SPECTRAL REFLECTANCE CURVES

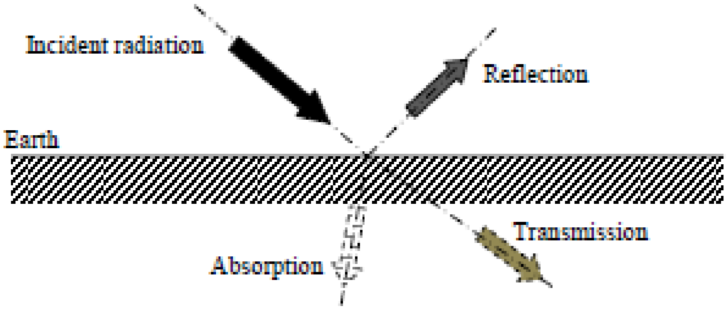
Energy Interactions (continued…)

As we have studied, energy incident on the Earth's surface is absorbed, transmitted or reflected depending on the wavelength, and characteristics of the surface features (soil, vegetation or water body).

These three processes are not mutually exclusive. Energy incident on a surface may be partially reflected, absorbed or transmitted. Which process takes place on a surface depends on the following factors:

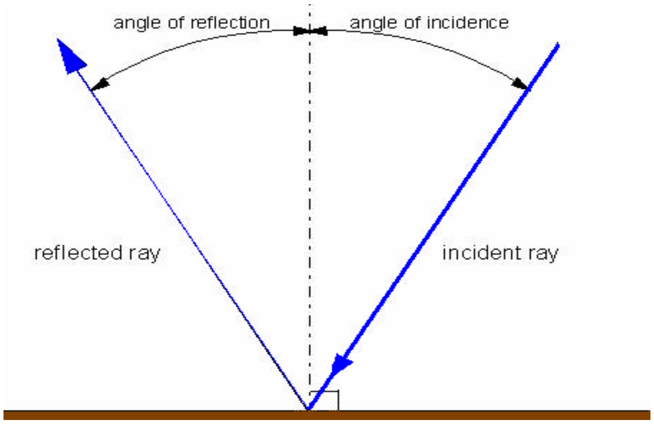
- Wavelength of the radiation
- the characteristics of the incident radiation
- Angle at which the radiation intersects the surface
- Composition and physical properties of the surface

After interaction with the surface features, energy that is reflected or re-emitted from the features is recorded at the sensors and are analysed to identify the target features, interpret their characteristics.

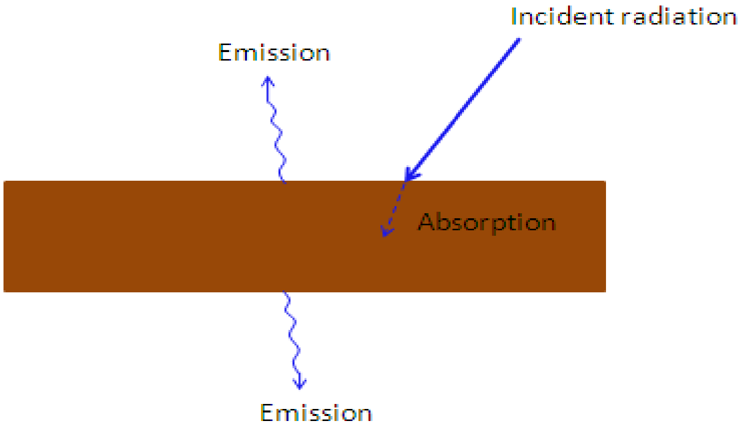


The incident electromagnetic energy may interact with the earth surface features in three possible ways: Reflection, Absorption and Transmission.

- Reflection occurs when radiation is redirected after hitting the target. According to the law of reflection, the angle of incidence is equal to the angle of reflection.



- Transmission occurs when radiation is allowed to pass through the target. Depending upon the characteristics of the medium, during the transmission velocity and wavelength of the radiation changes, whereas the frequency remains same. The transmitted energy may further get scattered and / or absorbed in the medium.
- Absorption occurs when radiation is absorbed by the target. The portion of the EM energy which is absorbed by the Earth's surface is available for emission and as thermal radiation at longer wavelengths. (Therefore, sometimes *Absorbance* in energy balance equation can be represented as emissivity.)



So, the energy balance equation becomes,

$$E_R(\lambda) = E_I(\lambda) - E_A(\lambda) - E_T(\lambda)$$

Dividing by $E_I(\lambda)$,

$$\frac{ER(\lambda)}{EI\ (\lambda)} = 1 - \{ \frac{EA(\lambda)}{EI\ (\lambda)} + \frac{ET(\lambda)}{EI\ (\lambda)} \}$$

$$Reflectance = 1 - (Absorbance + Transmittance)$$

∵ All the objects on earth are opaque in nature, ∴ *Transmittance* = 0 (neglected).

Now, $$Reflectance = 1 - (Absorbance)$$

Or

$$Reflectance = 1 - (Emissivity)$$

If absorbance =1, reflectance=0 implies that total energy incident is completely absorbed by the object. Black body such as lamp smoke is an example of this type of object.

If absorbance =0, reflectance=1 implies that total energy incident is reflected and recorded by the sensing system. The classic example of this type is Snow (i.e. White object).

Spectral Reflectance

The reflectance characteristics of earth surface features expressed as the ratio of energy reflected by the surface to the energy incident on the surface, measured as a function of wavelength is called spectral reflectance, R_λ. It is also known as albedo of the surface. It may vary from 0-100%.

$$\text{Spectral reflectance} = \frac{ER(\lambda)}{EI\ (\lambda)}$$

$$= \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident on the object}} \times 100$$

Spectral Reflectance/radiance of various Earth surface features is as follows

Surface type	**Albedo %**
Grass	25
Concrete	20
Water	5-70
Fresh snow	80
Forest	5-10
Thick cloud	75
Dark soil	5-10

Reflectance/radiance of fresh snow is generally very high. Dry snow reflects almost 80% of the energy incident on it. Clouds also reflect a majority of the incident energy. Dark soil and concrete generally show very low albedo. Reflectance of vegetation is also generally low, but varies with the canopy density. Albedo of forest areas with good canopy cover is as low as 5-10%. Reflectance of water ranges from 5 to 70%. Reflectance is low at lower incidence angle and increases for higher incidence angles.

The energy that is reflected by features on the earth's surface over a variety of different wavelengths will give their spectral responses in the remote sensing systems. Each type of feature/object has a unique spectral response/ reflectance characteristics, also known as *spectral signature*, which can be used to identify the respective surface features & to study their properties.

Spectral Reflectance Curve

The graphical representation of the spectral response of an object over different wavelengths of the electromagnetic spectrum is termed as *spectral reflectance curve*. The reflectance characteristics of the surface features are represented using these curves.

These curves give an insight into the spectral characteristics of different objects, hence used in the selection of a particular wavelength band for remote sensing data acquisition.

The graph is drawn between various wavelengths (μm) of EM spectrum on *x-axis* & the amount of reflectance (%) recorded by the R.S. system on the *y-axis*.

Spectral reflectance curve exhibits the "peak-and-valley" configuration. High amount of reflectance of a wavelength from a particular feature may result in *peaks* in the graph & low reflectance results in a *dip* or *valley* in the curve. In other words, the peaks indicate strong reflection of incident energy and the valleys indicate predominant absorption of the energy in the corresponding wavelength bands.

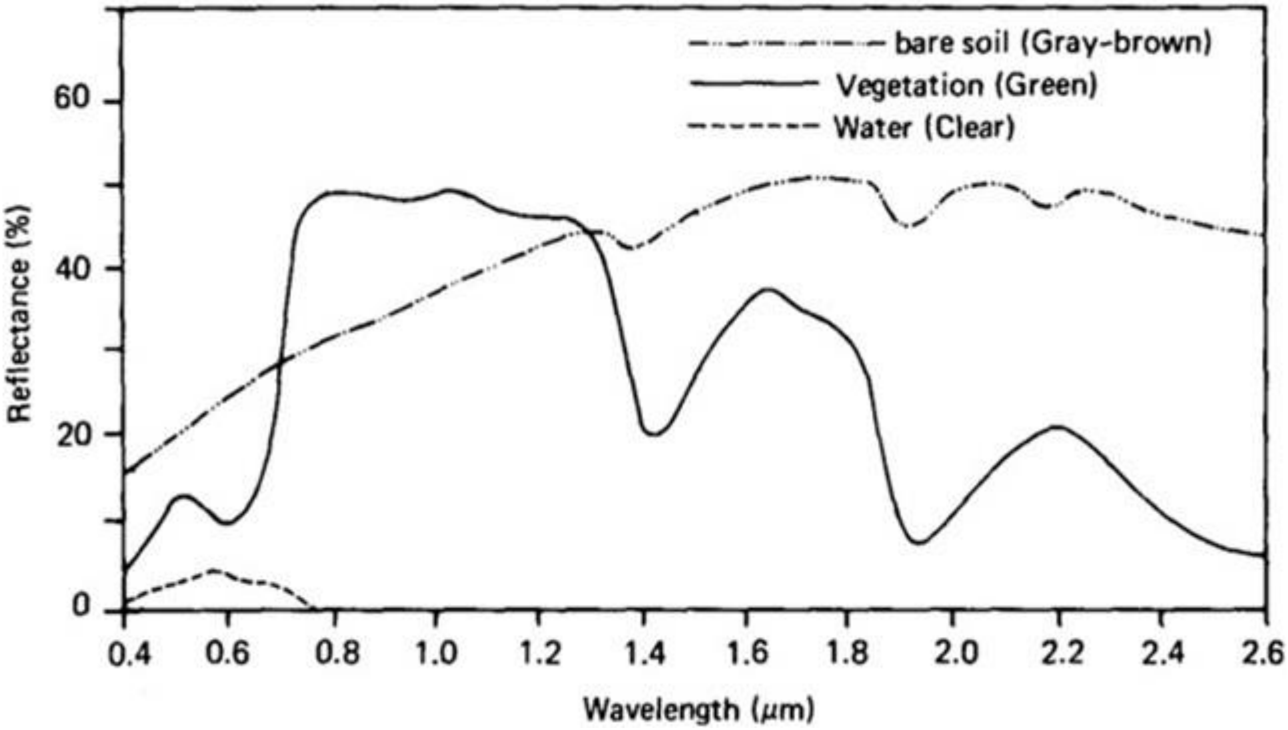


Figure: Spectral Reflectance Curve for vegetation, soil &water

NOTE: The peaks & dips in these curves are very specific, at definite wavelengths, so should be carefully & correctly drawn at exact wavelength (μm). For example, within visible region(0.4-0.7 μm), the curve for vegetation will have dips exactly at 0.45 μm & 0.67 μm.

1. Spectral Reflectance Curve for Vegetation

Spectral reflectance curve for healthy green vegetation exhibits the "peak-and-valley" configuration as illustrated in Fig.1. It can be studied in three categories viz. wavelength region (0.4-0.7µm), (0.7-1.3µm) & beyond 1.3µm.

In general, healthy vegetations are very good absorbers of electromagnetic energy in the visible region (0.4-0.7µm). The absorption greatly reduces and reflection increases in the red/infrared boundary near 0.7 µm. The reflectance is nearly constant from 0.7-1.3 µm and then decreases for the longer wavelengths.

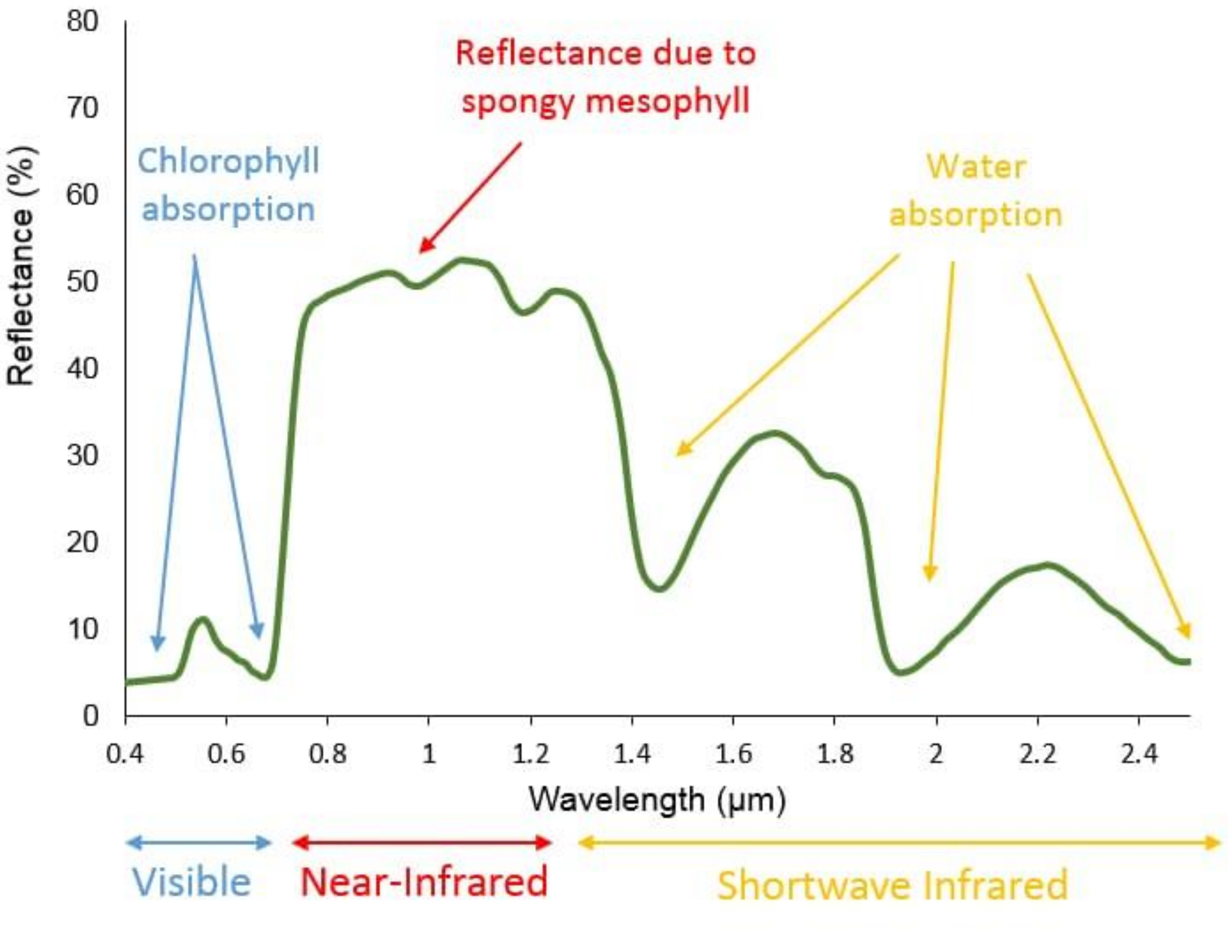


Fig.1. Typical Spectral Reflectance Curve for vegetation

Spectral response of vegetation depends on the structure of the plant leaves. Fig. 2 shows the cell structure of a green leaf and the interaction with the electromagnetic radiation (Gibson 2000).

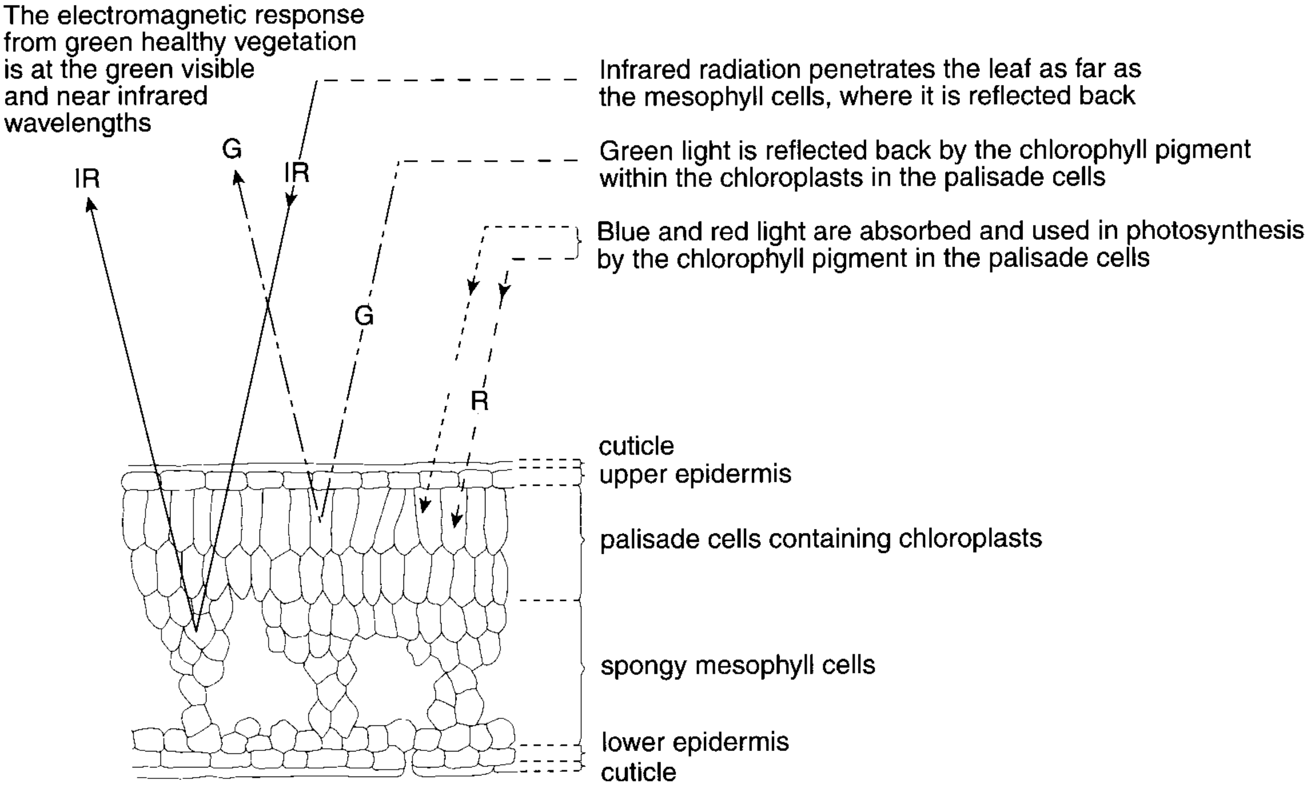


Fig.2. Cell structure of a green leaf and interactions with the electromagnetic radiation (Gibson, 2000)

The valleys in the ***visible region*** **(0.4 to 0.7 µm)** of the spectrum are due to the pigments in plant leaves. The palisade cells containing sacs of green pigment (chlorophyll) strongly absorb energy in the wavelength bands centered at 0.45 and 0.67 µm within visible region (corresponds to blue and red), as shown in Fig.3. On the other hand, reflection peaks for the green colour in the visible region, which makes our eyes perceive healthy vegetation as green in colour. However, only 10-15% of the incident energy is reflected in the green band.

In the ***near infrared (NIR) region*** **(0.7 to 1.3 µm)** of the spectrum, at 0.7 µm, the reflectance of healthy vegetation increases dramatically. In the range from 0.7 to 1.3 µm, a plant leaf reflects about 50 percent of the energy incident upon it. The infrared radiation penetrates the palisade cells and reaches the irregularly packed mesophyll cells which make up the body of the leaf. Mesophyll cells reflect almost 60% of the NIR radiation reaching this layer. Most of the remaining energy is transmitted, since absorption in this spectral region is minimal. Healthy vegetation therefore shows brighter response in the NIR region compared to the green region. As the leaf structure is highly variable between plant species, reflectance measurements in this (NIR) range often permit discrimination between species, even if they look same in visible range as seen in Fig. 3.

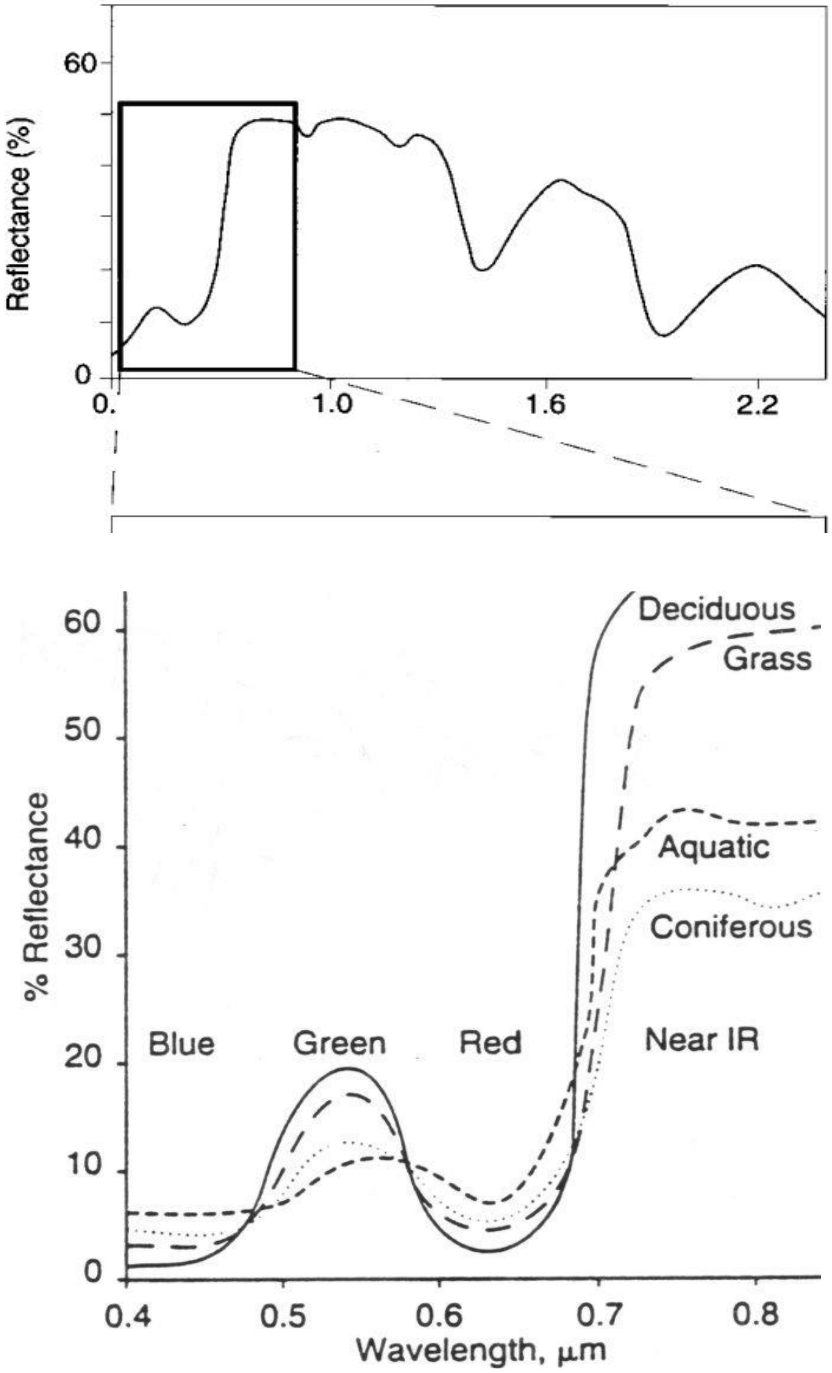


Fig.3. Spectral reflectance of healthy vegetation in the visible and NIR wavelength bands

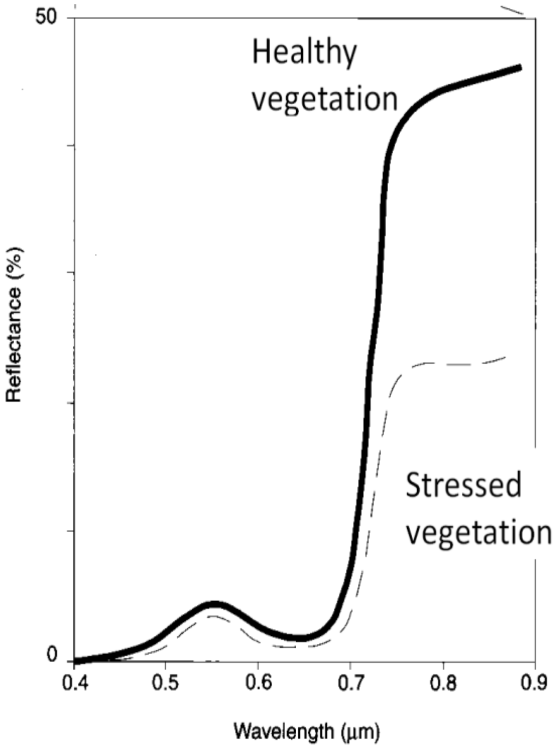
In the region *beyond 1.3 µm*, leaf reflectance is approximately inversely related to the total water present in a leaf as water absorbs the energy. This total water is a function of both the moisture content and the thickness of the leaf.

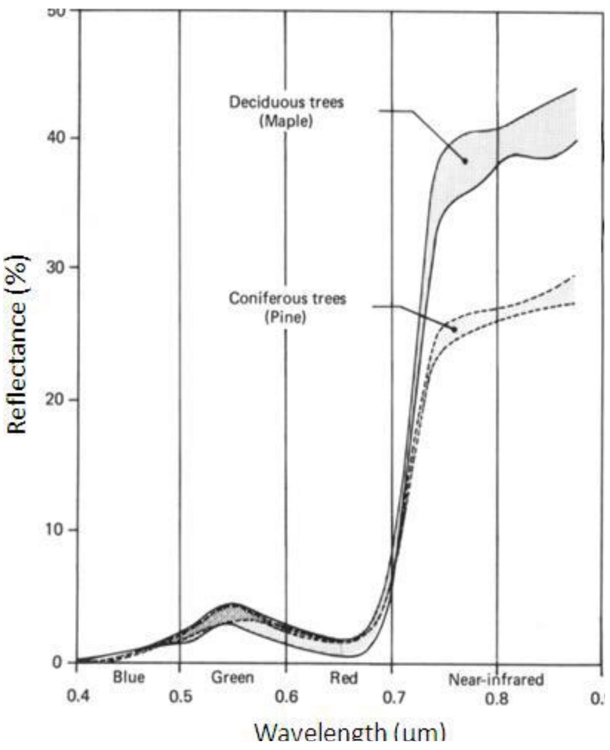
Dips in reflectance occur at **1.4**, **1.9**, and **2.7 µm** (Fig.1.) as water in the leaf strongly absorbs the energy at these wavelengths. So, wavelengths in these spectral regions are referred to as *water absorption bands*. Reflectance peaks occur at **1.6** and **2.2 µm** (Fig.1.), between the absorption bands.

Some important features & facts:

a) Vegetation canopies generally display a layered structure. Therefore, the energy transmitted by one layer is available for reflection or absorption by the layers below it (Fig. 4). Due to this multi-layer reflection, total infrared reflection from thicker canopies will be more compared to thin canopy cover. From the reflected NIR, the **density** of the vegetation canopy can thus be interpreted.

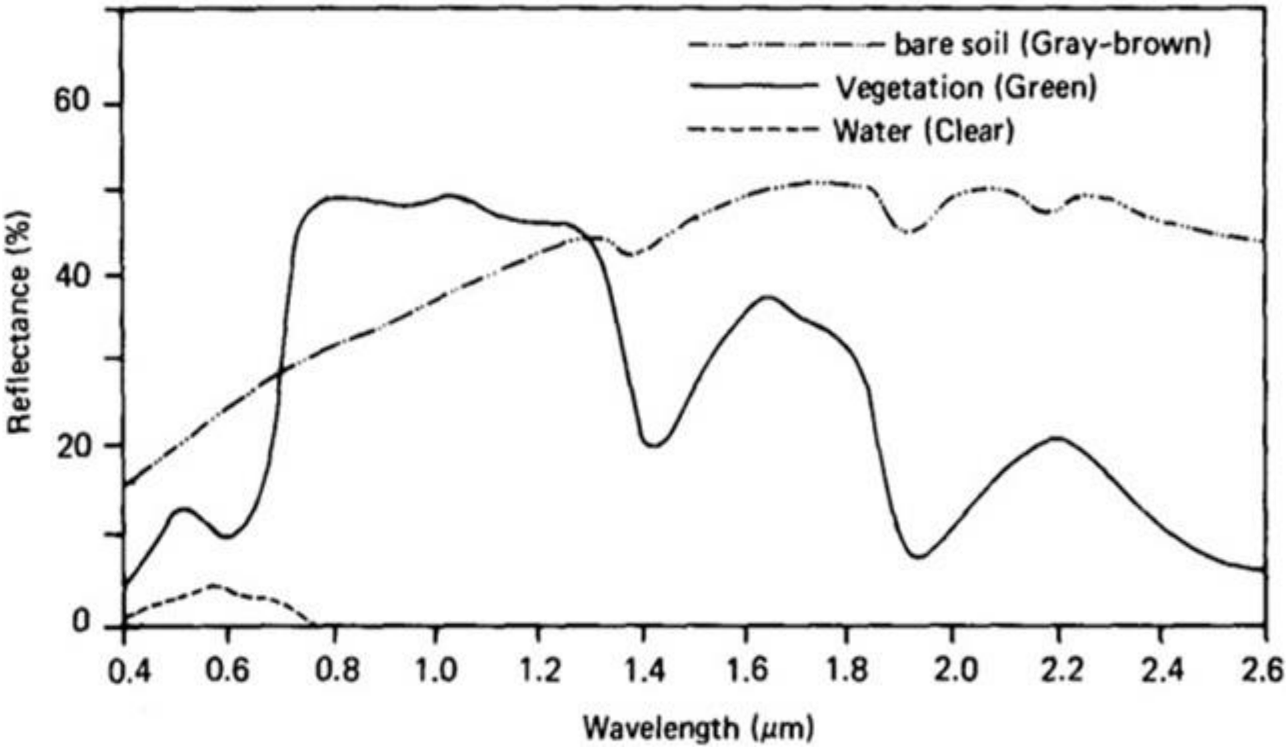
b) If a plant is subjected to some form of stress that interrupts its normal growth and productivity, it may decrease or cease chlorophyll production. The result is less absorption in the blue and red bands in the palisade. Hence, red and blue bands also get reflected along with the green band, giving yellow or brown colour to the stressed vegetation. Also in **stressed vegetation**, the NIR bands are no longer reflected by the mesophyll cells, instead they are absorbed by the stressed or dead cells causing dark tones in the image.





c) As the reflectance in the IR bands of the EMR spectrum varies with the leaf structure and the canopy density, measurements in the IR region can be used to discriminate the tree or vegetation species. For example, spectral reflectance of **deciduous and coniferous trees** may be similar in the green band. However, the coniferous trees show higher reflection in the NIR band, and can be easily differentiated (Fig.5). Similarly, for a densely grown agricultural area, the NIR signature will be more.

2. Spectral Reflectance of Soil



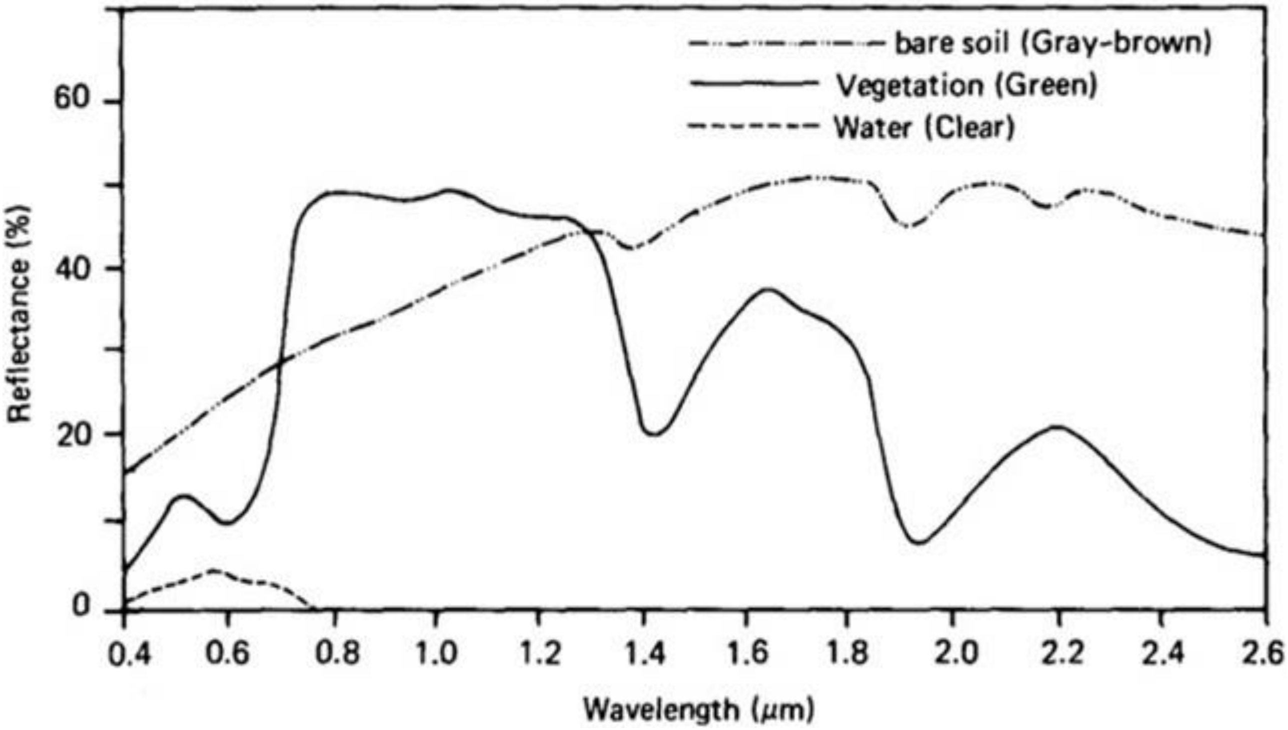
Some of the factors effecting soil reflectance are moisture content, soil texture (proportion of sand, silt, and clay), surface roughness, presence of iron oxide and organic matter content. These factors are complex, variable, and interrelated.

The presence of moisture in soil decreases its reflectance. This effect is greatest in the water absorption bands at 1.4, 1.9, and 2.1 μm. On the other hand, similar absorption characteristics are displayed by the clay soils. Clay soils have *hydroxyl ion absorption bands* at 1.4 and 2.2 μm.

Soil moisture content is strongly related to the soil texture. For example, coarse, sandy soils are usually well drained, resulting in low moisture content and relatively high reflectance. On the other hand, poorly drained fine textured soils generally have lower reflectance. In the absence of water, however, the soil itself exhibits the reverse tendency i.e., coarse textured soils appear darker than fine textured soils.

Two other factors that reduce soil reflectance are surface roughness and the content of organic matter. Presence of iron oxide in a soil also significantly decreases reflectance, at least in the visible region of wavelengths.

3. Spectral Reflectance for Water



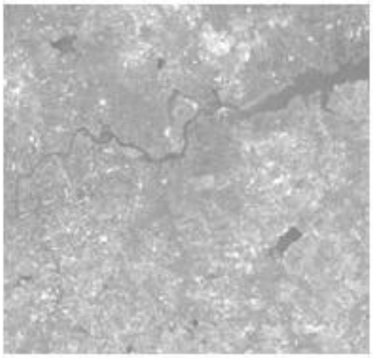
Water provides a semi-transparent medium for the electromagnetic radiation. Thus the electromagnetic radiations get reflected, transmitted or absorbed in water. The spectral responses vary with the wavelength of the radiation and the physical and chemical characteristics of the water.

Spectral reflectance of water varies with its physical condition. In the *solid phase* (ice or snow) water give good reflection at all visible wavelengths. On the other hand, reflection in the visible region is poor in case of water in *liquid stage*. This difference in reflectance is due to *the difference in the atomic bond* in the liquid and solid states.

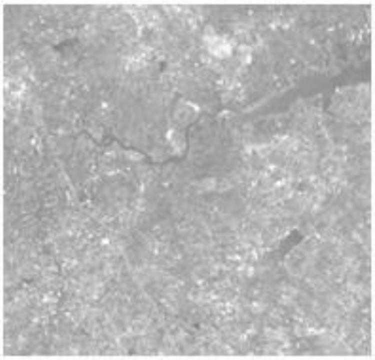
In the visible region between 0.4μm and 0.7μm, around 0.6μm water in the liquid form shows high reflectance. Wavelengths ***beyond 0.7μm*** are completely absorbed (i.e. no curve formed beyond 0.7μm). Thus clear water appears in ***darker tone*** in the **NIR** image. Locating and delineating water bodies with remote sensing data is done more easily in reflected infrared wavelengths because of this absorption property.

For example, the next Fig. shows a part of the Krishna River Basin in different bands of the Landsat ETM+ imagery. The water body appears in dark colour in all bands and displays **sharp contrast** in the IR bands.

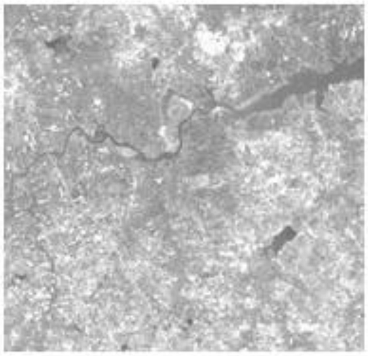
B1 (0.45-0.52 μm)



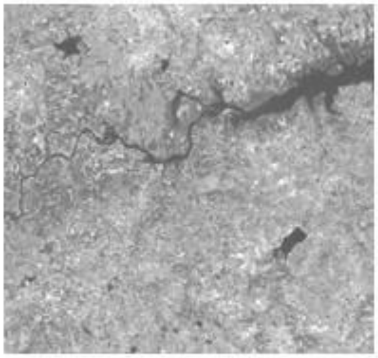
B2 (0.52-0.60 μm)



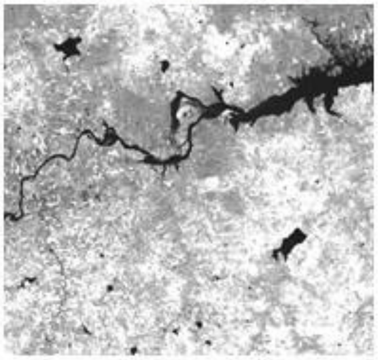
B3 (0.63-0.69 μm)



B4 (0.76-0.90 μm)



B5 (1.55-1.75 μm)



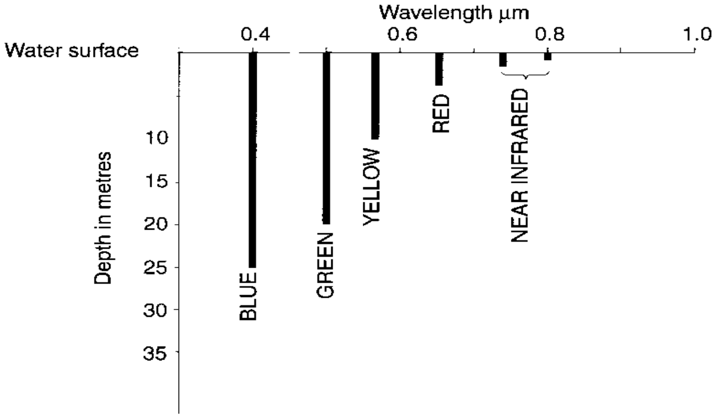
Some important features & facts:

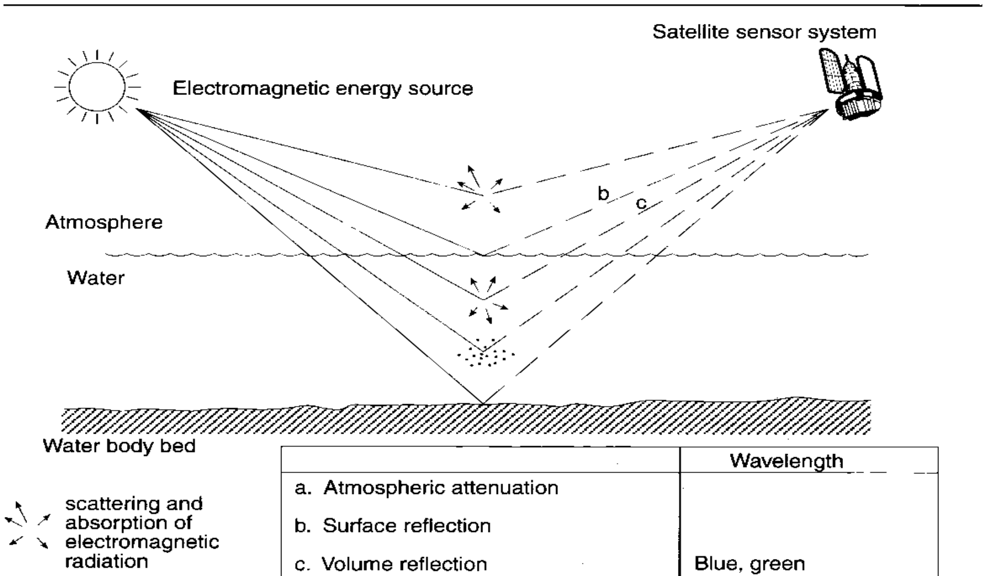
a) The energy/matter interactions at visible wavelengths are very complex and depend on a number of interrelated factors (as shown in next fig.). For example, the reflectance from a water body can stem from an interaction with the water's surface (specular reflection), with material suspended in the water, or with the bottom surface of the water body. Even in deep water, where bottom effects are negligible, the reflectance properties of a water body are not only a function of the water, but also of the material in the water.

b) Clear water absorbs relatively less energy having wavelengths shorter than 0.6 μm. as the turbidity of water changes (because of the presence of organic or inorganic materials), transmittance and therefore reflectance change dramatically. For example, water bodies containing large quantities of suspended sediments normally have much higher visible reflectance than clear water.

c) Likewise, the reflectance of water changes with the chlorophyll concentration involved. Increase in chlorophyll concentration tends to decrease reflectance in blue wavelengths and increase reflectance in green wavelengths. These changes have been used in remote sensing to monitor the presence and to estimate the concentration of algae.

d) Reflectance data in the visible region can also be used to differentiate shallow and deep waters, clear and turbid waters, as well as rough and smooth water bodies. Reflectance in the NIR range is generally used for delineating the water bodies and also to study the algal boom and phytoplankton concentration in water.





	Wavelength
a. Atmospheric attenuation	
b. Surface reflection	
c. Volume reflection	Blue, green
d. Reflection from suspended particles	Red, green
e. Reflection from bed material	Yellow, green, dark blue