Remote Sensing: Principles and Applications
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Lecture No -31
Spectral Properties of Few Common Earth Features in the Visible,
NIR and SWIR Bands – Part 5

Hello everyone. Welcome to the next lecture in the course remote sensing principles and applications. We are discussing the spectral reflectance properties of few commonly occurring earth surface features. Today we are going to start with the topic of discussing about the reflectance properties of water. So, when we take water, the reflectance that we observe from water bodies can take several different parts. Let us look at this particular slide.

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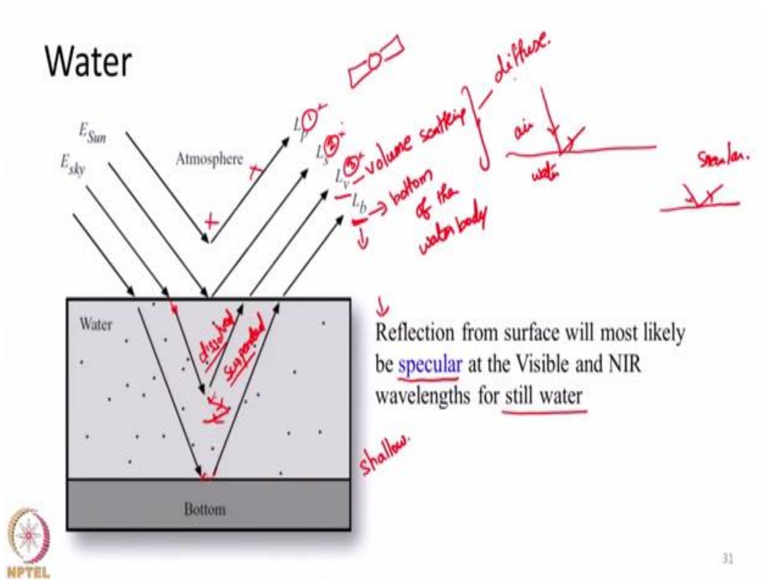

So, if you take the radiance let us assume the sensor is located here. So, the radiance reaching the sensor from a water body can come from different parts. First thing can be just the pure path radiance from the atmosphere which we are not interested. Second component can be from the surface reflected part of water. That is whenever EMR travels from one medium to another medium this is air, this is water, when the medium changes at the surface some reflection will happen. We have seen this. So, a part of the radiance reaching the sensor will be from the surface component of water. We know that water is not completely opaque, it will allow light or other wavelengths of EMR to pass through. So, some portion of EMR will be passing through the water body and there will be different elements either dissolved or suspended.

Different materials can be present there and the EMR that is penetrating through the water can interact with these dissolved or suspended materials and it can come out of water again and can reach the sensor. This we call as volume scattering or the reflection due to the presence of any materials in the volume of the water body. If the water body is shallow, then some portion of the EMR can penetrate water deep enough and it will interact with whatever present in the bottom of the water body and again come back and reach the sensor.

So, this is reflection from the bottom of the water body. So, essentially the radiance reaching the sensor from a water body can take any of these four parts. This is cannot be neglected, atmosphere always be there, surface will always be there and most likely volume will also be there. If the water body is shallow, effect of bottom of the water body will be there or the EMR may not reach the bottom of the water body at all depending on the depth.

So, four components we should consider or if we remove this, at least three components we should consider which includes the signal about the water body. And based on the materials present the signal will vary and that is what we are going to see in this particular lecture. Before moving on to understanding about what happens to these portions L_v or L_b the volume scattering part or the bottom part.

First we will make it clear that the reflection from the surface of water body will most likely be specular. Because for a clear or still water, if the water body is free of any sort of waves or any sort of disturbance, it will be fairly smooth. So, whatever reflection happens from the surface will most likely be specular in nature. On the other hand once the EMR penetrates through the water body and when it interacts with whatever present inside the water, that particular radiation when it comes out, it will be diffuse in nature.

That is component 3 and 4 here. Whatever we have written they will be most likely diffuse in nature. Because there are high chances that during the interaction with molecules present inside the water, it can be scattered in different directions or there can be multiple reflections say one molecule may reflect towards this, this may reflect here and so on. So, the EMR signal that we are going to receive from the volume component or the bottom of the water body is more likely to be diffuse in nature. But whatever reflection that happens from the surface is more likely to be specular in nature.

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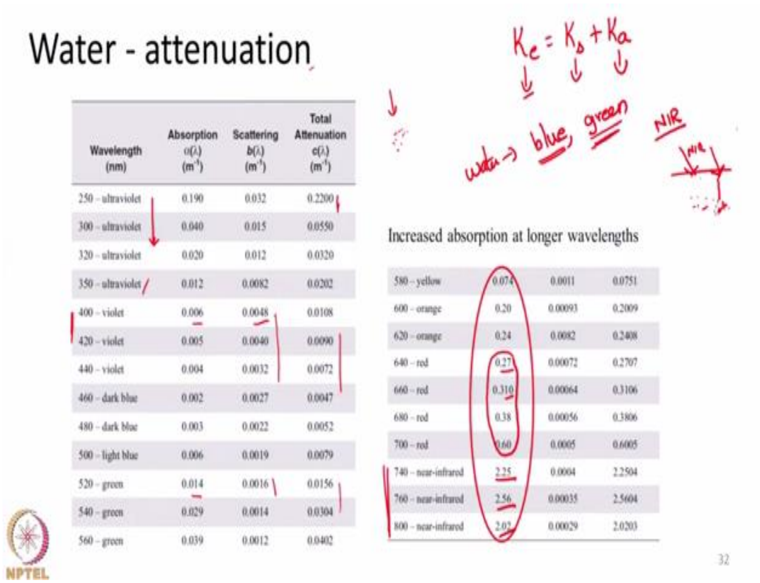

Wavelength (nm)	Absorption $a(\lambda)$ (m^{-1})	Scattering $b(\lambda)$ (m^{-1})	Total Attenuation $c(\lambda)$ (m^{-1})
250 – ultraviolet	0.190	0.032	0.2200
300 – ultraviolet	0.040	0.015	0.0550
320 – ultraviolet	0.020	0.012	0.0320
350 – ultraviolet	0.012	0.0082	0.0202
400 – violet	0.006	0.0048	0.0108
420 – violet	0.005	0.0040	0.0090
440 – violet	0.004	0.0032	0.0072
460 – dark blue	0.002	0.0027	0.0047
480 – dark blue	0.003	0.0022	0.0052
500 – light blue	0.006	0.0019	0.0079
520 – green	0.014	0.0016	0.0156
540 – green	0.029	0.0014	0.0304
560 – green	0.039	0.0012	0.0402

Increased absorption at longer wavelengths

580 – yellow	0.074	0.0011	0.0751
600 – orange	0.20	0.00093	0.2009
620 – orange	0.24	0.0082	0.2408
640 – red	0.27	0.00072	0.2707
660 – red	0.310	0.00064	0.3106
680 – red	0.38	0.00056	0.3806
700 – red	0.60	0.0005	0.6005
740 – near-infrared	2.25	0.0004	2.2504
760 – near-infrared	2.56	0.00035	2.5604
800 – near-infrared	2.02	0.00029	2.0203

So, this particular slide tells us how water absorbs or scatters in general for different wavelengths. So, essentially now we know a certain portion of EMR will penetrate through the water. And for water, reflectance is pretty low mostly in the order of less than say 10% or even less than 5% in most of the cases. Hence a large component of EMR which is incident on the water body will most likely penetrate through the water body or get transmitted through the water body.

So, once EMR gets transmitted through the water body then a certain fraction of it will be scattered and certain fraction of it will be absorbed. Only remaining fraction will be allowed to pass through or come out of it. So, in the earlier classes when we discussed about the properties of EMR we came across few terms what is known as absorption coefficient, scattering coefficient and attenuation coefficient.

Three different terms we defined in the class. What are they? So, the total attenuation coefficient is inverse of the attenuation length. That is one over attenuation length is the attenuation coefficient. What it represents, if certain amount of EMR enters the water body after traveling through certain length, that EMR energy will become one by e times of the original quantity which enter the water body.

So, what distance it has to travel for its power or energy to become 1 by e times. So, that distance we take, we make it 1 over the distance and calculate as attenuation coefficient. And the total attenuation what we studied has two components. One is scattering and another one is absorption. These two combines together and gives the total attenuation. So, if we study about the loss in power only due to scattering, we call the coefficient as scattering coefficient.

If the loss is only due to absorption, we call it as absorption coefficient or if we take both of them together, we call it as attenuation coefficient. So, essentially attenuation coefficient

$$K_e = K_s + K_a$$

So, if you look at here these three coefficients are actually experimentally got observed and it is given for different wavelengths.

So, let us leave ultraviolet portion because mostly we will not receive that radiation on the earth surface. We will start from blue wavelength from 0.4 micrometers. You can see that the absorption and scattering is fairly low for blue wavelengths. Slowly you can see it is in the same order, the value does not change much for blue wavelengths. Then when you encounter the green absorption slightly increases and when we move on to say yellow or red portion, the absorption further increases.

And when we move to NIR portion you can see the absorption has increased manifold, it is so high. So, what this means, water body or water in general is fairly transparent to blue wavelengths and green wavelengths. But water absorbs a good portion of NIR and even in red, the absorption is pretty high in comparison with blue or green wavelengths.

So, this suggests that water is a very good absorber of NIR wavelength, then it absorbs red to the next maximum extent. But it allows blue or green to pass through. That is its absorption is quite less. So, when absorption is quite less and when it is passing through there are high chances that it can fairly interact with whatever be present in the water body.

Let us say NIR is incident over a water body. NIR wavelength will be absorbed, there will not be any chance for the NIR to interact with whatever is being present within the water body. But let us say blue wavelength is being incident on water, then because it is less absorbed, it will be transmitted through. And if something else is present in the water, there may be some soil particle, there may be something got dissolved, whatever, this blue wavelength that is passing through will mostly interact with it. And this particular signal will be recorded by the sensor.

So, if we want to study what is being present inside the water body or if we want to study about the bottom surface properties of the water body, then we should use blue wavelengths or green wavelength which is less absorbed by water. On the other hand NIR will be strongly absorbed by water and its penetration depth in the water is extremely low. So, the total attenuation that happens is a combination of both scattering and absorption. The total attenuation that happens actually is very low for blue wavelengths then comes green and then for red. But for NIR the total attenuation coefficient is extremely high.

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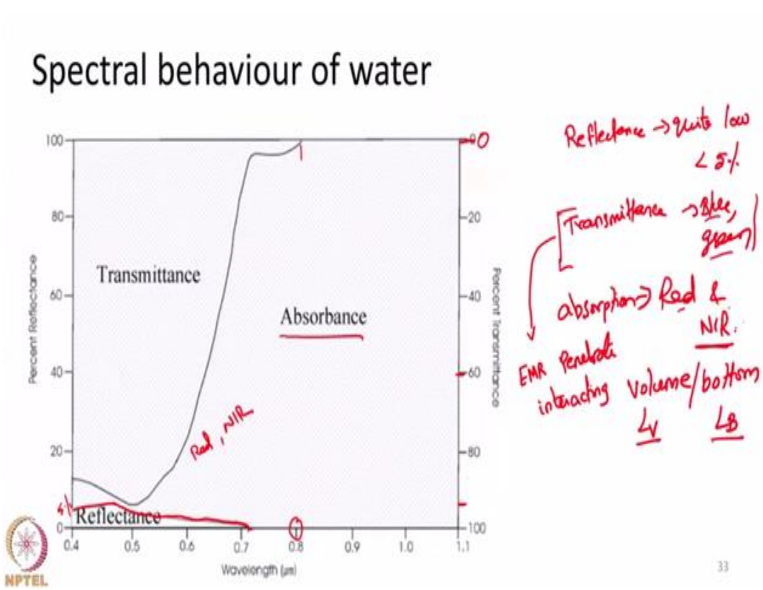

So, this particular slide shows us in a more clear way. You can see the reflectance of water is pretty low even in blue wavelength and green wavelength. Water is actually a very poor reflector, less than 5% in most of the cases. But you see the transmittance is increasing from here, the axis is marked from here from 0 to 10%.

You can see the transmittance is extremely high for blue and green wavelength. So, it is almost 90%. So, water allows blue or green wavelength to pass through with very less absorptance and reflectance. So, reflectance is quite low, once we cross the green wavelength the transmittance decreases very rapidly. The transmittance goes towards 0 very fast and once we reach around this 0.8 micrometer the transmittance is almost 0.

So, most of the red and NIR wavelengths will be absorbed whereas the blue and green wavelengths will be allowed to pass through. But in general the reflectance from water is very low in whatever the wavelength. Reflectance curve is somewhat higher in blue and green wavelengths. This is actually the reflectance curve that I am highlighting is somewhat high in blue and green wavelength.

But very low reflectance in red and NIR after NIR it becomes almost 0. So, in water the reflectance is quite low. Most probably less than 5% but transmittance is high in blue and green wavelengths and absorption is high in red and NIR wavelengths. And it is very high in NIR wavelengths. So, what is the implication of these things? Since the transmittance is extremely high for blue and green, EMR in these wavelengths will penetrate the water body and it has very high chances of interacting with whatever is being present in the volume of the water body or the bottom surface of the water body. So, in the previous slide I told you L_v component and L_b component will be predominantly observed in blue and green wavelength because of transmittance.

On the other hand in NIR wavelength, most of the EMR will be absorbed by water itself. So nothing will be coming out for us and red can penetrate through some extent. Because the transmittance around say less than 0.65 micrometers is still around 60 percent. So, it can penetrate to some extent, but due to increased absorption it will have very less chance of coming out of it. So, essentially what will happen is, a mix of EMR is going towards the water. And based on the wavelength, the penetration depth will vary. Blue wavelength can penetrate deep into water body, green can penetrate with less depth, red is further less depth and NIR has very low penetration. So, if some other object is being encountered by this wavelength, it will be scattered or reflected by that particular object.

Let us say some soil particles is suspended in the water body. So, blue which penetrates deep can get reflected by that object and can come out of water, again green also can do that. But red or NIR will not be able to do that. So, in blue wavelength the signals from the water can come even from very deep surfaces say 15, 20 meters. And there are reports telling that for very clear calm water bodies, signals has been obtained even from a depth of up to 50 meters in blue wavelength. Then in green, it may become something around say 5 meters depth from which the signal can come because only till then EMR can pass through and escape. Otherwise it will be absorbed completely by water. As EMR progresses more and more into the water, it will be continuously being absorbed.

So, its energy will be keep on reducing and at certain point it will become 0. So, after a certain depth any wavelength will be totally absorbed. So, mostly blue can penetrate much deeper around 15, 20 meters, green can be around 5 meters, red can be 1 or 2 meters and NIR is still lower even a thin layer of water, even half a meter. If the water is like really clear, then NIR can be absorbed very rapidly.

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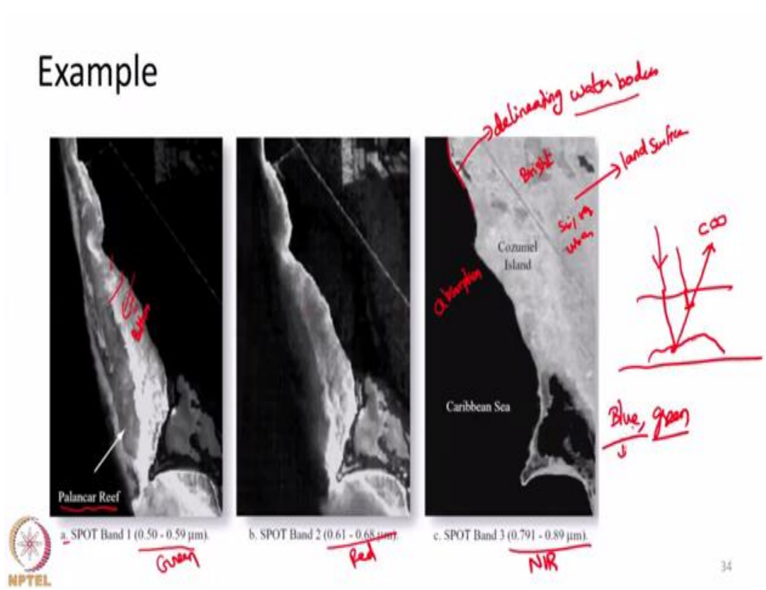

So, now we will see one example of this penetration capacity and what it can provide us for different, different wavelengths. So, in this particular slide we have a portion of land and water (Caribbean sea) together. So, this figure a is observed in green band, figure b is observed in red band and figure c is observed in an NIR band. So, if you take the NIR band, in NIR all land surface features have very high reflectance, much higher than water.

So, naturally whatever be the land surface feature, be it soi,l be it vegetation, be it urban surface whatever, will have relatively higher reflectance. So, land will be appearing bright in NIR portion. On the other hand, water body with its very high absorption in NIR will appear pitch dark. There will not be any reflectance from water body in the NIR portion of electromagnetic spectrum. This suggests that NIR band is very suitable or highly suitable for delineating water bodies. If we want to map the boundaries of water bodies or separate water body boundaries from land surface, NIR band can be highly suitable for mapping this. Because NIR is strongly absorbed by water bodies.

Then we will come to green band, green band has relatively higher transmission. So, what happens, green band gets transmitted inside and immediately after land surface we may have shallow water what is known as continental shelf, continental slope, all these things. So, immediately the depth will not increase. There will be some amount of land surface or soil present underneath the water. So, the EMR that is penetrating into the water is now getting reflected by the bottom features whatever is present there.

And that is what we are now seeing in this particular green band. And here there is a coral reef called the palanca reef and that signal is also being observed. This is because as EMR travels through water it get reflected from this particular feature and this signal we are now getting back and getting recorded at the sensor.

On the other hand, EMR in NIR band as soon as it hits the water body it penetrates and it gets absorbed. It does not have any chance to reach the spot. Even before reaching the spot it will get absorbed near the surface itself. So, as the penetration capacity of different wavelength changes, our ability to see the objects present underneath the water surface will increase. So, if we want to study about anything present inside the water it is always better to use blue or green wavelengths.

But the only problem with blue is, it will be highly scattered by atmosphere. So, we may not get good signals but green we can use for sensing underneath the water surfaces. If we want to map the water and land boundaries then NIR can be a most suitable band for doing it.

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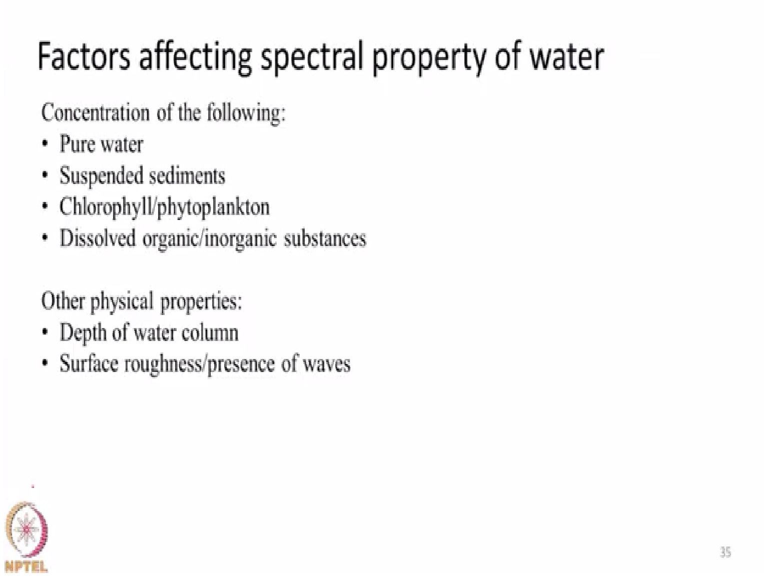

So, now we have seen general property of reflectance, how water reflects, how water transmits. So, in general, in the infrared portions, water is a very good absorber. It absorbs most of the things. In the visible portion, water is equally a poor reflector as well as a poor absorber. So it allows most of the EMR to pass through it. So, if we combine all these things then we can define certain factors which will affect the spectral nature of the wavelength of the EMR that interacts with the water body.

Some of the factors are, first thing how pure the water is. Concentration of pure water, presence of organisms like phytoplanktons or presence of chlorophyll in general alters the concentration. Then the presence of dissolved or suspended organic matter, like vegetation may die and decompose it may get dissolved in water or something it can happen.

Similarly inorganic substances like soil particles, it may be washed out from land, it can get mixed with water body. So, they will be suspended in the water body. So, presence or absence of such dissolved or suspended inorganic materials can change the reflectance. So, all these things can change the reflectance of water body. In addition to this, the depth of the water column, if it is really deep, then EMR will not have a chance to interact with the bottom surface at all.

But if it is relatively shallower, then some signals from the bottom surface will come up. So, how deep the water bodies may play a role. Similarly for large water bodies such as oceans or seas presence of waves, wind or basically the surface roughness can influence the reflectance reaching the sensor. So, now we will see little bit in detail about how these factors will affect the reflectance.

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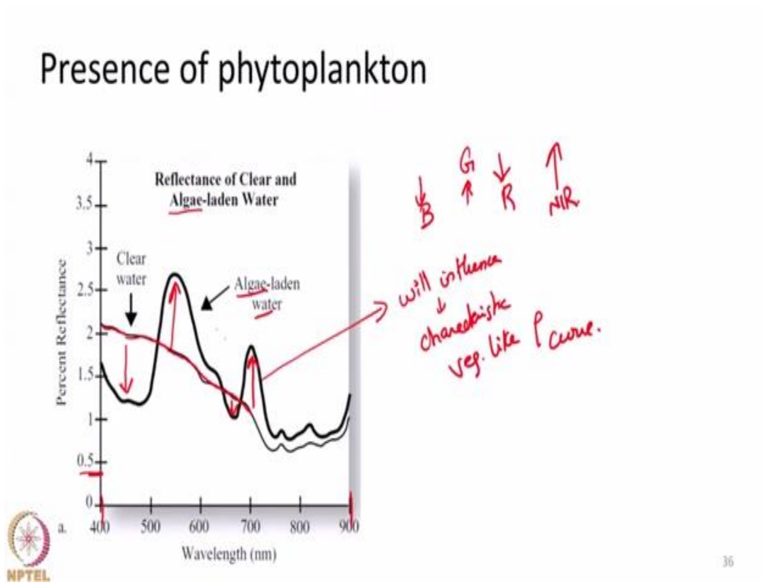

The first factor we are going to see is the presence of vegetation or what we commonly refer as phytoplankton. That is if we take large bodies of water such as oceans then tiny organisms of vegetation, very tiny particles of vegetation can live they are called phytoplankton's which will be seen in very large groups. So, hence it will be visible even from satellites.

But they are highly tiny organisms. So, they are really important in the global carbon cycle itself. They will be extremely abundant in the ocean surfaces in certain seasons and they will absorb carbon dioxide from the atmosphere and do photosynthesis. When they die they will sink to the bottom of the ocean, that is all the carbon that got assimilated within this particular organisms will sink to the bottom of ocean and it will settle there.

So, essentially the phytoplankton enables the ocean to act as a carbon sink. So, the presence of phytoplankton is the major reason how ocean is acting as carbon sink. The phytoplankton absorbs CO_2 it goes inside the water body. So, monitoring this phytoplankton in water bodies is an extremely important task for understanding global carbon cycles.

Similarly certain types of algae may be there in water bodies. We might have observed lot of algae in lakes or ponds or whatever. Some types of algae may be toxic in nature. Most of the cities or most of the livelihoods places around the world depends on fresh water sources like lakes or ponds for drinking water purposes. If such algae develops in water bodies, then the water may become unfit for human consumption or consumption by any other living forms.

So, it is really important to monitor them. So, monitoring vegetation in water bodies is actually a very important application of remote sensing. People are doing it on an operational basis for various purposes in understanding global carbon cycle for monitoring water quality. For all these applications, monitoring of vegetation is really important. So, how the presence of vegetation will change the reflectance, the example is given in this particular slide.

So, for clear water body we will talk mostly up to NIR range. Because after NIR there is no reflectance, everything is mostly absorbed. So for a clear water body, there will be higher reflectance in blue, then the reflectance will slowly decrease in green, further decrease in red and in NIR it will be very low the reflectance is almost close to 0. However, when vegetation is present or when algae or phytoplankton is present in the water body, then the characteristic vegetation kind of reflectance will come up.

Because we have seen for vegetation, reflectance in blue will be very low, reflectance will be relatively higher in green, there will be absorption in red and there will be increased reflection in NIR. Same thing will happen. So, in blue wavelengths, reflectance will go down because of presence of vegetation. In green wavelength reflectance will increase, in red wavelength reflectance will go down, again in NIR reflectance will increase.

So, the presence of phytoplankton or algae will influence the reflectance and we will see a characteristic vegetation like spectral reflectance curve rather than seeing the reflectance of pure water body. So, decreased reflectance in blue, increase reflectance in green, increased reflectance in NIR, these things will become more prominent as vegetation either algae or phytoplankton or water vegetation settles in water bodies.

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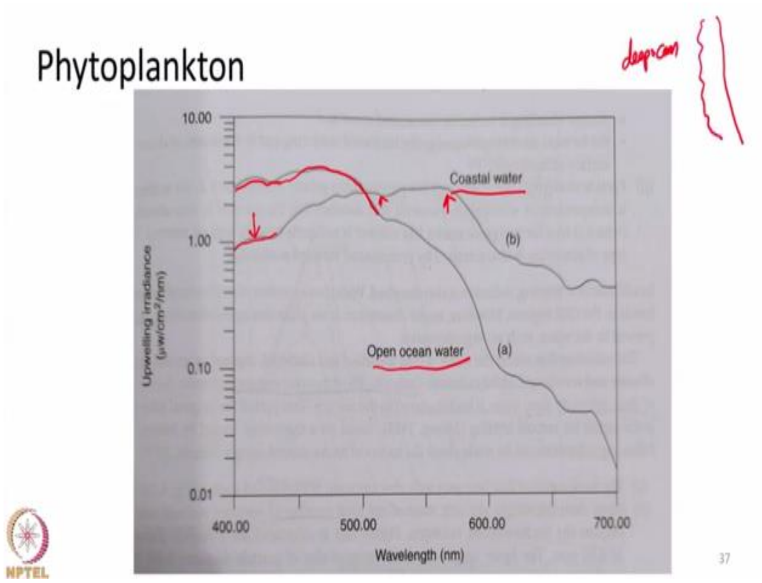

And here another example, normally in deep ocean water bodies, water can be relatively clean and relatively free from any other impurities. So, essentially we will observe the curve for clear water surfaces. But near the coast where other materials may be present like vegetation may be there, suspended sediments may be there, due to which a change in reflectance may occur.

So, here you can see, there is slightly decreased reflectance in blue, slightly increased reflectance in green portion, similarly increased reflectance in red and NIR. So, all these things happen because of presence of vegetation and other particles near the coast where there is the land surface. Near the land surface we can observe all these things while in deep oceans where water is fairly clean we can observe the curve for clean open ocean water.

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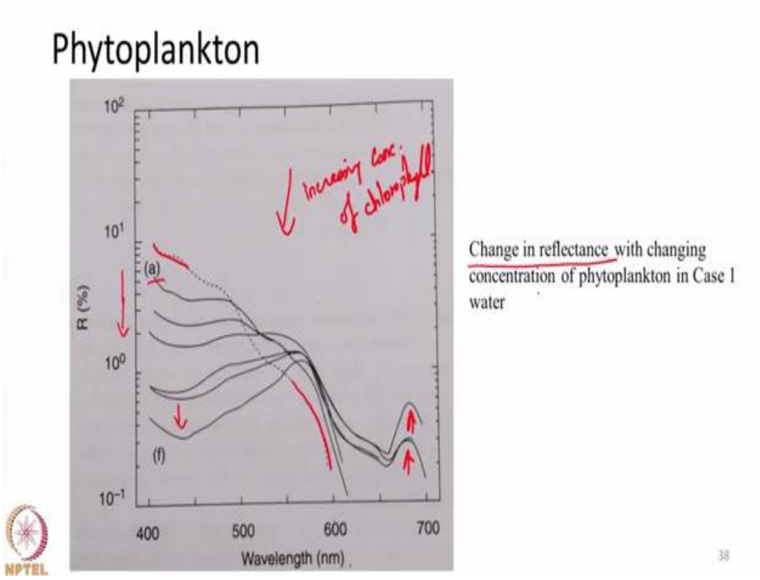

So, this is again for increasing concentration of vegetation or chlorophyll concentration. So, here the concentration increases from curve a to f. So, this direction represents increasing concentration of chlorophyll. We can see that as the chlorophyll concentration increases, the reflectance in blue goes down drastically and it increases falling in here.

You can see near the rear portion increased reflectance is seen whereas for clear water the reflectance becomes close to zero. So, this suggests that the presence or absence of vegetation will clearly change the reflectance and the concentration also will change. So, observing in visible and NIR wavelength will enable us to understand the presence or absence of vegetation.

This is monitoring of ocean color like in what color the ocean is? is kind of really important to know. If the water is extremely clear then EMR will penetrate through. Especially I already told you blue will be penetrating a lot. So, if you take a clear open ocean water, very clear nothing else is present. So, what will be there, it contains lot of dissolved salts within it. And we have studied in earlier classes if the molecular size is much lower than the wavelength involved then those molecules can cause Rayleigh scattering. So, in the clear open ocean water bodies when wavelength penetrates through, its blue wavelength will be scattered by the salt molecules.

Because still clear open oceans still has salt molecules within it. So, it will be undergoing Rayleigh scattering. So, all the blue wavelength will be scattered by this and will be allowed to spread throughout the water column. That is why clear water bodies appear blue to our eyes. Similar to the reason of why sky appears blue, the same concept. Whatever molecules present within the water be it salt or be the water molecules itself they will scatter blue and the scattered blue wavelength will spread inside the water body itself. That is the main reason why water appears blue to our eyes, clear water. But if something else is present then that will interact. And rather than seeing a blue water we will be seeing kind of greenish water or something else.

So, monitoring this ocean color is extremely important for us to understand what is being present in the water bodies. So, as a summary for this particular lecture we have seen a general introduction about the spectral reflectance property of water and what are the different factors that influences the spectral reflectance property of water bodies.

We discussed about the influence of vegetation on the reflectance part. So, in the next class we will further discuss the other factors which influences the spectral reflectance nature of water.

Thank you very much.