energies released by electromagnetic processes. Visible light is just one of many forms of electromagnetic energy. Radio waves, infrared light and X rays are all forms of electromagnetic radiation. The electromagnetic waves are formed by the vibrations of electric and magnetic fields, these vary in magnitude in a direction perpendicular to the direction of propagation of radiations at a constant speed of light (c= $3*10^8$ m/s).Figure 1 shows a generalized concept of EMR. These differ from mechanical waves as they need not require a medium to propagate, hence it is able to travel through air and solid materials, and can also travel through 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.

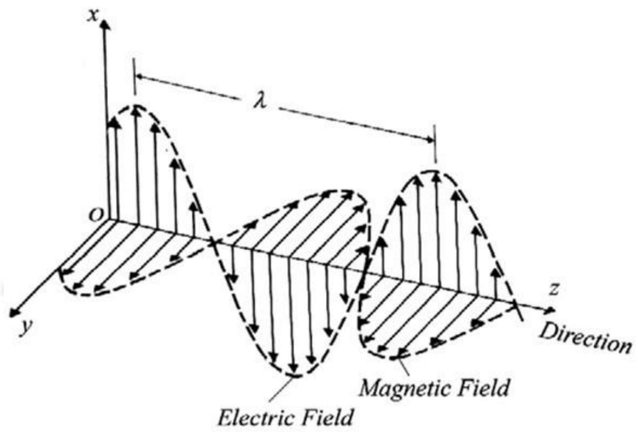

Figure 1. Illustration on the concept of EMR in which propagation of electric and magnetic field is shown

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 includes the electromagnetic energy ranging from Gamma rays to radio waves, where the wavelength becomes longer, so the energy and frequency gradually decreases. There are four kinds of resolution that are described from the EMR spectrum are as follows:

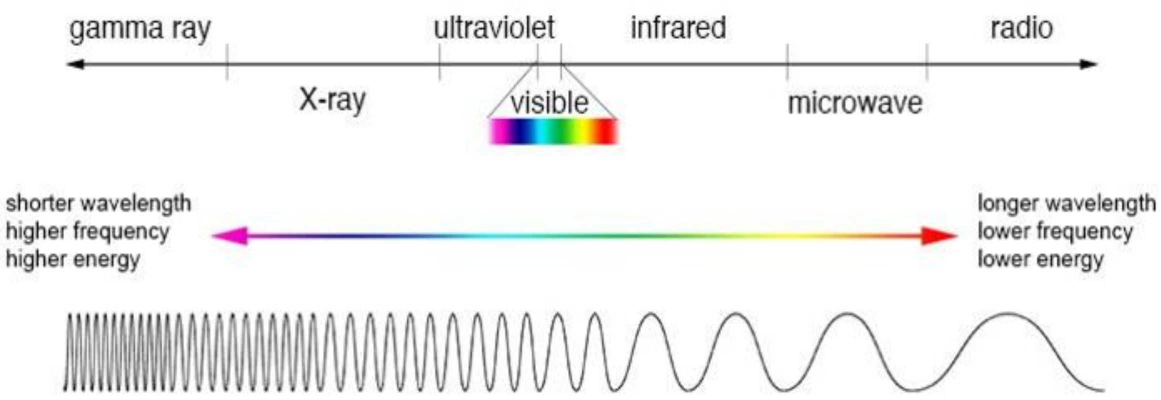

Figure 2: Electromagnetic spectrum showing waves and the radiations with respect to wavelength and frequency

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. Figure 3 depicts the spectral resolution through a reflectance curve. It is further divided into 4 class sub classes:

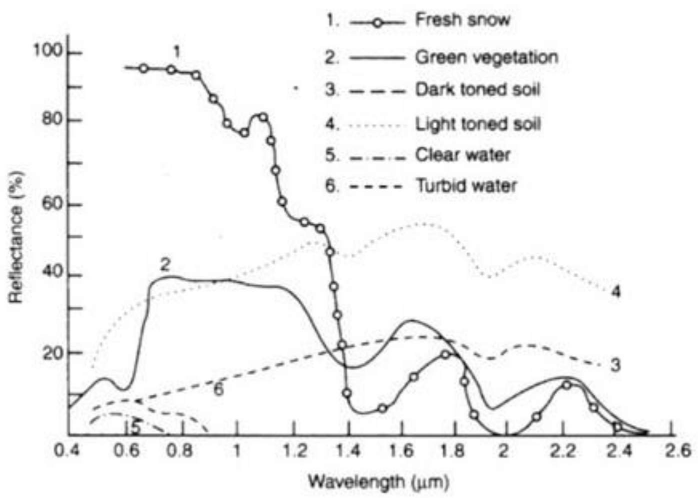

Figure 3: Spectral reflectance curve to determine spectral resolution

Source –Lillesand et al. (2015). Remote sensing and Image interpretation. 7e.

a. Panchromatic – It consists of only 1 band (B/W)

b. Colour – It consists the combinations of 3 colors of visible spectrum (RGB)

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

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

The combinations of spectral reflectance from two or more wavelength that indicate the relative abundance of feature of interest are known as spectral indices. 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 vary from satellite to satellite. Some of the most common spectral indices are listed in Table1.

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

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

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))

2. Spatial resolution–It is described as the measure of the smallest object that can be resolved by the sensor or the ground area imaged for the instantaneous field of view (IFOV) of the ground sensor, or the linear dimension on the ground represented by each pixel. in the reflectance/emittance determined by the shape, size and texture of the target, as discussed in the book entitled, Advance Remote Sensing, 2012. It is expressed in meters, like (250 m, 80 m, 10 m, 1 m 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 – the amount of time needed to revisit and acquire data for the exact same location, is called temporal resolution, for example, the revisit time period of Landsat is 16 days, and that of Sentinel is 10 days. Figure 5 shows the processed temporal resolution.

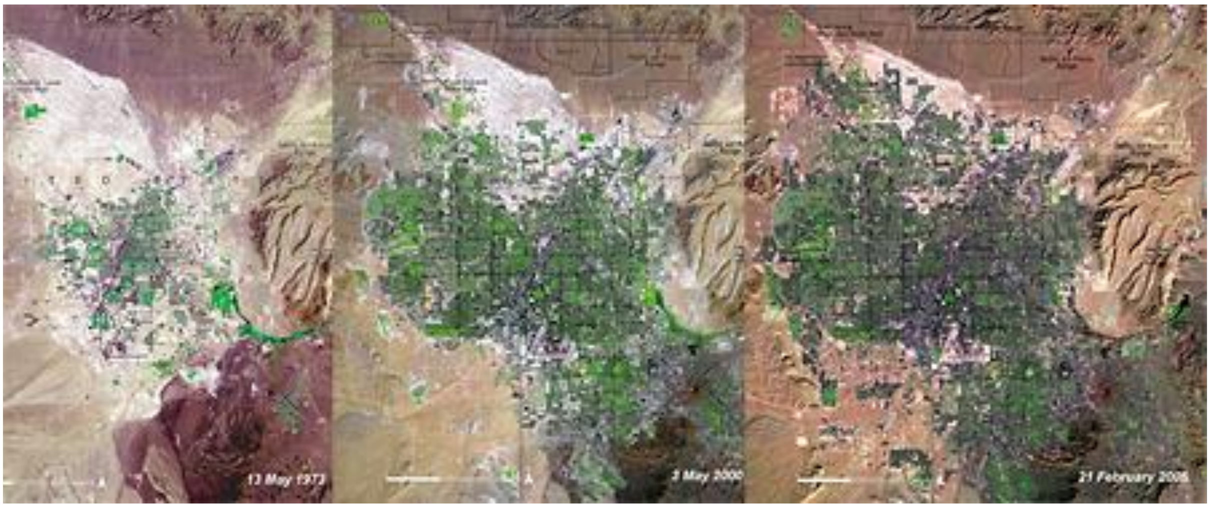

Figure 5: Example of Temporal resolution of Las Vegas over time in 1973, 2000 and 2006

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

4. Radiometric resolution – When an image is acquired by a sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

Components and process of remote sensing:

Figure 6 briefly describes the process of remote sensing. Though the methods for collection, processing, and interpretation of remotely sensed data are diverse, imaging systems have the following essential components:

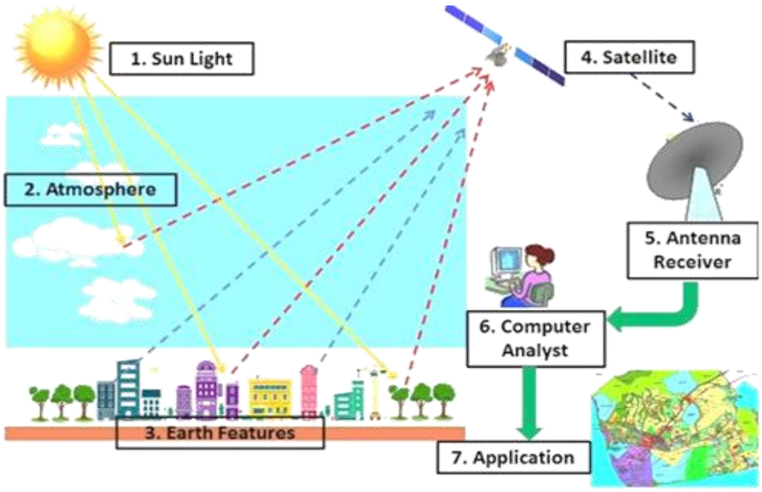

Figure 6: A generalized process components of remote sensing technology

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

1. Energy source or illumination:

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

2. Interaction with the atmosphere:

Before the electromagnetic radiation reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation and such type of effects are caused by the mechanisms of scattering and absorption (Figure 7).Scattering occurs when particles or large gas molecules present in the atmosphere interacts and cause the electromagnetic radiation to be redirected from its original path. It depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the are described in Table 2, All the different types of scattering with examples are briefly shown in figure 8.

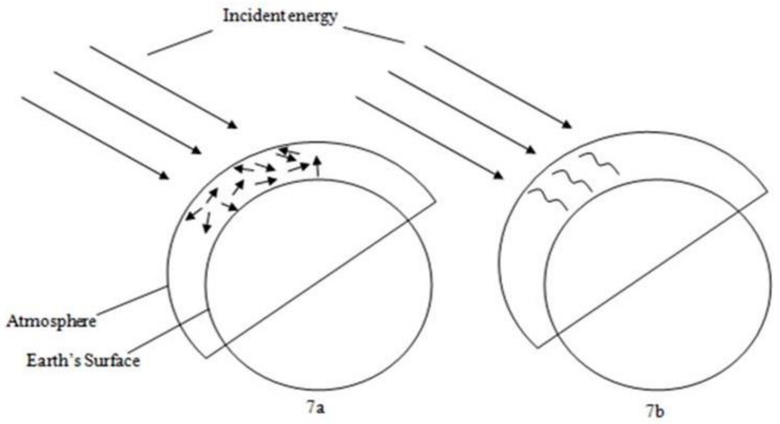

Figure 7: Interaction of EMR with atmosphere (a) Scattering and (b) Absorption

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

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

No.	Types of Scattering	Particle size (Micro meters 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

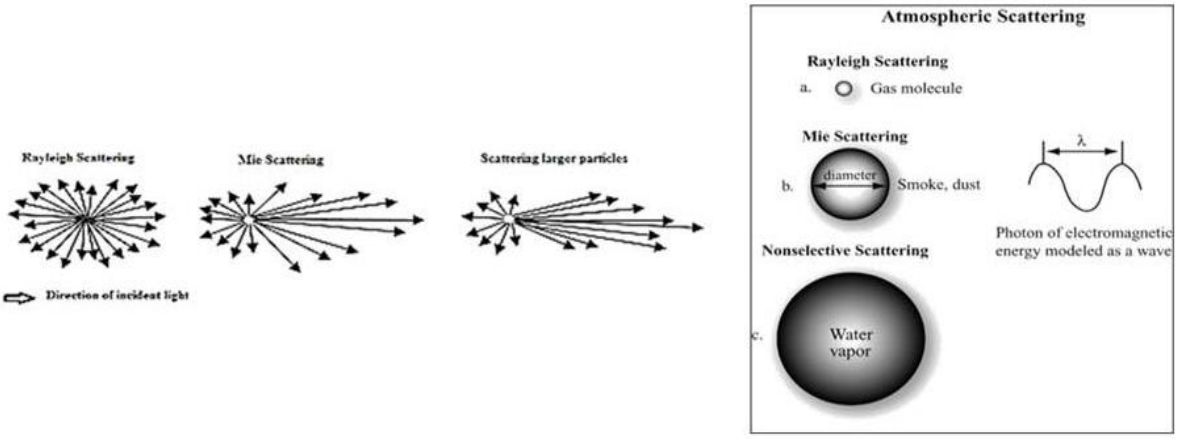

Figure 8: Different types of scattering when EMR interacts in the atmosphere or with the Earth's surface

Source - http://www.geo.oregonstate.edu/ , accessed on 8th April, 2021.

Contrast to scattering, it causes molecules in the atmosphere to absorb specific amount of energy at various wavelengths. O_3, CO_2, and water vapour are 3 main atmospheric constituents which absorbs radiation. Those areas of the EMR spectrum which are not severely influenced by atmospheric absorption and thus are useful for remote sensors, are called Atmospheric windows (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.

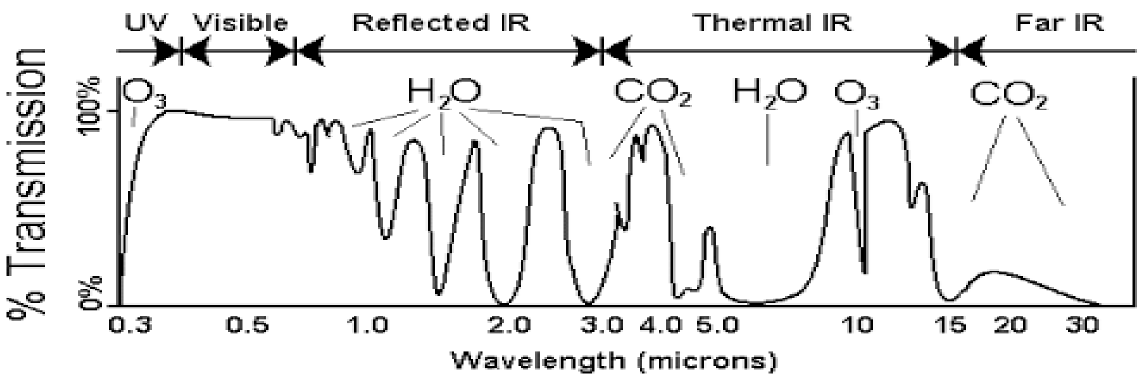

Figure 9: Atmospheric window showing the transmission of molecules at different wavelength with respect to different radiations

Source - http://www.sarracenia.com/astronomy, accessed on 8th April, 2021.

3. Interaction with the target:

After the interaction with atmosphere, once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation. Figure 10 shows such examples of interaction. This can take place a second time as the energy travels back from the target to sensor. Several interactions are possible when electromagnetic energy encounters matter, whether solid, liquid or gases are as follows:

- Radiation may be transmitted or passed 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 emissivity and temperature.
- It may be reflected in 2 ways, specular and diffused (Scattered).

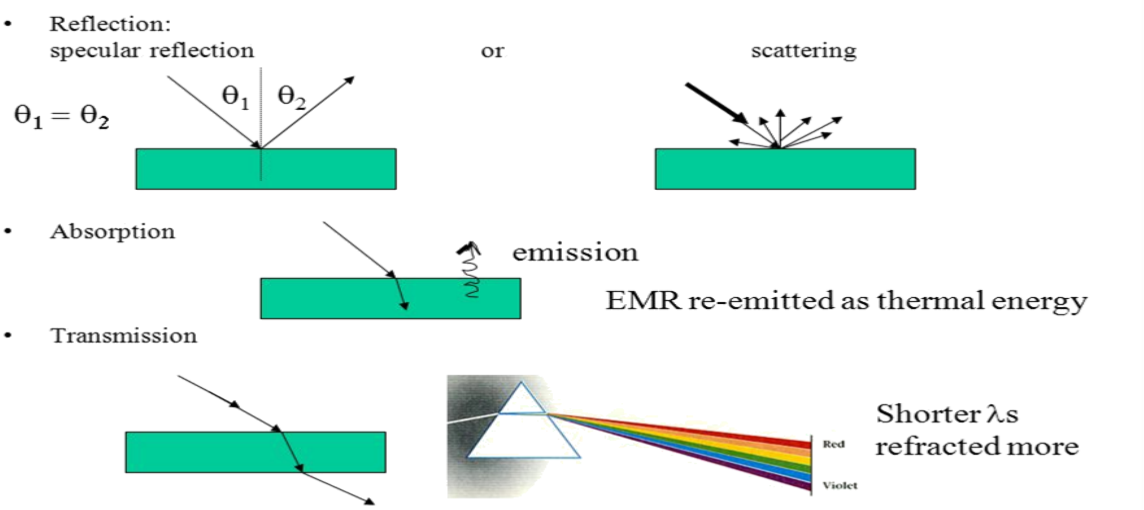

Figure 10: EMR interaction with the Earth's Surface

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 popularly known by EMR region they sense. Remote sensing has a broad classification of optical and microwave as well as active and passive remote sensing as discussed by Navalgund et al.,(2007); Feng et al., (2020); Ray, (2013). The sensors, for taking observations, needs to be mounted on a platform. This could be ground based (e.g., handheld radiometers), airborne (e.g., Drone, AVIRIS sensor of NASA on board aircraft) or space-borne (i.e., satellite based).

5. Transmission, Reception, and Processing:

The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station at the earth where the data are processed and stored in digital form.

6. Interpretation and analysis:

Furthermore, this processed data is interpreted, visually and digitally to extract information about the target which was illuminated. 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:

The final element or component of remote sensing process is achieved when we apply the extracted and processed information in solving a particular issue or problem. Specialists who work in each application theme are able to perform and carry out this task.

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). In modern era, the remote sensing proved very effective to understand and resolve the challenges in almost all the fields, few of its major applications are illustrated in this article.

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:

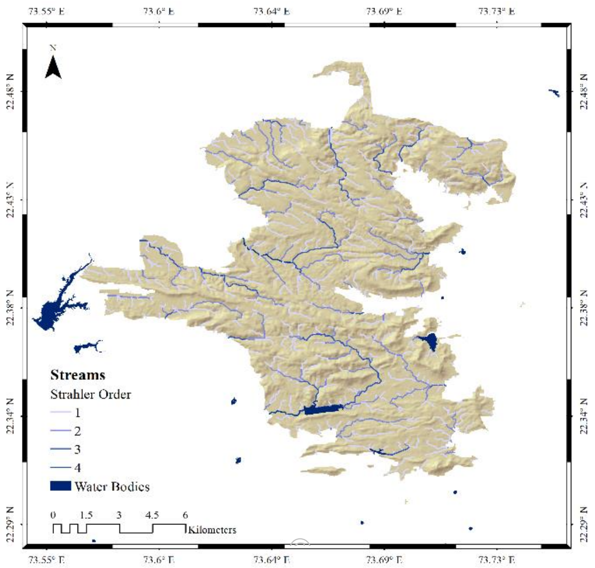

Figure 11: Drainage modelling in Jambughoda Wildlife sanctuary, Gujarat (after Dharaiya, 2020a)

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 more. Figure 11 and 12are an example of one of the studies undertaken for hydrological modelling and mapping of wetlands, respectively (Dharaiya, 2020a; Dharaiya et al., 2021).

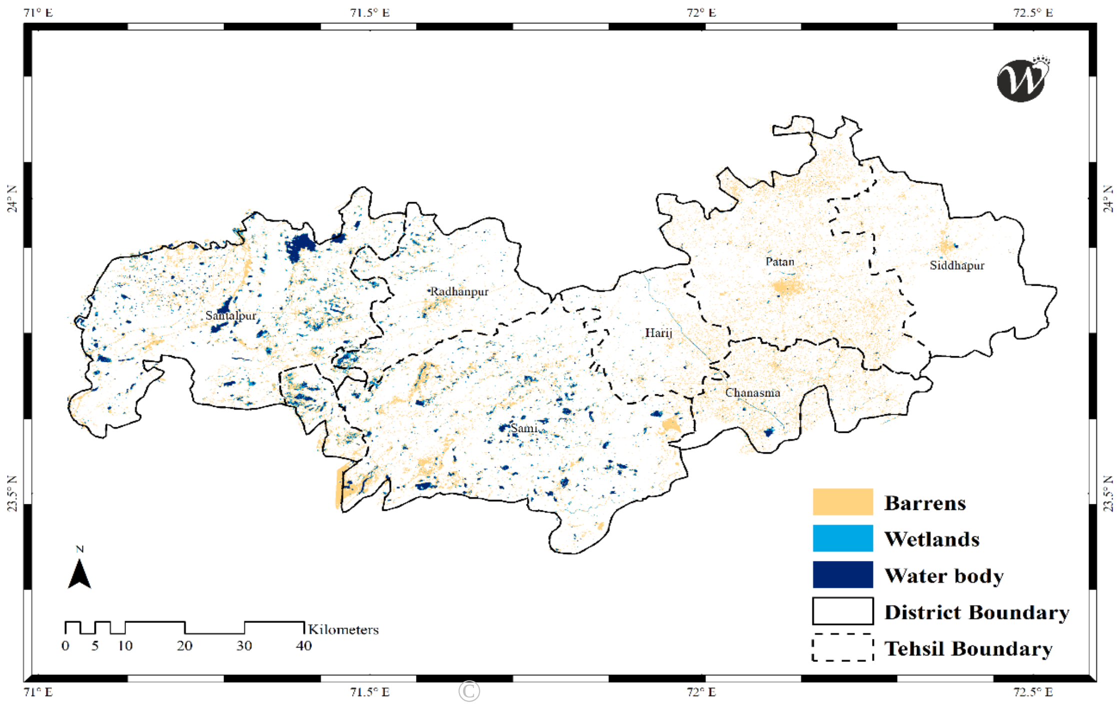

***Figure 12: Mapping of wetlands in Patan district, Gujarat (Dharaiya et* al., 2021)**

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), monitor snow thickness (Gantayat et al., 2014; Kulkarni et al., 2002), meteorological change research, snow-water equivalence, snowmelt run-off estimation and many more.

4. Agriculture:

In the science of agriculture, the remote sensing is mostly used as a decision-making tool viz. for crop type classification, crop condition assessment, crop yield estimation, soil characters, soil management practices 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. It has been used for reconnaissance mapping, commercial forestry and environmental monitoring are some objectives which can be fulfilled and that further helps in managing and conserving the natural resources. Figure 13 is an example of mapping the forest coverat Ratanmahal wildlife sanctuary, Gujarat, using spectral indices.

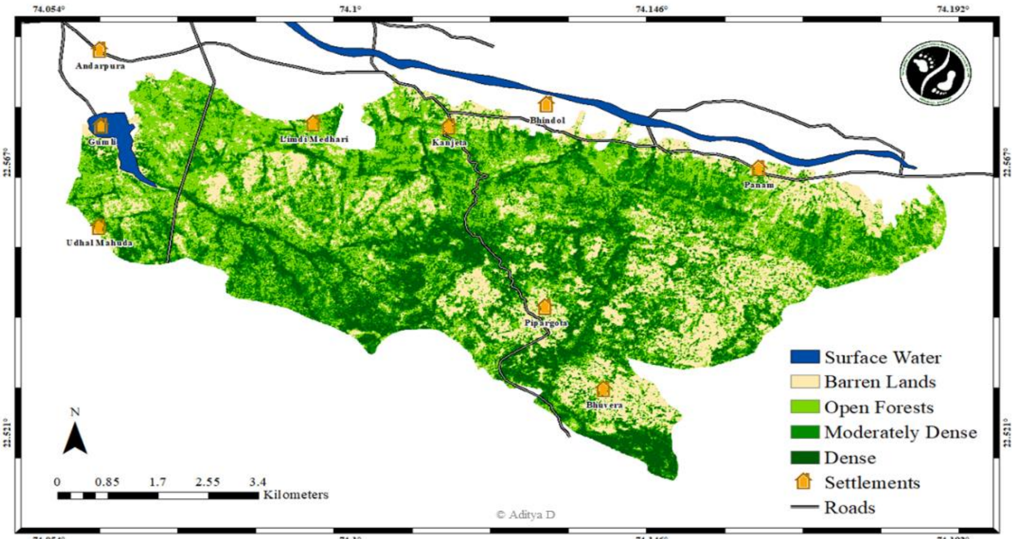

Figure 13: Forest cover map of Ratanmahal wildlife sanctuary, Gujarat © Aditya Dharaiya

6. Land use Land cover (LULC):

Yacouba et al., (2010) has discussed the LULC with reference to two terms 'land use' which refers to the purpose the land serves and 'land cover' refers to natural surface cover on the ground. For example, it is widely used in habitat and natural resource management, urban expansion, baseline mapping, risk assessment, legal boundaries for tax evaluation, change detection, etc. Figure 14 and 15depicts the LULC classification and change detection of wetlands, respectively (Dharaiya, 2020b; Dharaiya et al., 2021).

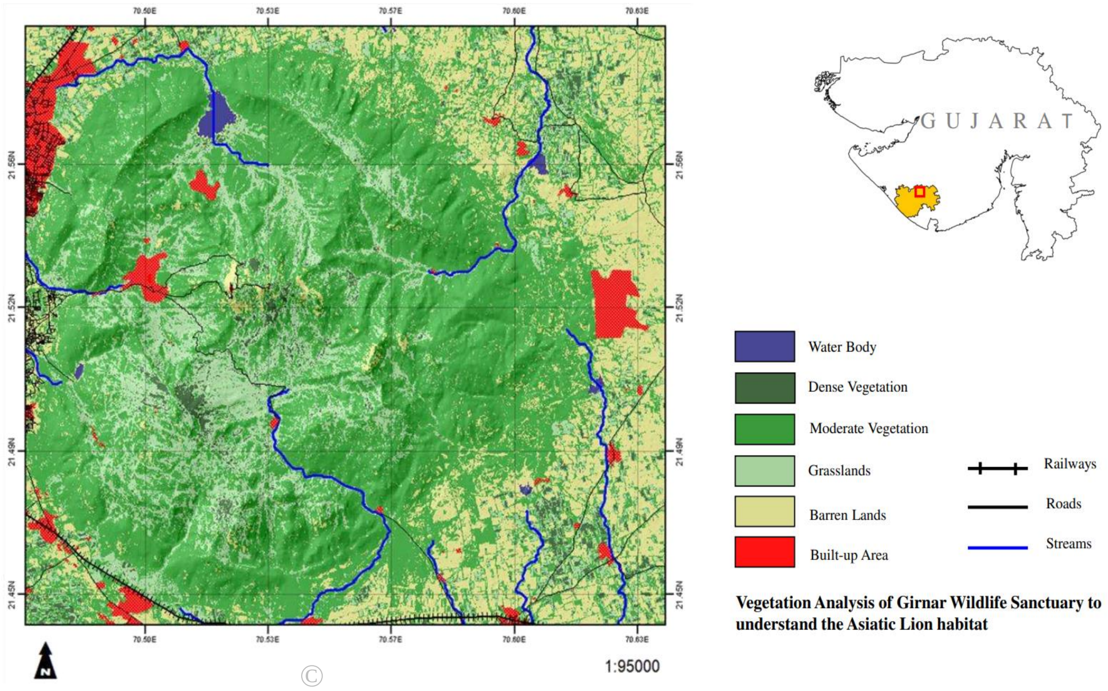

Figure 14: LULC classification with vegetation cover in Girnar Wildlife sanctuary, Gujarat (After Dharaiya, 2020b)

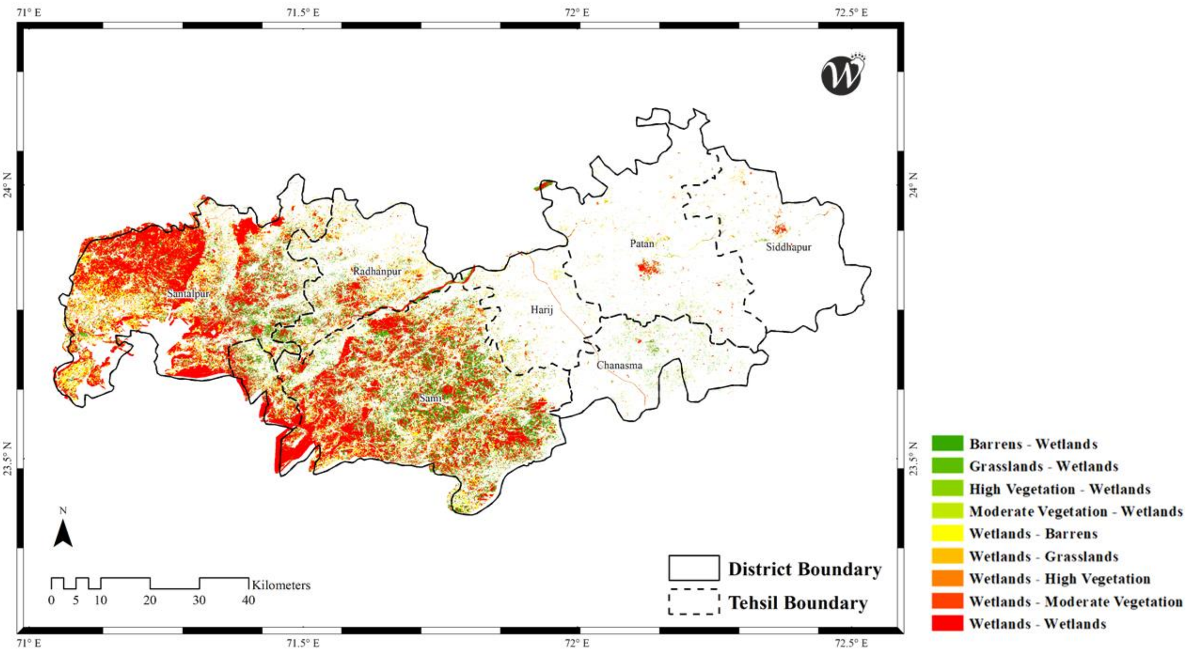

Figure 15: Change detection of wetlands in Patan district, Gujarat using Landsat 8 OLI (Dharaiya et al., 2021)

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 (30 cm). Generating Digital Elevation Models (DEMs) from remote sensing products are used to generate elevation profiles by means of radar interferometry, radargrammetry and photogrammetry. To extract the planimetric details about mineral exploration activities, topographic mapping and surface monitoring, base map imagery provides a priori information about the areas.

Conclusion:

This emerging technique of remote sensing is a significant tool to monitor the Earth's surface. It has progressively expanded applications which allow users to collect, interpret, and manipulate data over vast areas. Multi-temporal satellite data help to delineate changes of the earth's surface, thus it can be also said to be a useful and handy tool for all the users, as it increases the accuracy, efficiency and quality of the analysis in such a way that it can be helpful in decision-making process. Furthermore, the products can be conveniently used by other scientists too, who are even not much familiar with this technology and for the greatest level of detail to be extracted.

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