Remote Sensing: Principles and Applications

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Lecture No -34
Spectral Indices

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last lecture we started discussing about the concept of spectral indices and in this lecture, we are going to look at some of the few commonly used spectral indices and their application. So, I told you what a spectral index is in the last class.

So, just as a quick recap a spectral index is a single numerical value obtained by combining the spectral reflectance values in two or more than two bands for a certain feature and the main aims of creating such spectral indices are first thing to highlight some important biophysical property about the object of our interest. And also, to reduce or to completely remove some other unwanted effects such as effects due to topography, atmospheric correction, soil background effect etcetera. Also in the last class I told you about earliest developed spectral index known as the ratio index and also some of the limitation associated with this.

So, today we will start looking at the other spectral indices that exist for monitoring different features on the earth surface. The major application of remote sensing from earliest days was to monitor vegetation. Monitoring how healthy the vegetation is or monitoring whether the vegetation is undergoing any sort of stress is one of the primary applications for which remote sensing is used still even today. Because monitoring vegetation has lot of implications starting from understanding the global carbon cycle, global vegetation cycle or if we monitor crops then it will help us to ensure food security, take precautionary measures and so on.

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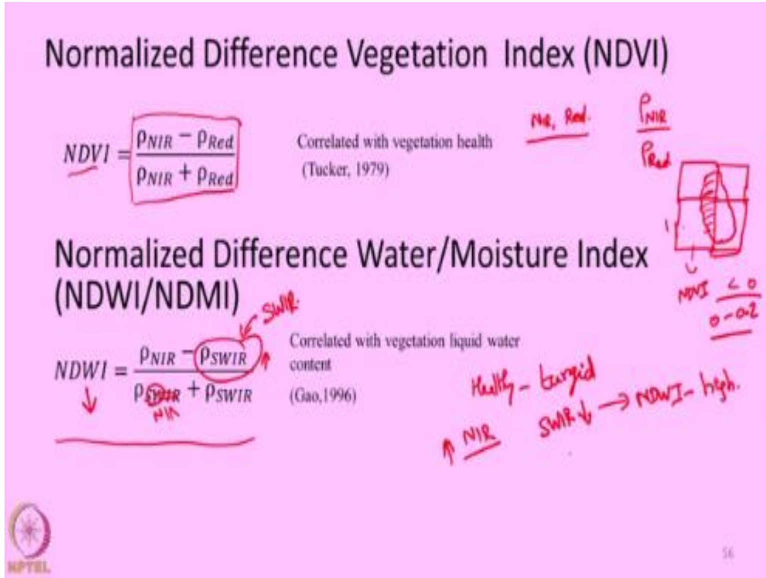

So, vegetation in a single domain encompasses lot of different species starting from large dense rainforest to crops that we use for our daily food needs. Since vegetation is one of the most important features on the earth surface, the primary application of remote sensing is to monitor vegetation. The other indices or the earlier indices that were developed primarily concentrated on understanding the healthiness of vegetation.

One such commonly used spectral index or vegetation index is normalized difference vegetation index NDVI. So, in order to obtain NDVI we need to have the spectral reflectance in NIR band and red band. So, same two combinations we used for creating the ratio spectral index. But instead of just creating a ratio of ρ_{NIR}/ρ_{red}, here we are devising a slightly different way of equation. So NDVI is,

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

So, this is like a slightly modified representation of the ratio index. So, it will look like the name normalized difference vegetation index. It is a vegetation index primarily developed to monitor vegetation that we can understand, difference - we are taking a difference of spectral reflectance in two bands NIR and red. So, that is why it is called difference.

Then normalized, here normalized means we are changing the reflectance values and bringing them to one single range. That is the physical range of NDVI will vary from minus 1 to plus 1. It is now bounded on both the sides. On the lower end it is minus 1 and on the upper end it is plus 1. So, by normalizing here we mean that, whatever be the reflectance value in the red and NIR band we are modifying them and bounding them such that the final result will be one single number within this particular range.

So, that is the reason for the name normalized difference vegetation index and this particular index is primarily developed for monitoring vegetation. The main application of this index is to monitor the healthiness of vegetation what we call vegetation health or vegetation vigor. So, the same concept similar to that of ratio index applies here too. That is for healthy vegetation, NIR will be having very high reflectance and red will be having very low reflectance.

When vegetation starts to undergo any sort of stress, red reflectance will first increase and finally after prolonged period of stress NIR reflectance will also come down. So, for healthy vegetation NDVI values will be in the positive side in the higher range maybe more than 0.5 or 0.6. If you take one pixel in a remote sensing image and if the pixel is full of healthy vegetation then the NDVI of the pixel may be more than 0.5, 0.6 even sometimes for some sensors like MODIS, NDVI can be 0.8. So, higher the value in the positive domain indicates healthy vegetation. Similarly for land surfaces in general whatever be the soil, urban settlements or vegetation etc, reflectance in NIR tends to be slightly higher than reflectance in red band and hence for normal surfaces NDVI value will be positive, more than 0.

For clear deep water bodies, the reflectance in red band will be slightly higher than the reflectance in NIR band. Similarly for snow, reflectance in red band will be higher than reflectance in NIR band. For such features NIR will be negative. So, negative NDVI most likely will indicate water bodies. And also lower values of positive NDVI that is say between 0 to 0.2 or 0.25 typically indicates barren dry soil or even sometimes wet soil. But in general for soil, based on the moisture content within the soil, the values of NDVI may be changing from 0 to 0.2 or 0.25.

For pixels contaminated with cloud cover that is let us say one pixel is here, pixel number 1 there is another pixel 2 some other pixel 3 and 4. So single cloud is kind of distributed across 4 different pixels. So, due to the presence of cloud here, the reflectance between land surface here and the cloud will be totally different and for such mixed pixels the NDVI value will be either negative or in the range of 0 to 0.2 on the positive side. So, by looking at the NDVI number or the value of NDVI we will be in a position to tell at least to some extent the condition of vegetation in that particular pixel or that particular area.

NDVI is one of the most widely used spectral index to monitor vegetation and due to its high correlation with vegetation health, NDVI has been used in several applications related to vegetation monitoring starting from understanding vegetation cycle, seasonal cycle of vegetation, getting crop yield, monitoring vegetation stress etc. For various applications NDVI is being used and there are thousands of published journal articles available which will tell us the use of NDVI.

Most of the remote sensing agencies produce NDVI values or NDVI images on an operational basis. For example from MODIS sensor we will be getting daily values of NDVI, 8 day aggregates of NDVI, monthly values of NDVI at different spatial resolutions. So, these products are produced operationally. That is first they will take the satellite DN, convert it into radiance, do some sort of atmospheric correction and then finally calculate NDVI and give it to us. So, as an end user we can just directly download the data and use it. Similarly even if you take Indian sensors, NDVI products are commonly available on operational basis for us to download both from satellites in geostationary orbit as well as in near polar orbits. So, it is one of the most widely used and widely produced products in remote sensing.

Then the next index what we are going to see is known as the normalized difference moisture index or otherwise known as normalized difference water index. So, the NDVI that we have seen is highly correlated with vegetation health as it is related to NIR and red reflectance. And while we discussed the spectral reflectance property of vegetation, we came to know that the reflectance in visible bands green, red and blue is highly controlled by chlorophyll absorption. So, any change in chlorophyll activity or the amount of chlorophyll present in the vegetation will change red reflectance which will in turn change the NDVI value.

So, NDVI is highly correlated with the amount of chlorophyll and how healthy it is. Because we know that for a change in NIR to occur, the cells internal structure itself should be modified or destroyed. Then only reflectance in NIR will drastically come down and that will take a long time. But first thing whenever a vegetation undergo some sort of stress after say few days of stress occurrence maybe the chlorophyll activity may decrease or the amount of chlorophyll may decrease and photosynthesis will go down. All these things will happen which will eventually increase the red reflectance. We have seen it. So, most likely any change in NDVI value will first tell us some information about the chlorophyll activity present in the leaf. But let us say some water stress is occurring today. So, for this water stress to translate into a change in the red reflectance or a change in the chlorophyll activity it may take at least some time maybe in order of few days. Then only there will be a change in the chlorophyll activity.

So, there is always like some sort of time lag between stress occurrence and its effect on the chlorophyll concentration within the leaf. But if we want to monitor the water stress in vegetation immediately, then we know that short wave infrared band SWIR is one of the band where any change in leaf water content will be immediately reflected as change in reflectance. Higher the water content, lower will be the reflectance.

So, taking this particular clue in the year 1996 Gao developed a new index called NDWI, normalized difference water index or otherwise known as NDMI normalized difference moisture index. The equation for this particular index looks like below.

$$NDWI = \frac{\rho_{nir} - \rho_{swir}}{\rho_{nir} + \rho_{swir}}$$

So, here we are replacing the red band with the reflectance in SWIR bandwidth. So, what will be the use of it? So we know that for a healthy leaf with high water content we call that leaf as turgid. So, if the leaf is healthy and turgid, its NIR reflectance will be pretty high and its SWIR reflectance will be pretty low. And when we combine these two as a difference ratio, then the NDWI value will be high. Similarly as the water content in the leaf decreases then the reflectance in SWIR will increase leading to a decrease in NDWI. So, this suggests for healthy and turgid vegetation the

NDWI value will be quite high and as the water content in the leaf decreases the reflectance in SWIR will increase leading to a decrease in NDWI.

This also will vary between minus 1 to plus 1 because again we are bounding it and higher values of NDWI signifies healthy as well as vegetation with high turgidity that is with high water content. So, in addition to NDVI it gives more information about leaf water content. So, when this was developed, Gao said it is not a replacement for NDVI but it can act or add along with NDVI to provide more information about the vegetation.

And when compared with NDVI it can quickly respond to vegetation water stress. As soon as vegetation water stress occurs, the reflectance in SWIR band will change leading to a change in NDWI. So, it can help to identify water stress pretty quickly in comparison with NDVI. So this is not like one of the most widely developed or used product. Even though it has like lot of potential applications, most of the sensors which was launched sometime back they did not have this SWIR band. Most of them concentrated on visible and NIR bands. Only recently in the last few years almost all the sensors are equipped with SWIR band. So, due to this factor this index has not gained that popularity. But it has lot of potential in monitoring vegetation.

Most of the satellite agencies give us processed surface reflectance value. From MODIS we can get surface reflectance, from Landsat we can get surface reflectance and once we have the surface reflectance we can just take the reflectance values from the corresponding bands, put it in this equation and calculate NDWI and use it for our applications.

The definition of NDWI normalized difference water indexes prone to some sort of confusion. Like in the same year 1996 one more definition of NDWI was given. So, that definition reads something like this.

$$NDWI(waterbody) = \frac{\rho_{green} - \rho_{nir}}{\rho_{green} + \rho_{nir}}$$

So, the primary aim of giving this definition is to identify open water bodies. When we discussed about the spectral reflectance nature of water bodies, I told you that NIR band is most suitable for identifying the border between land and water bodies. Water absorbs almost all NIR wave length and land will reflect good amount of NIR wavelength.

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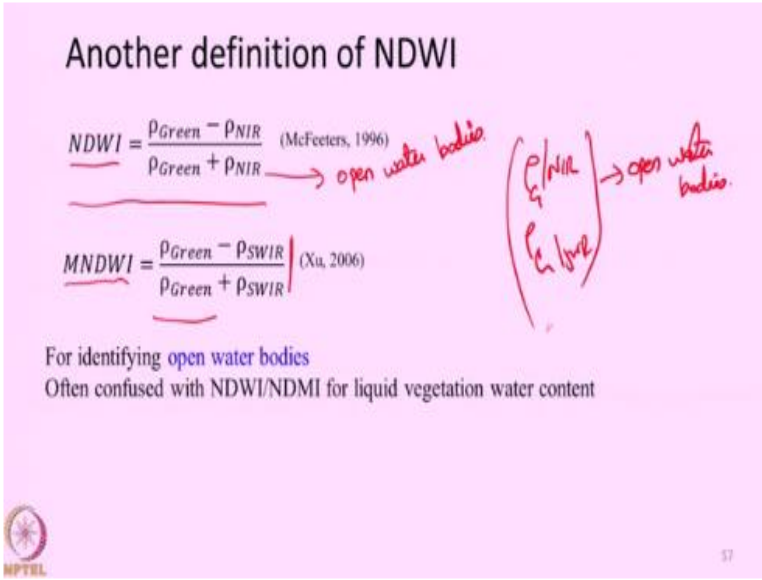

At the same time green will be slightly reflected by water bodies which means green reflectance will be higher and NIR reflectance will be lower. Taking this particular character MacFeeters developd this particular index for mapping or identifying open water bodies in a remote sensing image. So, this is also unfortunately has been given the name of NDWI, normally difference water index.

Similarly Gao, when he developed the vegetation index he also named it as NDWI. So, this is causing major confusion even today. Even, if you look at some papers the same term NDWI may be used in one paper to denote open water body and in one paper to denote vegetation liquid water content. So, we always have to ensure caution when we read NDWI and we always have to look for the equation for which it is being used. So if it contains green and NIR band or a modified definition with green and SWIR band then it is primarily used for monitoring or mapping open water bodies. But if it uses NIR and SWIR bands in combination, then it is for monitoring vegetation water content. We should be really clear, Are we going to use this index for mapping or monitoring vegetation water content? or Are we going to use it for identifying open water bodies? With our applications, the definition of NDWI will change. That is the reason why in the previous slide I coined two terms NDWI or NDMI. So, in order to avoid confusion some authors in the remote sensing domain prefers to use the term NDMI normalized difference moisture index for the one used for monitoring vegetation water content that is NIR and SWIR combination. So, potentially you can avoid combination by calling vegetation index as NDMI but the original name given by the authors who developed it is NDWI for both the indices for both monitoring water bodies and also for monitoring vegetation liquid water content. So these two indices combining green and NIR or green and SWIR, this particular combination ratio is helpful for identifying open water bodies and this particular index has nothing to do with monitoring vegetation or vegetation water content.

We just saw that NDVI is one of the most widely used index and is used in various applications related to vegetation and its monitoring. But whether NDVI is only controlled by vegetation chlorophyll activity or will something else change the values? Two important factors we need to consider when we use NDVI for different applications. The first thing is the soil background effect. When we studied about the spectral reflectance property of vegetation, I told you that when a remote sensing sensor observes vegetation, it will not only see the leaf, it will also see other non-leafy parts of a tree like stems, branches, flowers etcetera and in addition it will also see the soil.
And we will get a integrated signal of all these things in a remote sensing image. This will cause a major change in the NDVI value that we calculate from the images. So, a very good example of influence of soil is given in this particular slide.

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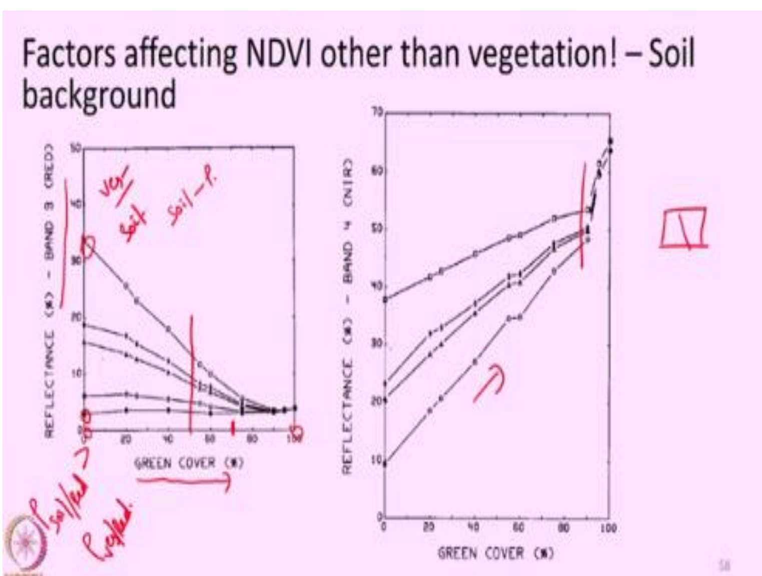

So, here if you see on the x axis percentage of green cover in a particular plot is given. So, what fraction of particular pixel is covered by vegetation that is given by the percentage green cover. On the y axis we have red reflectance. We know that for a very healthy vegetation reflectance in red will be quite low but if the pixel has mix of vegetation and soil then the reflectance may be higher.

Because soil reflectance in red band is generally higher than reflectance from vegetation in the same red band. So, when we have a mix of soil and vegetation then definitely the integrated effect will be seen. So, 0% green cover means it is bare soil, 100% green cover means the entire pixel is covered with vegetation, we are not able to see any soil in between. If that is the case you can see red reflectance is quite high for 0% green cover.

And then it decreases and only after crossing say 60 or 70% vegetation cover everything converges. So the difference between different fields or different moisture content, that is each line here corresponds to different crop type or different soil type with different moisture content. So, there are lots of differences in this. So, there are lot more other factors that will influence soil reflectance including moisture, its chemical composition, etcetera.

So, the difference in soil types and the moisture content will influence the red reflectance and this effect will be quite large when the pixel is composed of both soil and vegetation. For example, let us take these two curves here. Let us assume the vegetation is exactly one and the same and almost in same condition. The major difference between the curve is due to just because of background soil effect and the change in moisture content of soil. So, similarly if we observe in NIR band, the same thing will happen for healthy vegetation. So, here the trend of this curve is in opposite direction towards the red reflectance. So, until we cross that 80% or some very high percentage of green cover we are seeing a large effect of soil reflectance here basically.

So, these two curves tell us in a mixed pixel which contains both vegetation and soil, the influence of soil background will be quite high in changing the NDVI value. So, the basic reflectance of soil, the presence of any water in the soil all these things will change reflectance. And hence the NDVI value changes to a significant extent and this effect is highly pronounced in mixed pixels where soil and vegetation are intertwined with each other.

If more than 80% in the pixel is vegetation cover, then the background effect will reduce. We will get signals from pure vegetation. So, removing the soil background effect is one of the primary needs that was identified in the earlier days.

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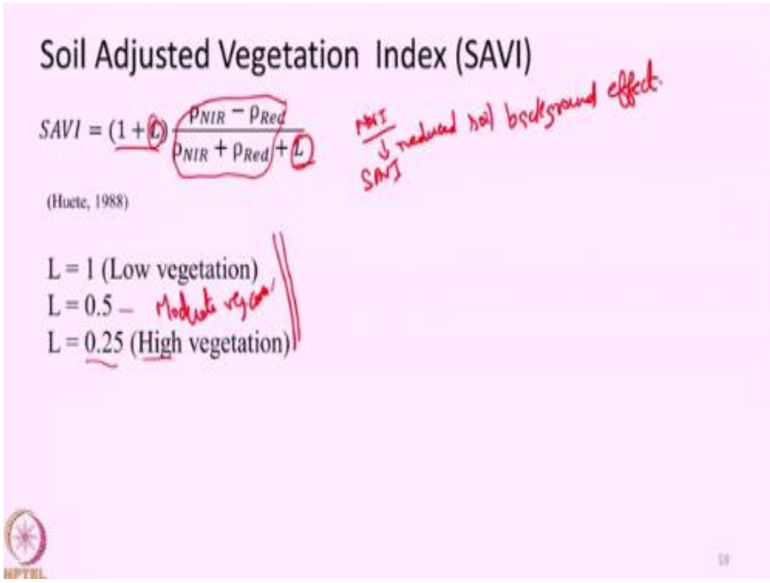

So, in the year 1998 Alfred Hewett came up with a new index what is known as a soil adjusted vegetation index, SAVI. The main aim of developing this particular index is to remove the effect of or at least reduce the effect of soil background from vegetation. So, in the original paper there was a clear explanation and a simple demonstration of how this index being derived from NDVI.

It is actually a modified index from NDVI but we are not going into the finer details about how this is derived. But the general equation of SAVI is something like this. Here you have two terms 1+L and L where the L takes different values based on vegetation cover. So, L will be 0.25 for high vegetation covered and L will be 1 for low vegetation covered.

And it will be 0.5 if we do not have any other information or for moderate vegetation cover. So, the introduction of this particular L term was able to reduce or remove the effect of background soil in NDVI. So, SAVI is nothing but NDVI with reduced soil background effect. So, now we may not know when we want to work like some unknown remote areas for our applications for our projects we may not know about the nature of vegetation present there. So, in general the threshold commonly used is 0.5. So, we can use

$$SAVI = (1.5)\ \frac{\text{NIR}-\text{red}}{\text{NIR} + \text{red} + 0.5}$$

So, this will give us the information about SAVI which will remove or at least reduce the effect of background soil. Apart from this atmosphere also plays a major role in changing the NDVI, like when we discuss the effect of atmosphere and spectral reflectance we have seen atmosphere in many different ways can change the reflectance values or radiance reaching the sensor. So, if we do not do proper atmospheric correction while we derive the surface reflectance and then we calculate NDVI then that final derived NDVI will change a lot. So, an example for this is given this particular slide.

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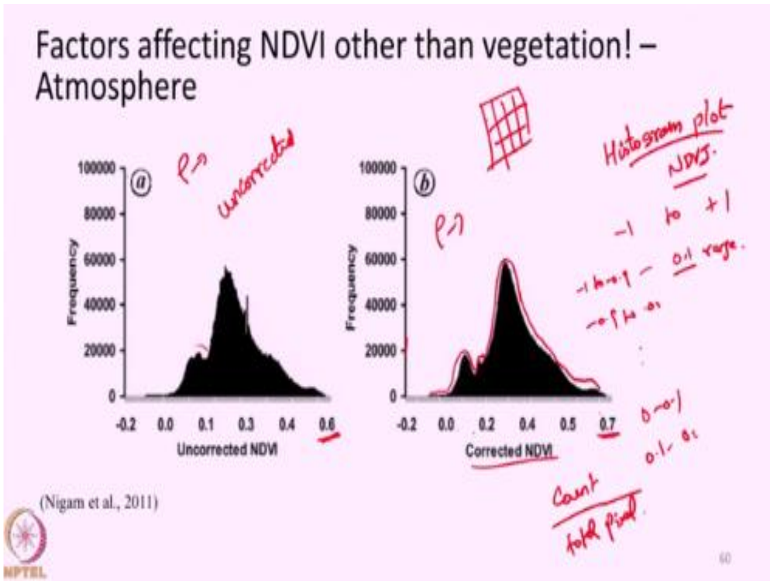

So, here on, we have what is known as a histogram plot for NDVI values. Say we have NDVI values ranging from minus 1 to plus 1. We divide them into different bins say minus 1 to minus 0.9, minus 0.92 0.8 and so on and then 0 to 0.1, 0.1 to 0.2 etcetera. We divided into different bins of say point one range. Within the each bin we will count how many pixels are there? Say 1000 pixels are there between values 0 to 0.1, 500 pixels are there in the range between 0 to minus 0.1 and so on. So, here we will plot each bin on the x-axis and the count of the pixels in the y-axis. So, if we plot them the bin values and the count, we will get a figure what is known as a histogram. So, the histogram will tell us about how the values are distributed within any given image. So, in image processing of remotely sensed data histogram analysis is one of the most important thing. But since this course does not deal with image processing, we are more interested in understanding the physical concepts of remote sensing, we are not going into detail about image processing details. But histogram analysis is widely used.

So, in this particular slide we have histogram of NDVI values from the same image. But on the left side we have uncorrected for atmospheric effect. That is the reflectance data is obtained without doing atmospheric correction and on the right side we have the reflectance values after doing atmospheric correction. So, here we can see there is a considerable change in the NDVI values like here the peak value itself is 0.6 here the peak value is 0.7. And here the maximum frequency occurs something around close to 0.4, here it occurs something differently and there is change in position here, all these things will happen. So, in general not doing atmospheric correction will change the value of NDVI. So, it is always suggested to do or calculate NDVI from properly atmospherically corrected surface reflectance. We may not have enough data for doing atmospheric reaction. But whatever is possible we should do correct the effects of atmosphere and then calculate surface reflectance and use it for estimating NDVI for our application.

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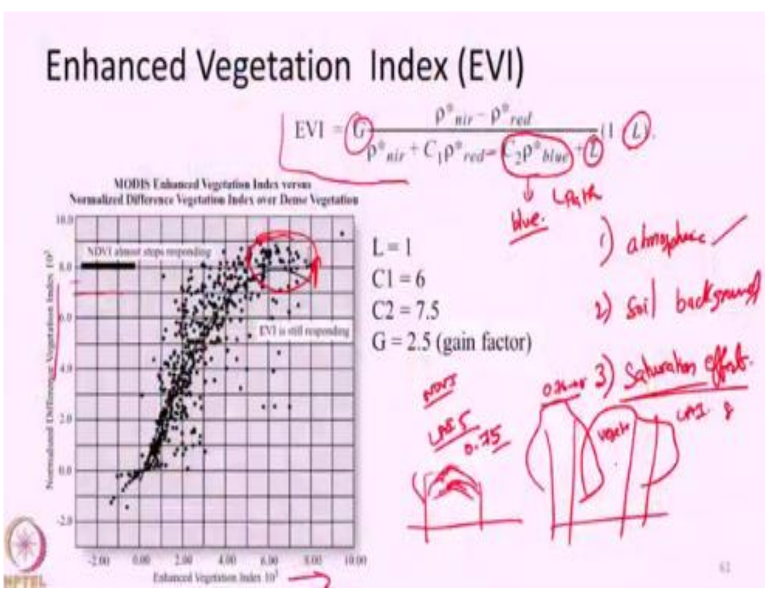

Then comes another important and widely used vegetation index called enhanced vegetation index, EVI. So, EVI was developed when the sensor MODIS was launched. It was primarily developed for MODIS sensor in the year 1999. So, the EVI is like a combined index we can say, it was designed to reduce three effects, one is to reduce atmospheric effect, two is to reduce soil background effect and three is to reduce saturation effect. So, we will understand atmosphere and soil background effect. So, what exactly saturation effect is? let us look at this particular slide. So, here we have on the x axis EVI value and y-axis we have NDVI value. So, we are seeing both of them increase almost simultaneously, as NDVI increases, EVI increases almost. But after certain range say after this particular range of 0.7, NDVI kind of becomes horizontal. If you look in the y axis, it stops increasing and becomes almost like horizontal. So, only EVI is increasing now, NDVI has almost stopped increasing after it reached threshold of something around 0.7 or 0.8. This is because NDVI is related to chlorophyll content we know that. So, as vegetation becomes more dense and dense, NDVI will keep on increasing. But after certain limit of this chlorophyll or after certain limit of this vegetation growth NDVI will saturate and it will not increase anymore.

so let us remember the concept of LAI, leaf area index. The amount of or the area of leaf content in one square meter area. So, this LAI can vary a lot maybe 0 for bare soils and sometimes even say 8 or 10 for healthy dense forest. So, after a certain value of this LAI say 5 or 6 values, NDVI values will saturate. It will not increase. But sometime dense forest may have LAI close to 8 or 9. Very high amount of leaves in one square meter area which signifies large amount of vegetation is present in that particular range. So, technically speaking the NDVI value for crop fill should be less than the NDVI value for the dense forest. But it may not happen, NDVI will saturate and then it will remain more or less constant. Let us say this is a crop land whose leaves became dense and completely close the soil. Soil is not at all visible. Here let us say LAI is five. Now here we have a dense evergreen forest complete canopy closure LAI is 8. So for the cropland itself, NDVI may become close to 0.75. And if you look the evergreen forest, NDVI something around say 0.76 within 0.8 not much changes even though there is a very high amount of change in amount of leaves percent or amount of chlorophyll activity that is happening. This is known as saturation effect. After certain amount of leaves or amount of vegetation content, NDVI will saturate, it will not increase beyond certain value that is what given in this particular figure on the left side. After crossing a threshold of 0.7 or 0.75, NDVI is almost like constant without increasing. So, in order to remove the saturation effect, people designed this EVI. So, the EVI has the L term very similar to SAVI. It uses reflectance in blue because blue band is highly susceptible to atmospheric scattering and using this blue term will help us to remove the path radiance effect as blue will carry the signals of atmosphere scattering and everything. So, we are subtracting the reflectance from blue in order to remove the path radiance effect. Similarly we have this gain factor g in order to improve the sensitivity of EVI for high vegetation. So, if you look EVI for this cropland and dense rainforest, we will see a difference. EVI for dense rainforest will be higher than EVI for this cropland with LAI 5 and LAI 8. So, this was the major application of EVI in order to improve the information content of NDVI. Again this is one of the operationally produced products from MODIS sensor and from other Earth observing sensors also, EVI is now being produced consistently. And this is also now one of the most widely used vegetation index for monitoring vegetation.

So, just before we wrap up the topic of spectral index there are like lot more other indices. We have primarily concentrated on spectral indices for monitoring vegetation. But as I said several other spectral indices are also developed for understanding various other features such as snow, for identifying burnt areas in forest fire, what area got burnt, for identifying built up areas and spectral indices exist for several of these things.

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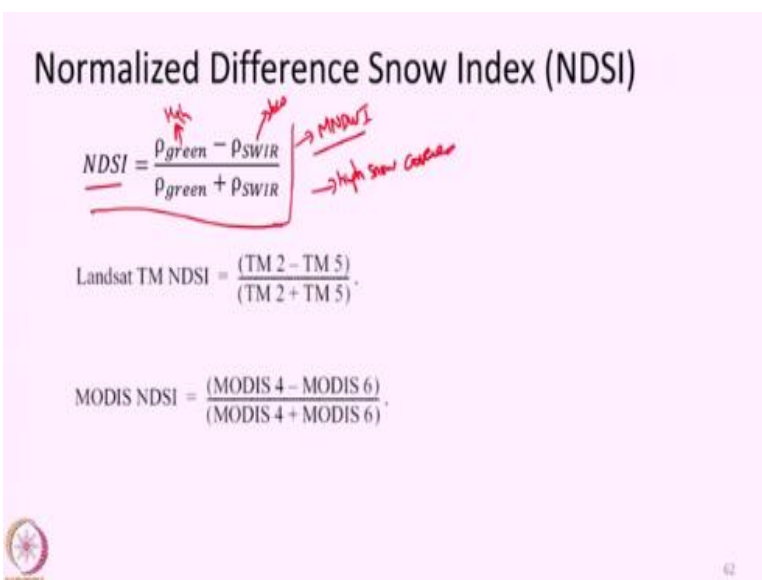

So, now we are going to see spectral index for snow known as NDSI normalized difference snow index. So, NDSI takes advantage of the reflectance property of snow in green and SWIR band. So, this is very similar to that MNDWI definition we have seen earlier green and SWIR. But when applied over snow covered conditions, reflectance in green for snow will be very high and in SWIR it will be quite low. So, high NDSI is seen in high snow covered area. And this index is also one of the widely used index for monitoring snow.

We have operational snow products from MODIS sensor and various other sensors for mapping snow cover area, for mapping snow depth, etc. So, as I said there is plenty of other indices represent but for the want of time we are not going into detail. Interested readers can look at several sources in internet where detailed information about various spectral indices exist that are being used in various applications.

So, as a summary to this particular lecture, we have discussed about some of the few commonly used spectral indices with special emphasis on vegetation. We have seen index such as NDVI, NDWI, EVI, SAVI etcetera and also we have seen a spectral index called NDSI normalized difference snow index. So, with this we complete the topic of understanding the spectral reflectance properties of materials and also spectral indices. So, from the next lecture onwards we will move ahead to a new topic of thermal infrared remote sensing, with this we conclude this lecture.

Thank you very much.