Course Name: Watershed Hydrology

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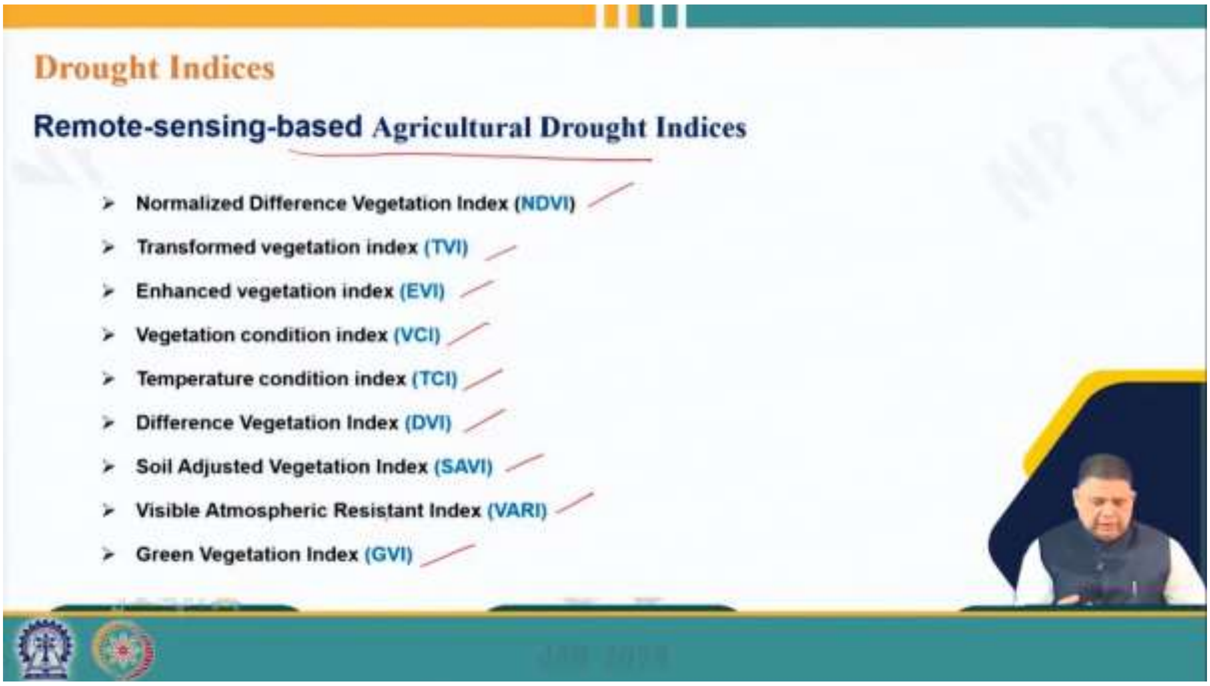
Week: 11

Lecture 54: Agricultural Drought II

Hello friends, welcome back to this online certification course on watershed hydrology. I am Rajendra Singh, Professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in module 11, and this is lecture number 4 where we will be discussing part 2 of agricultural drought.

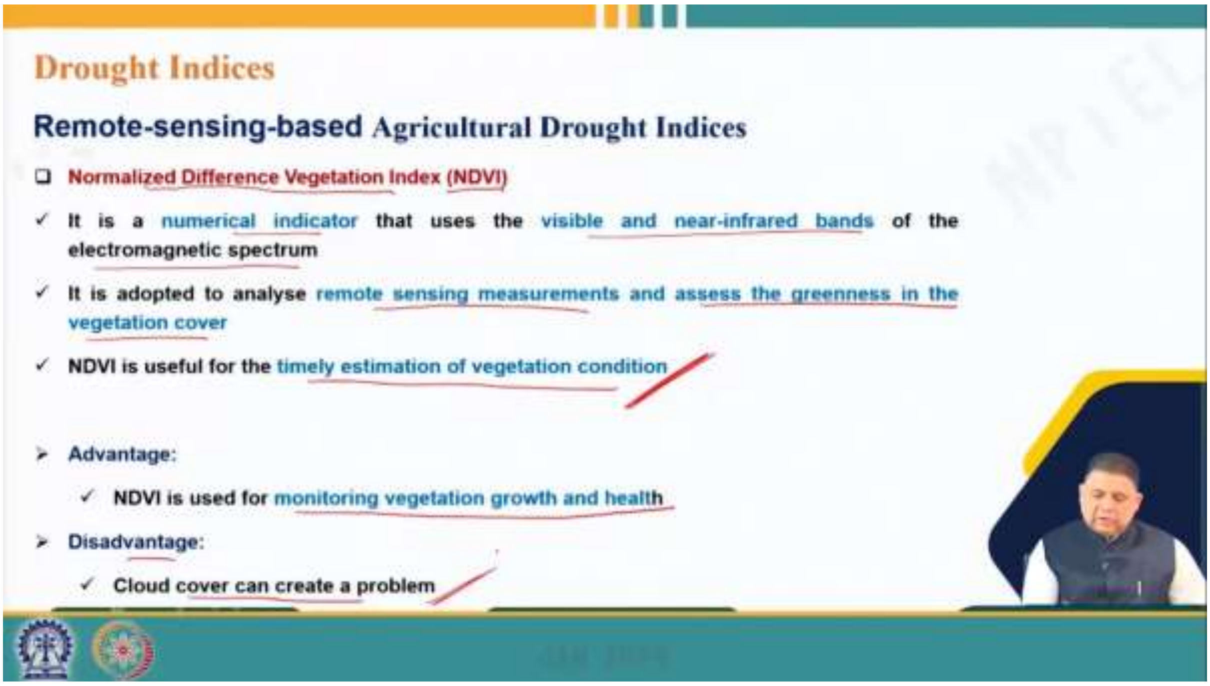
In this lecture, we will focus on remote sensing-based agricultural drought indices.

We discussed agricultural drought indices in the previous lecture, but they were not remote sensing-based; mostly, they were based on ETA and ET0. Today, we will delve into remote sensing-based agricultural drought indices, meaning the parameters or variables can be obtained directly from satellite data. These indices include NDVI (Normalized Difference Vegetation Index), Transform Vegetation Index DVI, Enhanced Vegetation Index (EVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Difference Vegetation Index (DVI), Soil Adjusted Vegetation Index (SAVI), Visible Atmospheric Vegetation Index (VARI), and Green Vegetation Index (GVI). In fact, there are many more, but I will provide definitions and details for these indices.

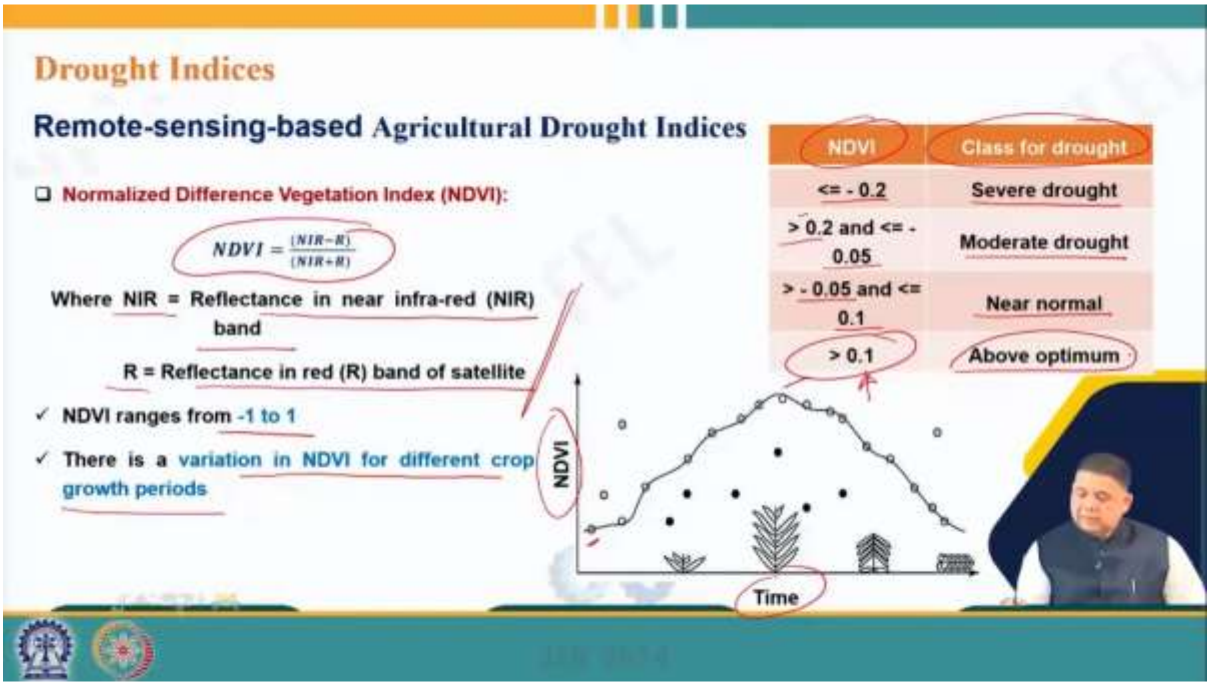


Let's begin with NDVI, which is a numerical indicator utilizing the visible and near-infrared bands of the electromagnetic spectrum, derived from satellite data. It is adapted to analyse remote sensing measurements and assess the greenness in the vegetation cover. So, basically, it gives you an idea about the level of greenness in the vegetation. It is useful for timely estimation of vegetation conditions. Based on the greenness or NDVI value, we can determine whether the plant is healthy or not. The advantages are that it is used for monitoring vegetation growth and health, serving as a good indicator of vegetation growth and health.

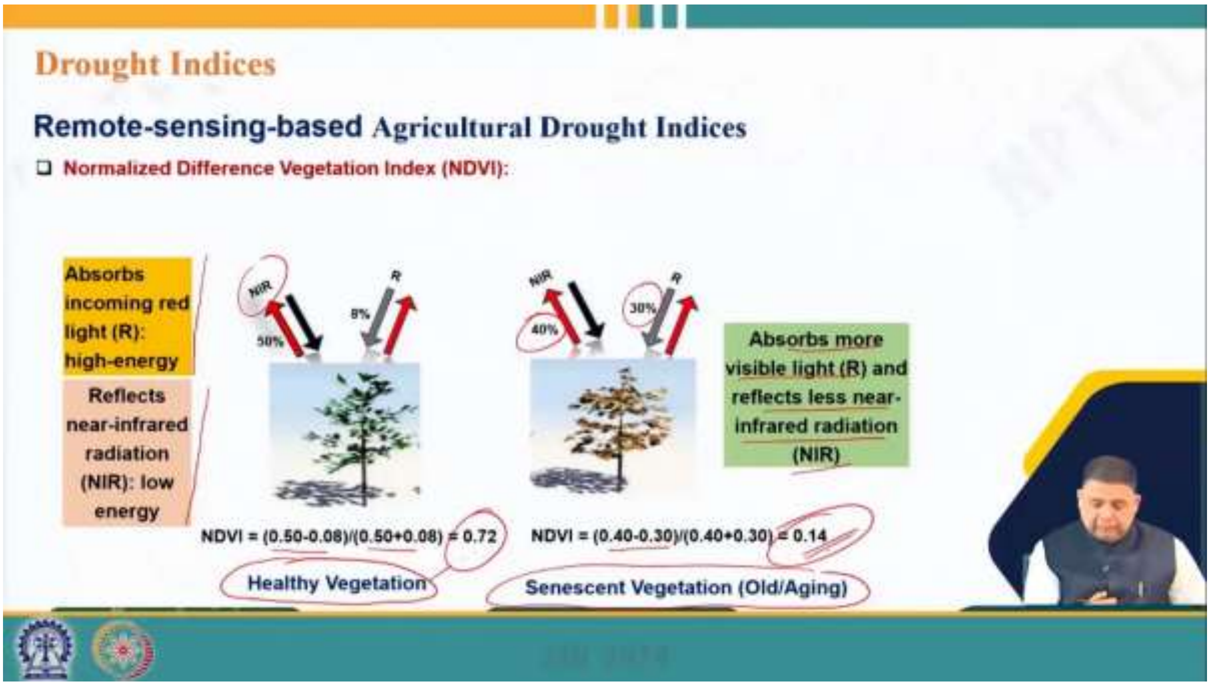
However, a disadvantage is that cloud cover can create a problem. Obviously, if there is cloud cover, you will not be able to obtain the data, thus unable to estimate NDVI. In fact, this is the drawback for almost all remote sensing agricultural drought indices.



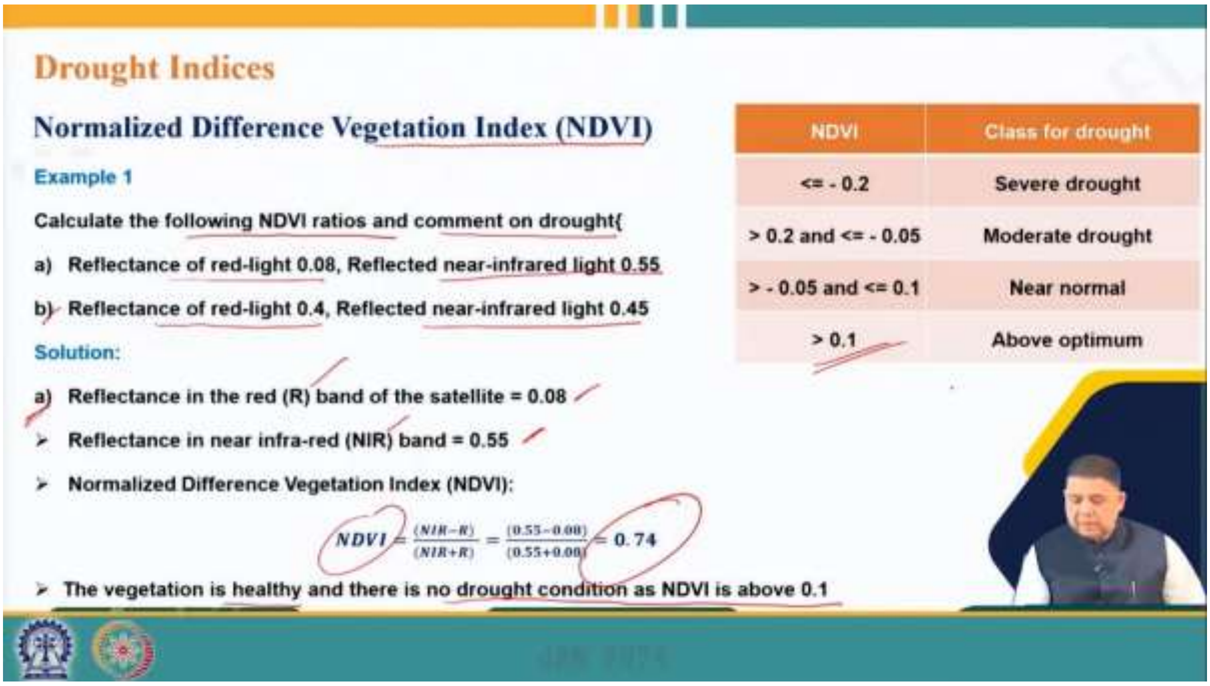
Basically, it is given by this relationship: NDVI equals NIR minus R divided by NIR plus R, where NIR is the reflectance in the near-infrared band and R is the reflectance in the red band of the satellite. So, depending on the type of satellite you are using, different satellites have different cameras and bands. Therefore, based on the satellite, you need to utilize either the NIR or red band to acquire the data. NDVI ranges from minus 1 to 1, and there is variation in NDVI for different crop growth periods. As you can see, this variation reflects the greenness. So, obviously, it starts with a low value and as the greenness increases, it also increases. But as the crop matures, meaning the greenness decreases, NDVI values also decrease. Based on NDVI, the classes of drought are defined. If its value is less than or equal to minus 0.2, then it is severe drought. If it falls between minus 0.2 and minus 0.05, then it is moderate drought. If it falls between minus 0.05 and 0.1, then it is near normal, and if it is greater than 1, then it is above optimum. So, if the NDVI value is greater than 1, then it indicates the vegetation is perfectly fine. Otherwise, there is a drought condition if the values are negative. Based on the NDVI value, you can estimate whether the crop growth is satisfactory or not.



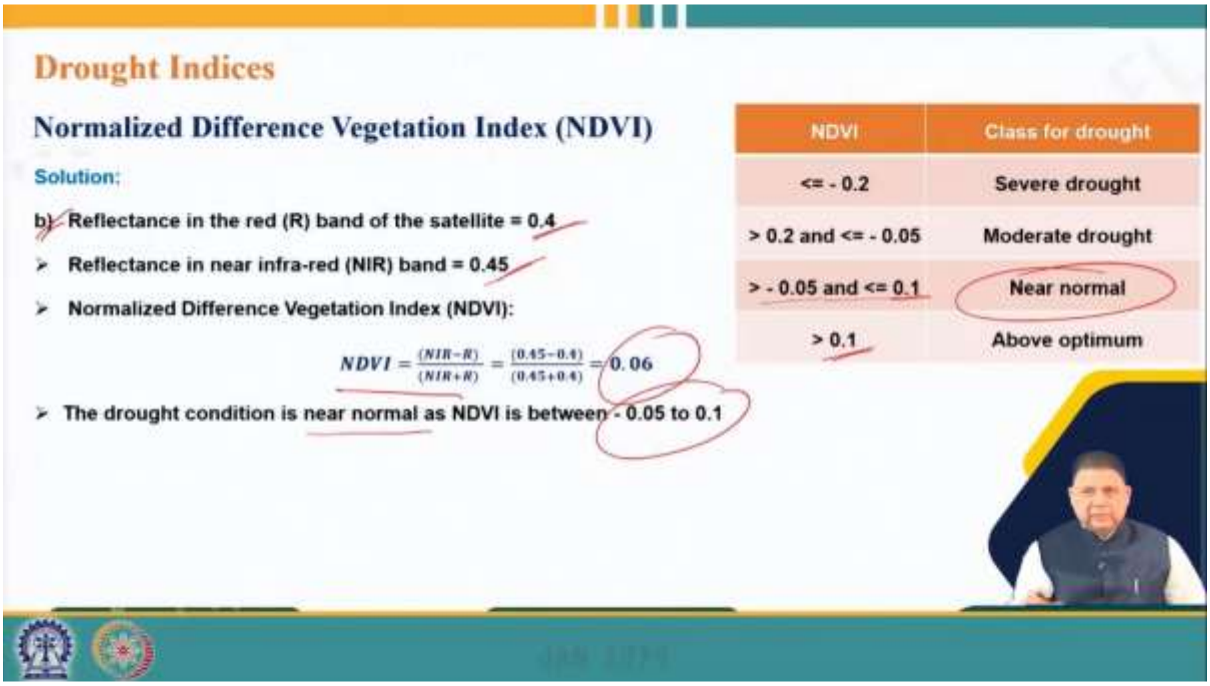
If you examine the NDVI typically for healthy vegetation compared to senescent or aging vegetation, you'll find that healthy vegetation absorbs incoming red light, which is high energy, and reflects near-infrared radiation, which is low energy. Typically, if the values are, let's say, 50 percent of NIR reflected and 0.08 of incoming light absorbed, based on this value, the NDVI comes out to be 0.72. Remember, anything above 0.1 is considered healthy according to this classification. Now, if you look at old or aging plantations, they absorb more visible light, possibly even 30 percent, and reflect less near-infrared light, maybe only 40 percent. So, the difference between these two is less, resulting in an NDVI value of 0.14. Obviously, one will indicate a green plant, while the other will show an older, aging plant. Thus, the impact of greenness can be reflected by NDVI values, allowing us to make judgments about the health of vegetation for a given location.



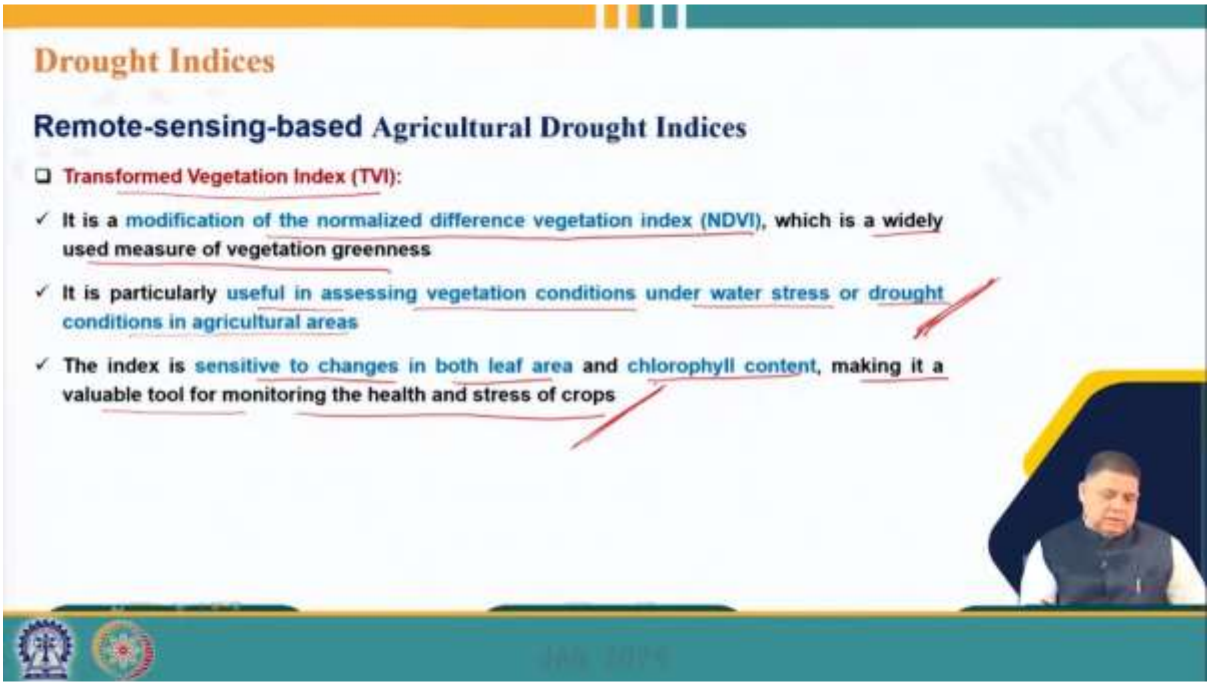
Now, let's take an example of NDVI calculation. Calculate the following NDVI ratios and comment on drought conditions: in case 1, where the reflectance of red light is 0.08 and reflected near-infrared light is 0.55, and in case 2, where the reflectance of red light is 0.4 and reflected near-infrared light is 0.45. Of course, we know that in NIR, these are the two values we focus on in calculating NDVI. In case 1, with R as 0.08 and NIR as 0.55, the NDVI comes out to be 0.74. This means it is above optimal, indicating healthy vegetation with no drought condition as NDVI is above 0.1.



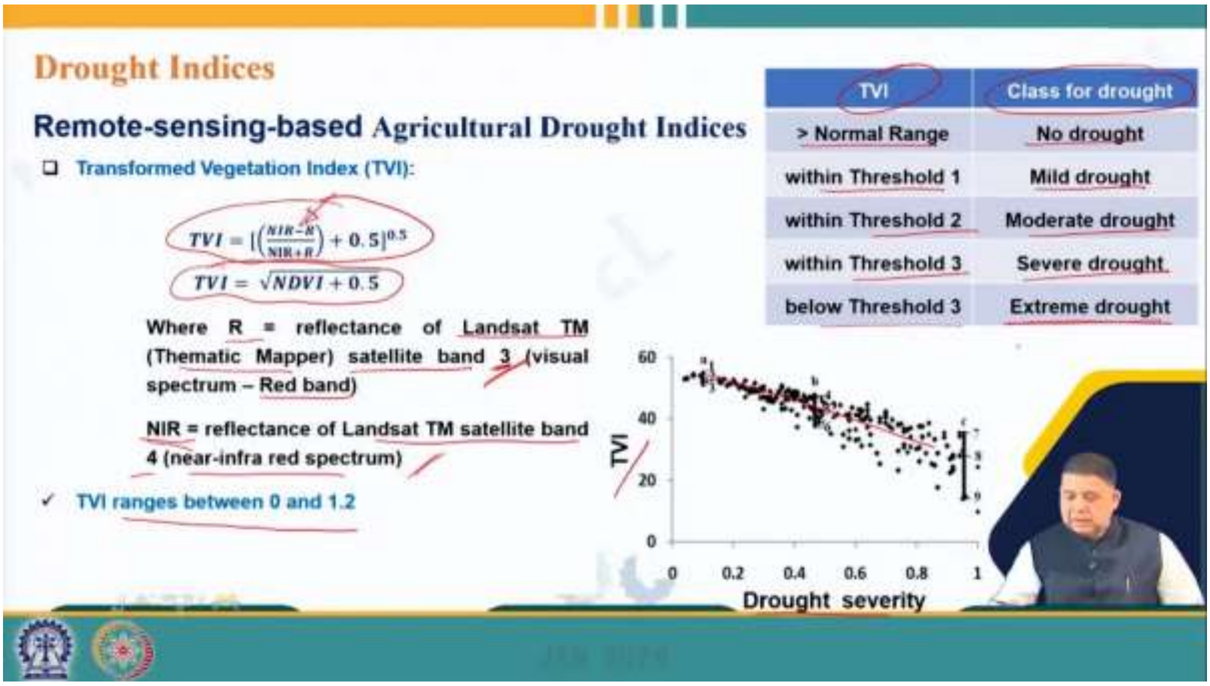
In case 2, with R as 0.4 and NIR as 0.45, the value we get is 0.06. Here, it falls between -0.05 and 0.1, indicating a near-normal condition. So, the drought condition is near normal. Although there is no drought per se, it is almost tending towards drought, being just below optimal or slightly below optimal condition, you could say. Based on R and NIR values, we can determine the NDVI value for different vegetation and make our judgments accordingly.



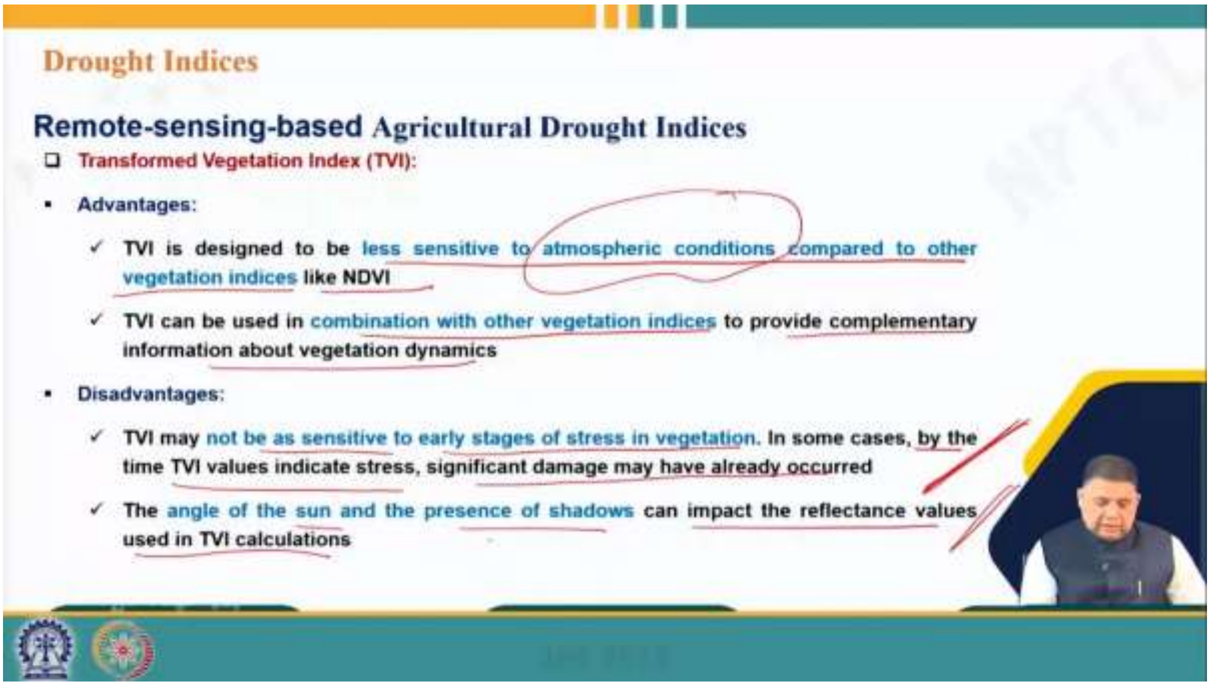
Next, let's discuss TVI, which stands for Transform Vegetation Index. It is a modification of the NDVI, which is a widely used measure of vegetation greenness and is particularly useful in assessing vegetation conditions under water stress or drought conditions in agricultural areas. So, obviously, if you notice water stress or drought conditions in an agricultural area, TVI will likely be more useful. The index is sensitive to changes in both leaf area and chlorophyll content, making it a valuable tool for monitoring the health and stress of crops. Therefore, it is considered a better indicator than NDVI, hence the term "modified NDVI".



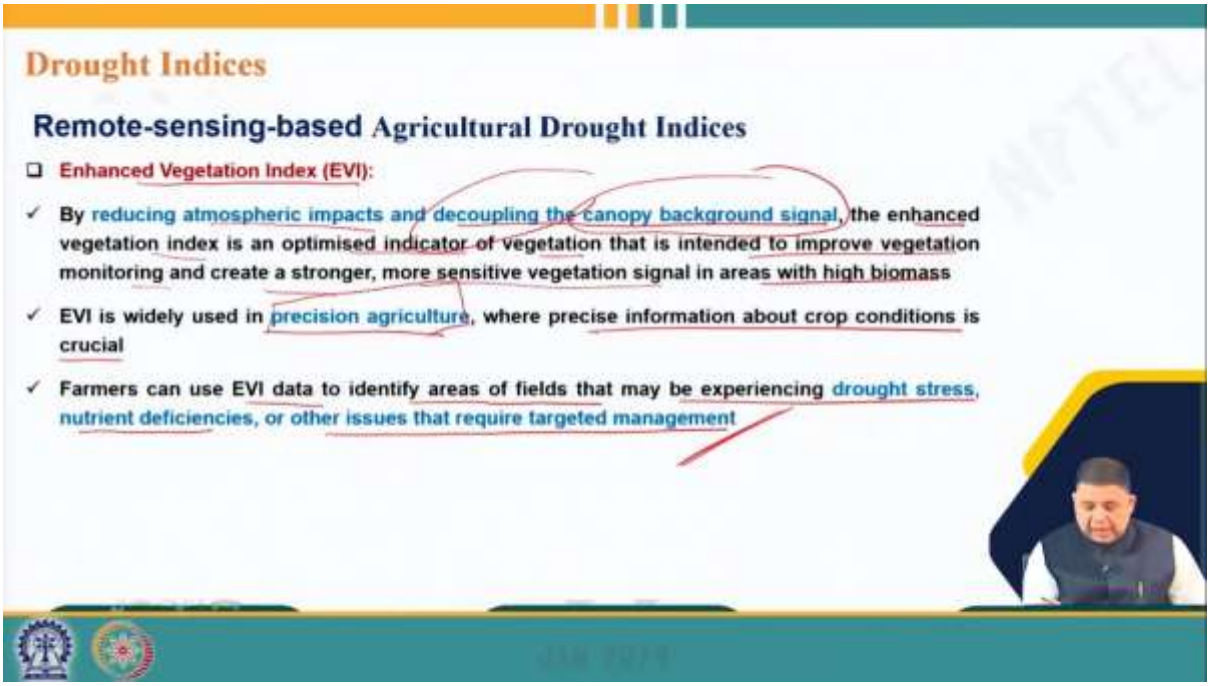
In this case, the formula used is similar to NDVI, with the addition of 0.5 and the use of the square root. Essentially, in terms of NDVI, TVI can be understood as the square root of NDI plus 0.5. R and NIR remain the same, but here it is defined in terms of Landsat Thematic Mapper Satellite Bands. Band 3 of the Landsat TM Satellite, which represents the red band, is denoted as R, while Band 4, in the near-infrared spectrum, represents NIR. So, basically, if you are using Landsat TM satellite data, which is very popular, freely available, and widely used, you need to utilize bands 3 and 4 for R and NIR, respectively, to calculate TVI. In fact, these values can also be used for estimating NDVI. Typically, TVI ranges between 0 and 1.2, indicating TVI versus drought severity. As TVI values decrease, drought severity increases. Based on TVI value, drought classes are defined as follows: if it is within the normal range, then there is no drought; if it falls within threshold 1, then it is a mild drought; within threshold 2, it's a moderate drought; within threshold 3, it's a severe drought; and below threshold 3, it's an extreme drought. So, this is how one can estimate the drought condition based on TVI values.



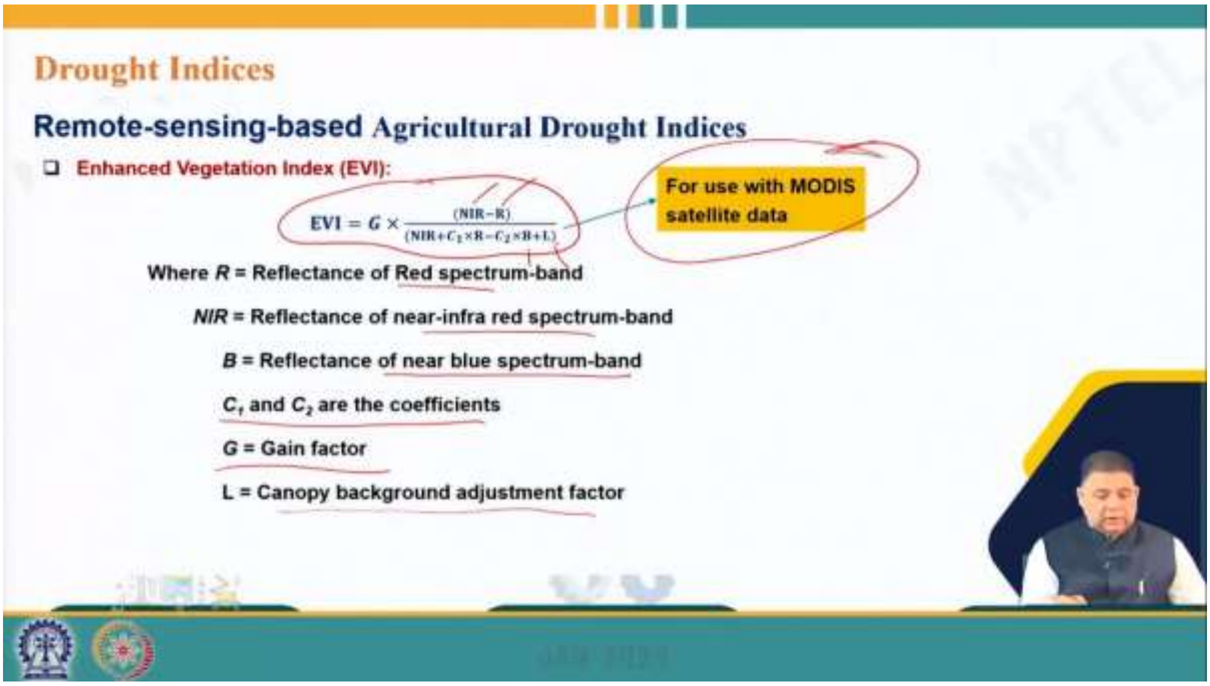
Regarding its advantages, TVI is designed to be less sensitive to atmospheric conditions compared to other vegetative indices like NDVI. Atmospheric correction is taken into account while estimating TVI. Additionally, it can be used in combination with other vegetation indices to provide complementary information about vegetation dynamics. One disadvantage is that it may not be sensitive to early stages of stress in vegetation. In some cases, by the time TVI values indicate stress, significant damage may already have occurred. So, this is a point of caution. The angle of the sun and the presence of shadows can impact the reflectance values used in TVI calculations, which is typical for any satellite-based data. However, one significant drawback of TVI is that it gives a late indication of drought onset.



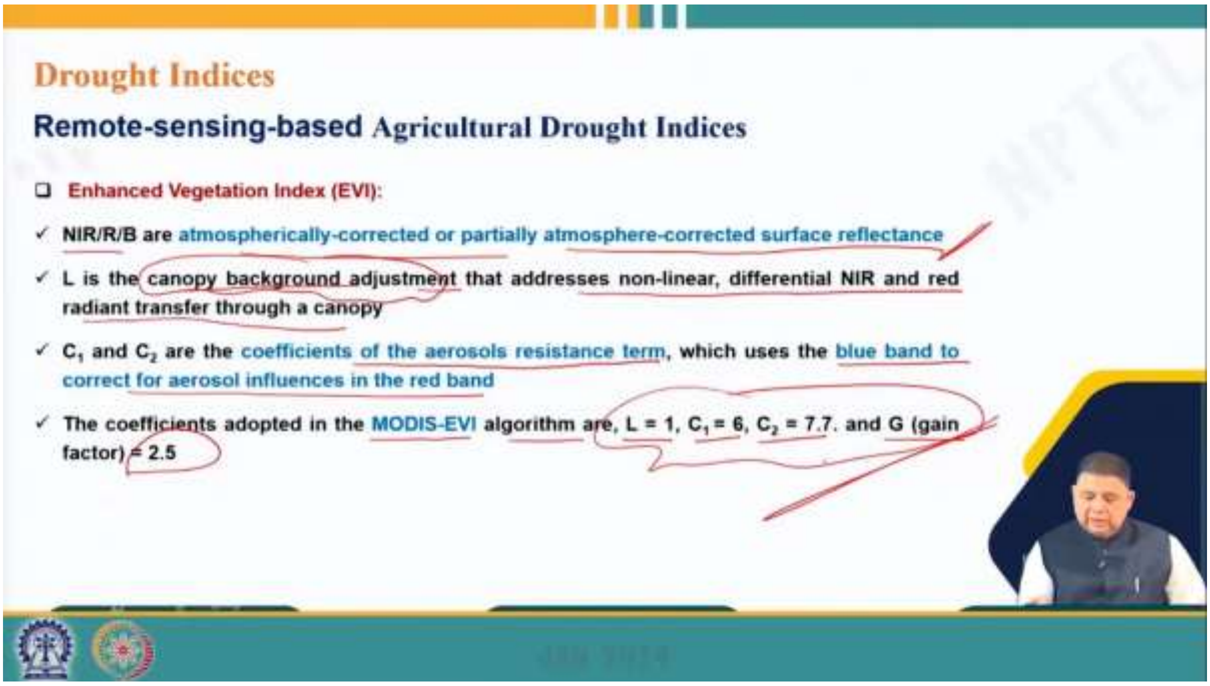
Moving on to the third index, the Enhanced Vegetation Index (EVI), it aims to reduce atmospheric impacts and decouple the canopy background signal, making it an optimized indicator of vegetation. The purpose is to improve vegetation monitoring and create a stronger, more sensitive vegetation signal, especially in areas with high vegetation density. So, basically, they all function on the same principle, with some modifications. Essentially, the canopy background signal is decoupled when calculating EVI. It is widely used in precision agriculture, where precise information about crop conditions is crucial. By removing background information, EVI provides a more precise picture, which is why it is preferred in precision agriculture where accurate information is necessary for effective management. Farmers can use EVI data to identify areas of fields that may be experiencing drought stress, nutrient deficiencies, or other issues that require targeted management. In fact, because it is precise, within or among fields, it can provide insight into drought stress, allowing for precise management procedures to be adopted to address the issue.



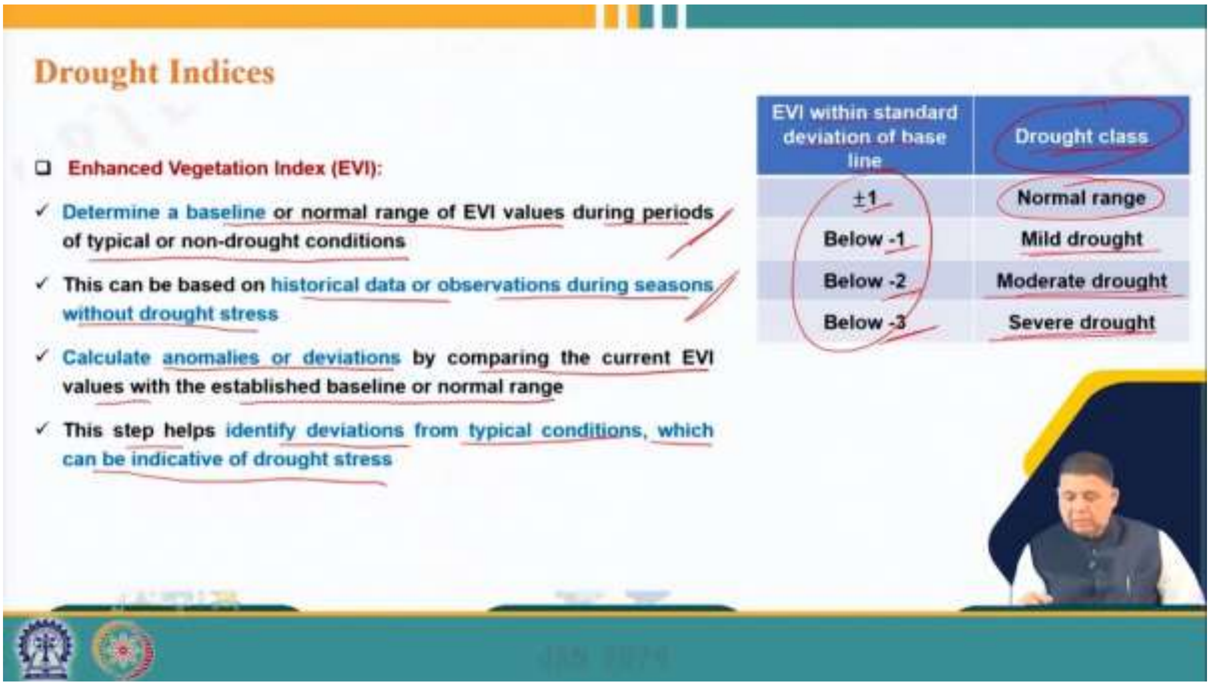
EVI is calculated using a relationship specifically designed for MODIS satellite data, which we discussed earlier. MODIS provides free satellite data commonly used by researchers. In the calculation, NIR and NR represent the red spectrum and near-infrared spectrum, respectively. Additionally, B represents the reflectance of the near-blue spectrum band, while L accounts for canopy background adjustment. Coefficients C1 and C2, along with G as the gain factor, are utilized in EVI calculation, making it a more precise remote sensing-based agricultural drought index.



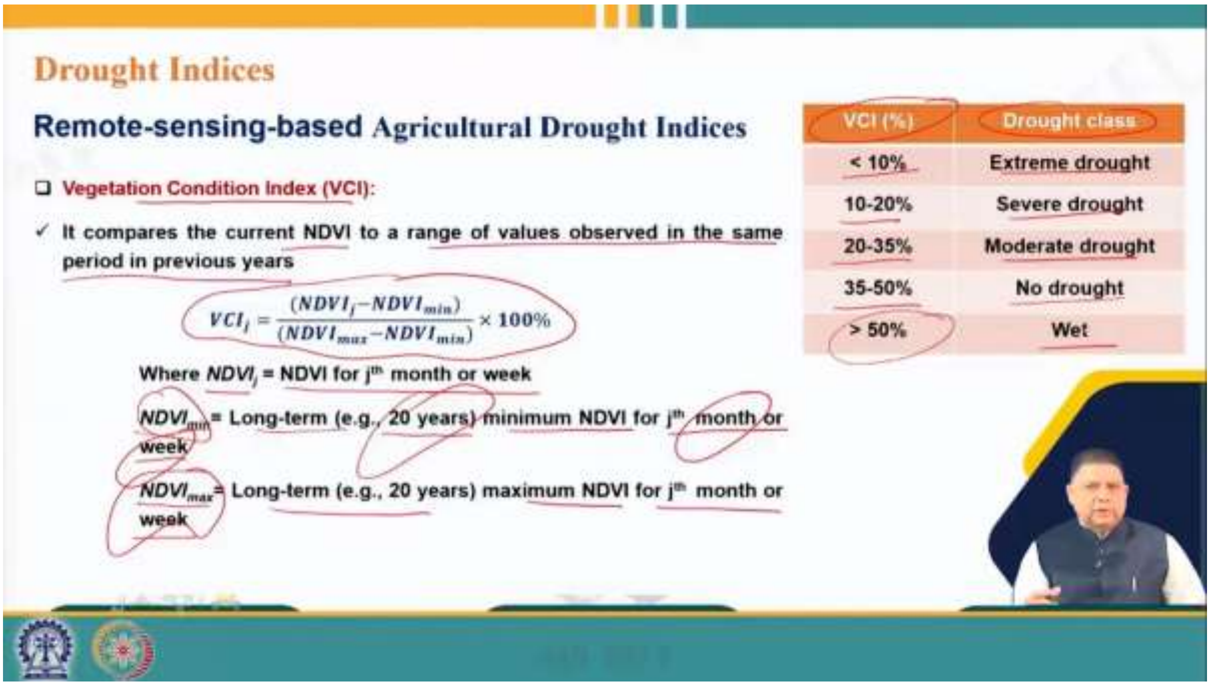
NRI, R, and B are atmospherically corrected or partially atmospherically corrected surface reflectances. L represents the canopy background adjustment, which addresses non-linear differential NIR and red radiant transfer through a canopy. This adjustment ensures a more precise indicator of vegetation health. Coefficients C1 and C2 are part of the aerosol resistance term, using the blue band to correct for aerosol influences in the red band. So, of course, the red band data is also corrected for precise estimation of the vegetation index. The coefficients adopted for the MODIS EVI algorithm are as follows: L is 1, C1 is 6, C2 is 7.7, and G is 2.5. Therefore, when using MODIS data and the equation, these coefficients are already assigned values. Next, if you have values for R, NIR, and B, then you can estimate EVI.



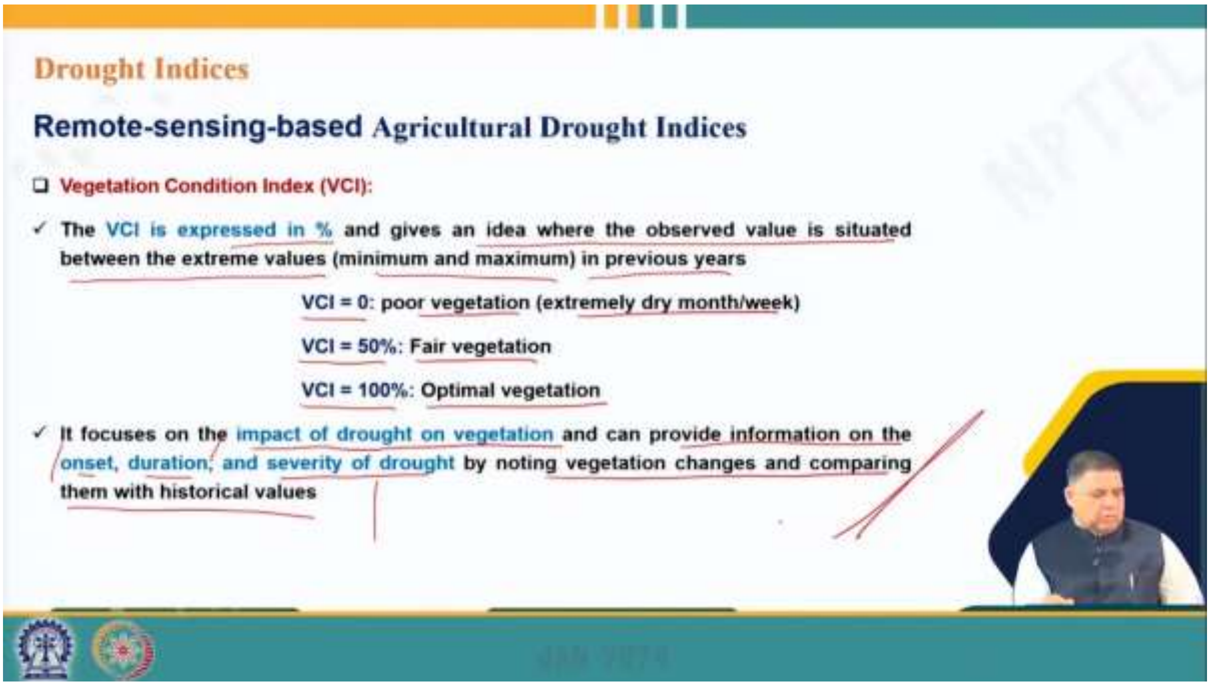
Basically, while determining EVI, a baseline or normal range of EVI values during periods of typical or non-drought conditions is established first. This can be based on historical data or observations during seasons without drought stress. So, you can either use historical data where there was no drought condition or ideal conditions were present, or you can use current season data where no drought is observed, and then develop a baseline value. Afterward, you calculate anomalies or deviations by comparing the current EVI values with the established baseline or normal range. This step helps identify deviations from typical conditions, which can be indicative of drought stress. EVI within the standard deviation of the baseline defines the drought class. If it is within plus or minus 1 standard deviation, it is considered normal; below minus 1 indicates mild drought, below minus 2 is moderate drought, and below minus 3 signifies severe drought conditions. Essentially, the standard deviation is used to define the drought class, indicating the deviation of EVI from the normal or baseline.



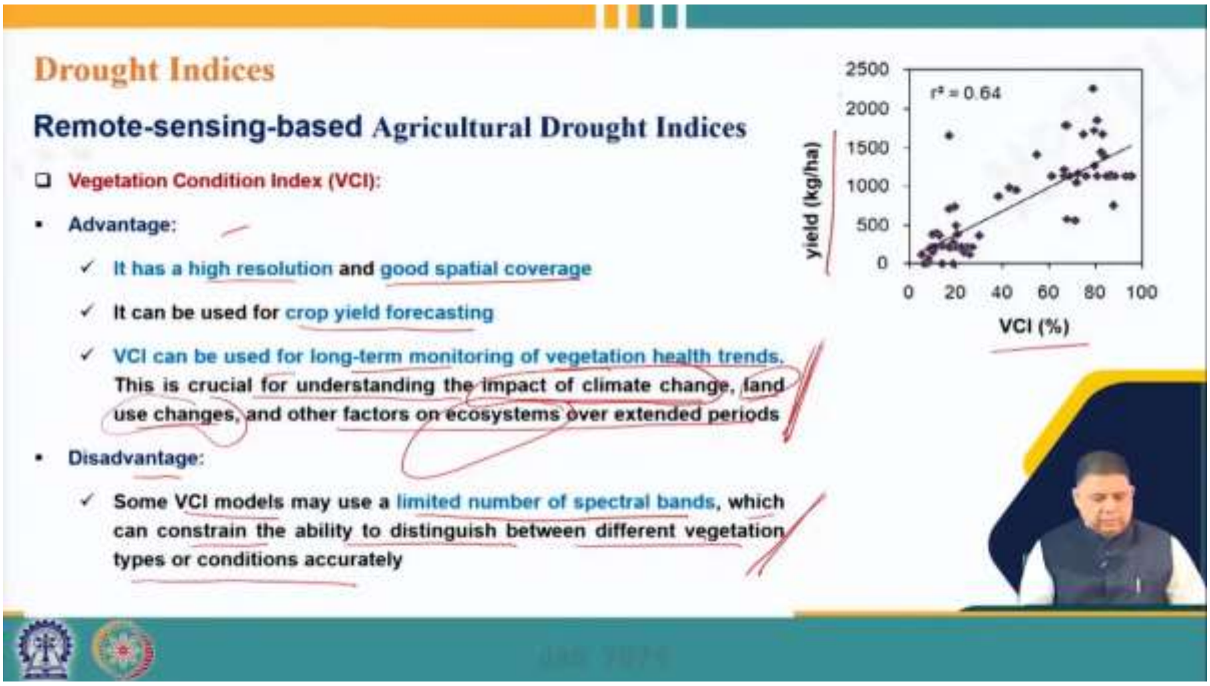
Next, we move on to the vegetation condition index (BCI), which compares the current NDVI to a range of values observed during the same period in the previous year. So, basically, it is based on NDVI values of current and previous data. The equation used for this is shown here. NDVI J minus NDVI minimum, divided by NDVI J minus NDVI max, and then multiplied by 100 to convert it into a percentage. Here, NDVI J represents the NDVI for a specific year, month, or week, NDVI minimum is the long-term minimum NDVI for that year, month, or week, and NDVI max is the long-term maximum NDVI for the same period. If you want to calculate the Vegetation Condition Index (VCI) for a particular month or week, then you obviously need long-term data, typically spanning 20 years. This helps determine the minimum and maximum NDVI values for that specific time frame, allowing you to calculate the VCI value for that particular week or month. The drought class is defined based on the percentage value. If it is less than 10 percent, then it indicates extreme drought; 10 to 20 percent suggests severe drought; 20 to 35 percent signifies moderate drought; 35 to 50 percent indicates no drought; and if it is greater than 50 percent, it suggests normal or wet conditions. Essentially, this can be considered an advanced version of NDVI, where not only the current NDVI is considered, but also the long-term historical data of NDVI, including the minimum and maximum values for the period of concern, to calculate the VCI value.



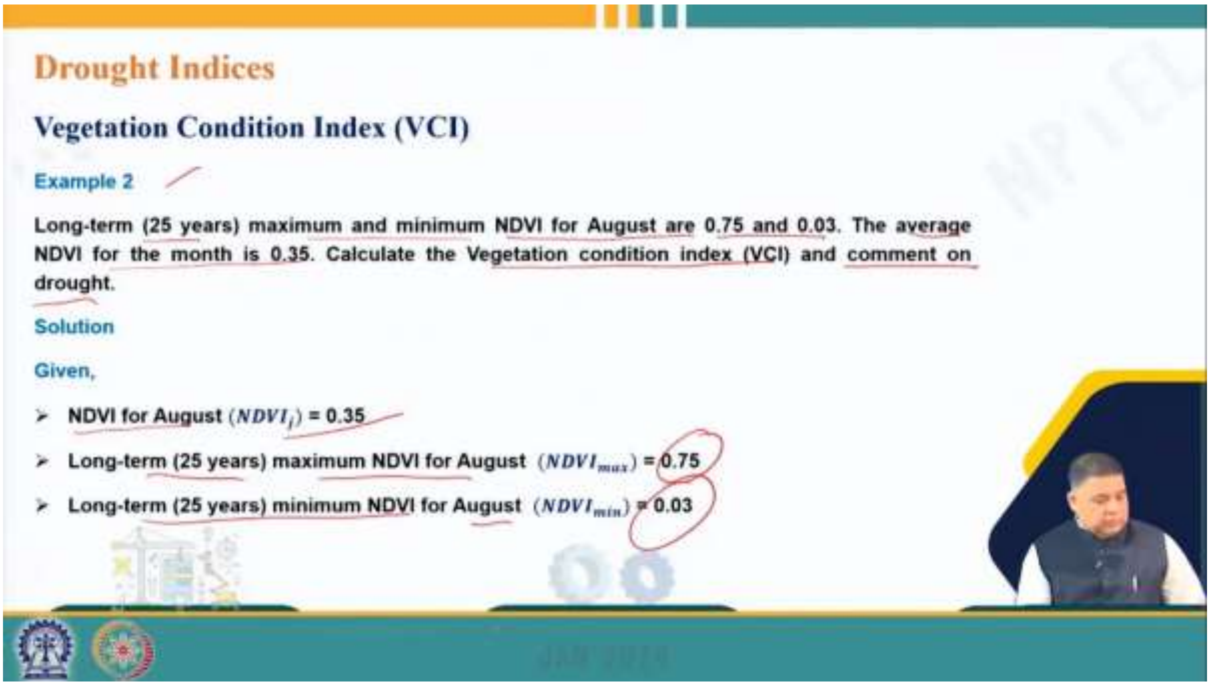
It is expressed in percentage, as we have seen, and provides insight into where the observed value stands between the extreme values of minimum and maximum from previous years. If the VCI is 0, it indicates poor vegetation health, signifying an extremely dry month. At 50 percent, it suggests fair vegetation, while at 100 percent, it indicates optimal vegetation. This provides insight into the health of plants or vegetation in a particular area. VCI focuses on the impact of drought on vegetation and can provide information on the onset, duration, and severity of drought by observing vegetation changes and comparing them with historical values. By analysing week-by-week data alongside historical data, one can gain a fair idea about the likely onset of the monsoon, the duration, and the severity of drought. All this information can be obtained through long-term analysis.



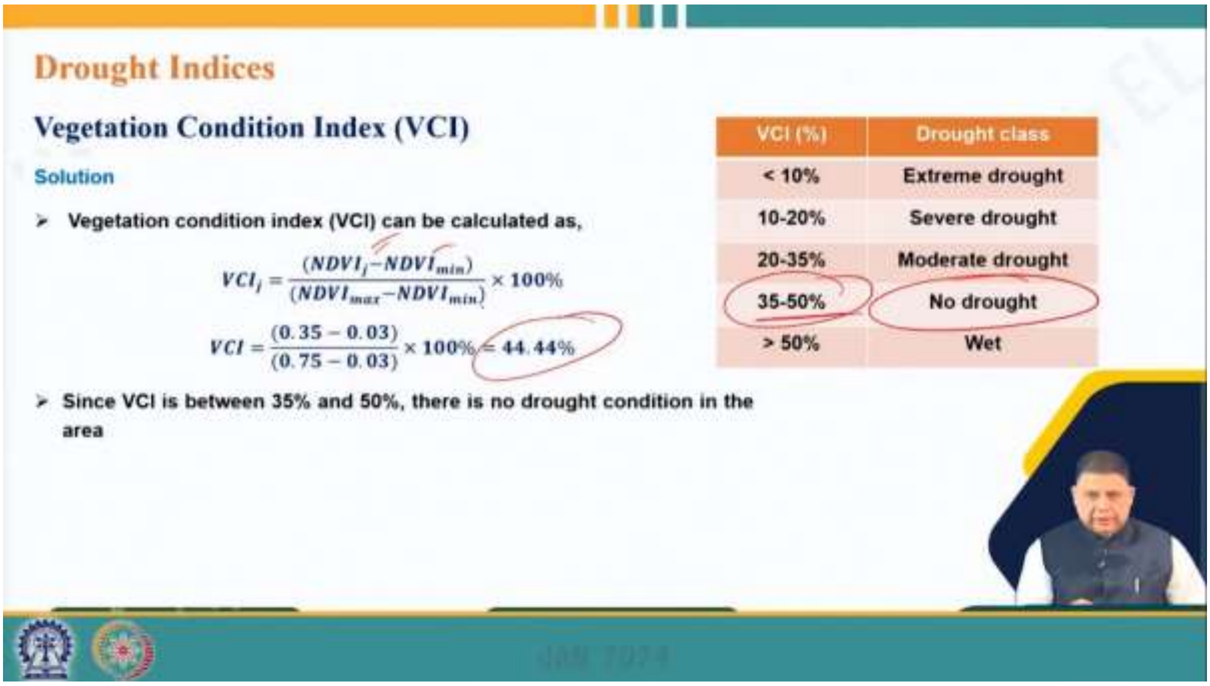
The advantages of VCI include its high resolution and good spatial coverage. It can be used for crop field forecasting and long-term monitoring of vegetation health trends. This is crucial for understanding the impact of climate change, land use changes, and other factors on ecosystems over extended periods. By analysing historical data, one can observe trends in vegetation health in a given area. This allows for an assessment of the impact of climate change or land use changes in that area, as well as any significant changes in the ecosystem over an extended period of time. Typically, the curve you observe is yield versus VCI, where a higher VCI indicates higher crop yield, while a lower VCI suggests lower crop yield. However, it's important to note that some VCI models may use a limited number of spectral bands, which can constrain the ability to distinguish between different vegetation types or conditions accurately. Therefore, caution must be exercised when selecting the data used to calculate the VCI.



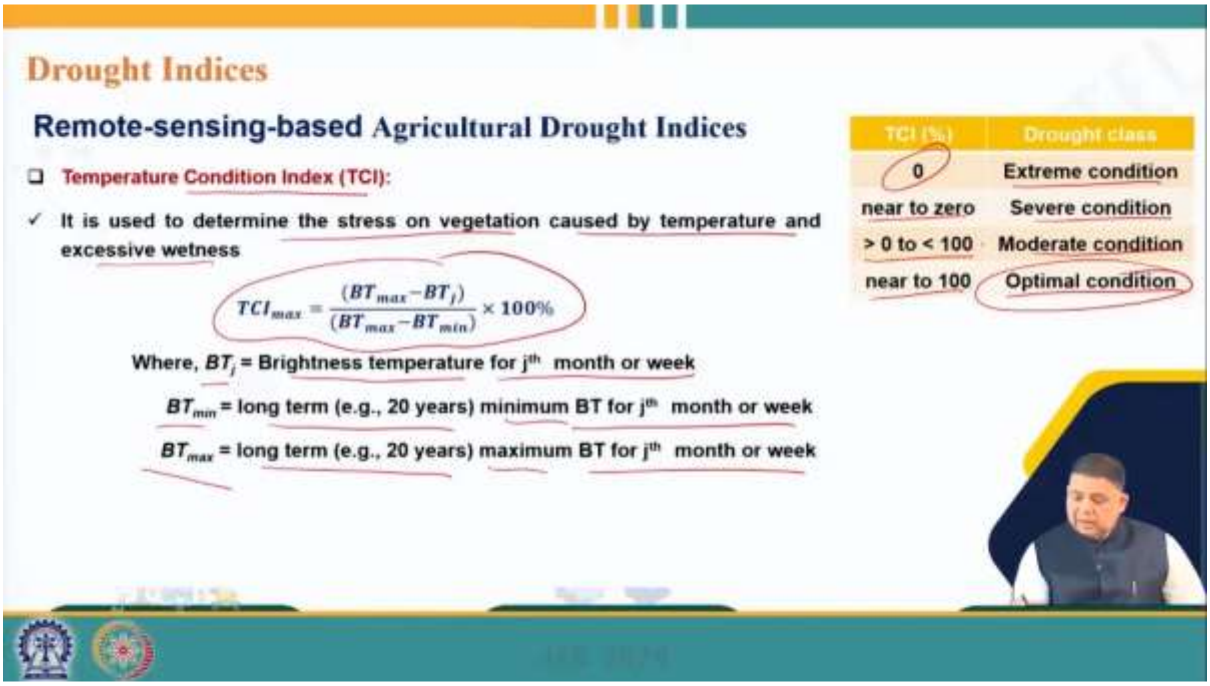
Let's take an example: the long-term maximum and minimum NDVI values for August are 0.75 and 0.03, respectively. The average NDVI for the month is 0.35. Now, let's calculate the Vegetation Condition Index (VCI) and comment on the drought situation. The given NDVI value for August is 0.35, and the long-term maximum and minimum NDVI values for August are given as 0.75 and 0.03, respectively.



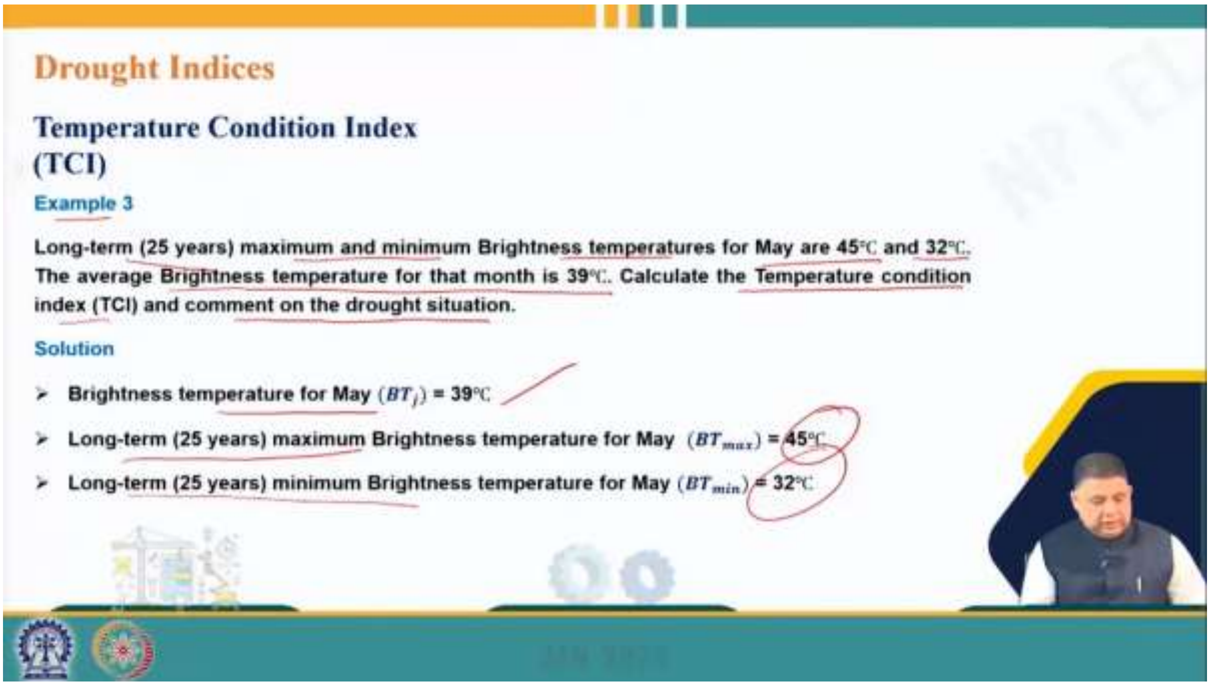
Now, we can use the formula to calculate the Vegetation Condition Index (VCI). By substituting the NDVI value for August and the minimum and maximum values for August into the formula, we can calculate the VCI value, which turns out to be 44.44 percent. This indicates a no-drought condition, as the VCI value falls within this range. Therefore, based on the NDVI of the month and the long-term data, we conclude that there is no drought in the area under consideration. This serves as an important indicator.



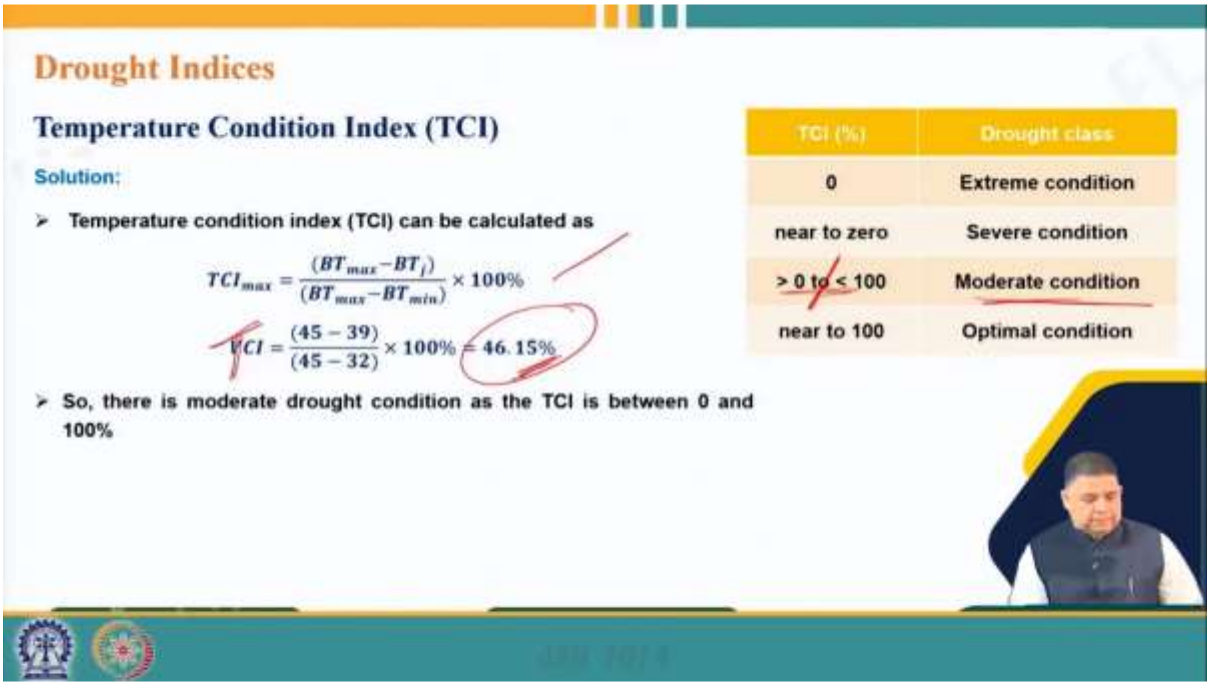
Moving on to the next index, the Temperature Condition Index (TCI). It is used to determine the stress on vegetation caused by temperature extremes. The formula used for TCI involves BT, which represents brightness temperature, and VT, which is the brightness temperature for a specific year, month, or week. BT min and BT max are the long-term minimum and maximum brightness temperatures for that particular month. Instead of NDVI, brightness temperature is used in this formula. Based on the TCI value, different conditions can be determined. If it is 0, it indicates an extreme condition, near to 0 suggests a severe condition, 0 to less than 100 indicates a moderate condition, and near to 100 suggests an optimal condition. Naturally, 100 percent represents the best condition, and the closer one is to 100, the better the conditions. Conversely, the closer one is to 0, the more severe the conditions are, potentially ranging from severe to extreme.



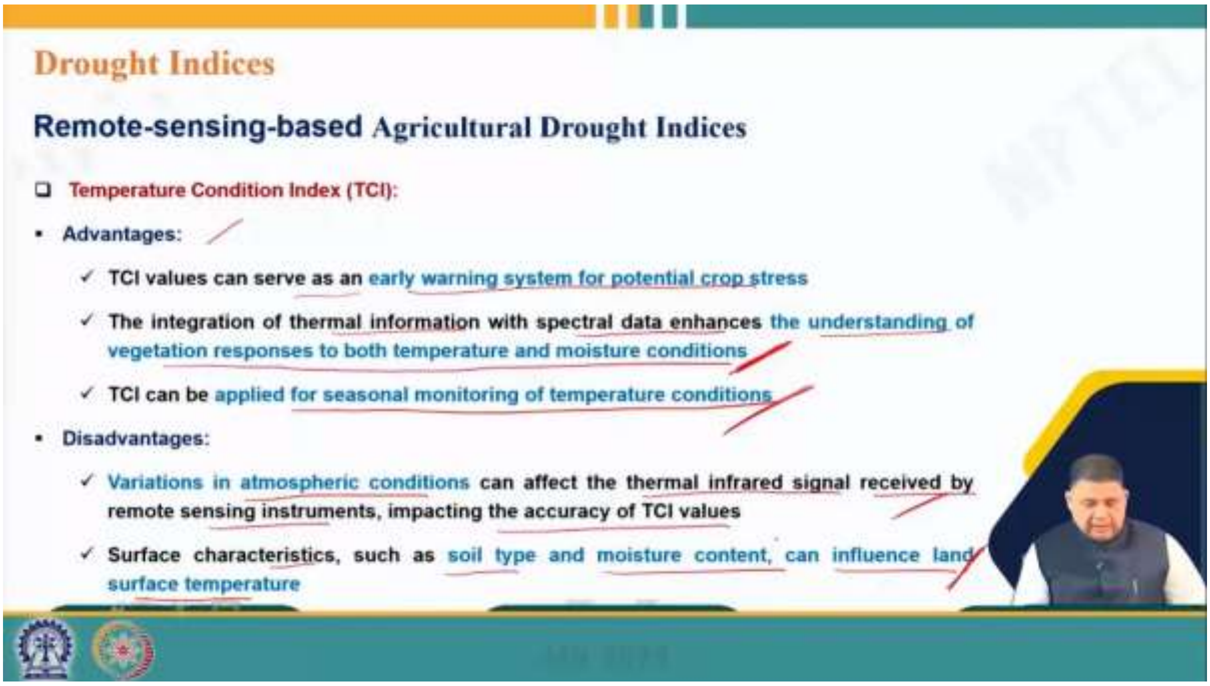
Let's consider an example, Example 3, where the long-term maximum and minimum brightness temperatures for May are 45 degrees Celsius and 32 degrees Celsius, respectively. The average brightness temperature for that month is 39 degrees Celsius. Now, let's calculate the Temperature Condition Index (TCI) and comment on the drought situation. Given that the brightness temperature for May is 39 degrees Celsius, the long-term maximum BT is 45 degrees Celsius, and the long-term minimum BT is 32 degrees Celsius.



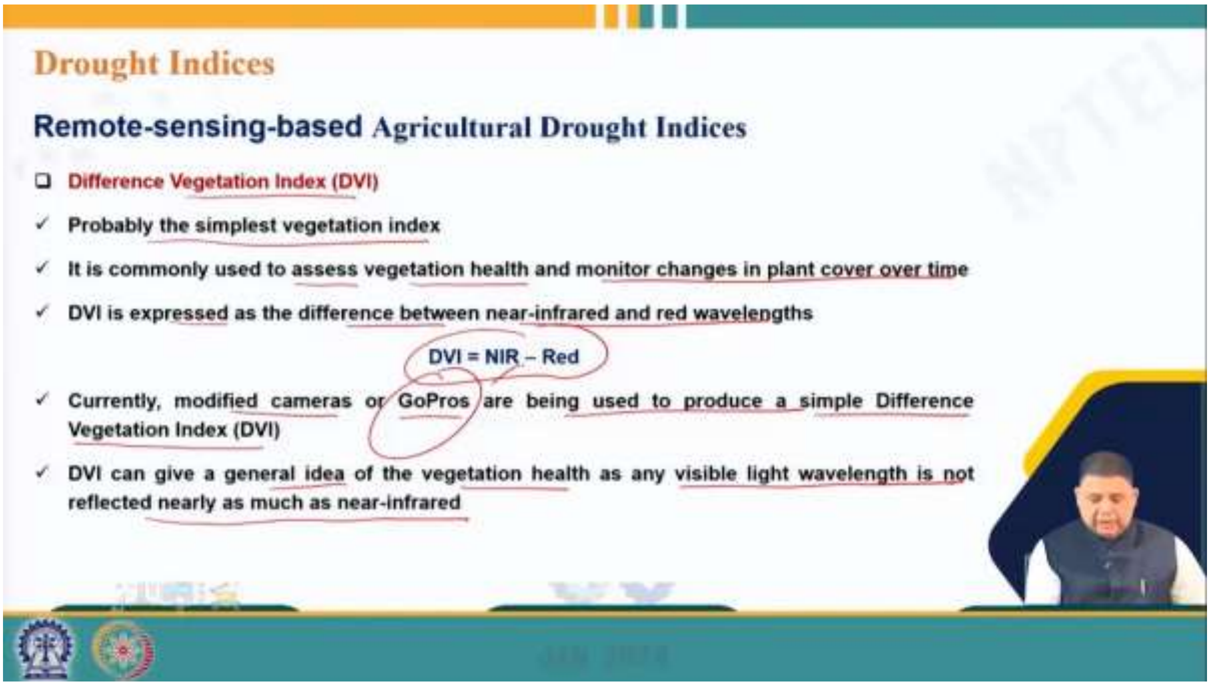
We can plug these values into the formula to calculate the TCI value, which turns out to be 46.15 percent. This places us somewhere in between, indicating a moderate drought condition. However, it's a position of caution, as we are hovering between drought and normal conditions. This demonstrates the value of TCI in providing insights into drought conditions.



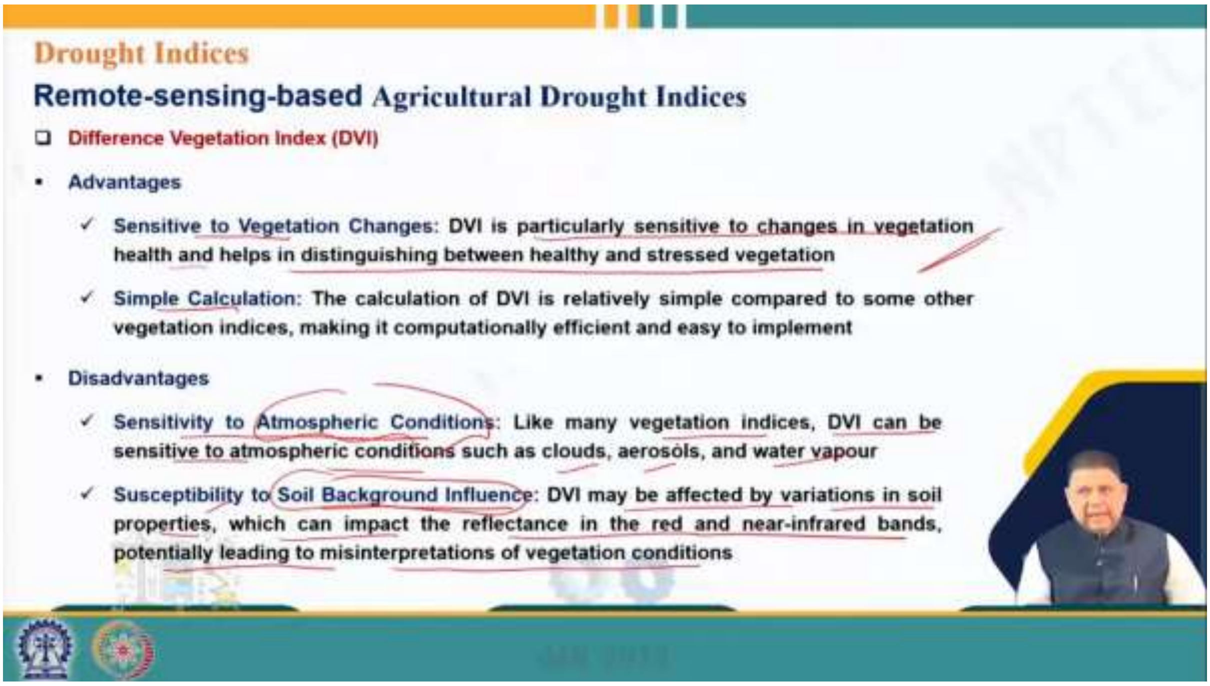
Moving on to the advantages of TCI, it can serve as an early warning system for potential crop stress. Integrating thermal information with spectral data enhances our understanding of vegetation responses to both temperature and moisture conditions. Therefore, TCI can be applied for seasonal monitoring of temperature conditions, allowing for a better analysis of the impact of temperature on vegetation. However, there are some disadvantages to consider. Variations in atmospheric conditions can affect the thermal infrared signal received by remote sensing instruments, impacting the accuracy of TCI. Additionally, surface characteristics such as soil type and moisture content can influence land surface temperature. These factors are important to consider, as they can affect the reliability of TCI readings. This drawback is typical for any remote sensing measurement.



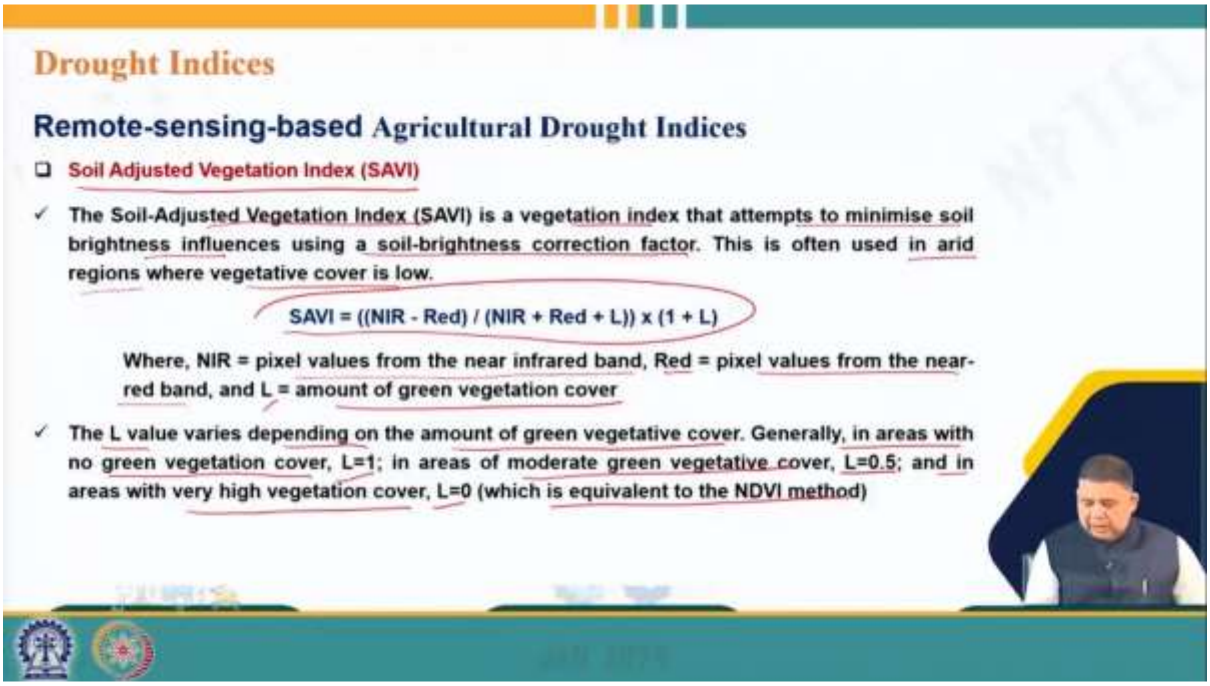
Now, let's move on to DVI. DVI is probably the simplest vegetation index. DVI, or Difference Vegetation Index, is commonly used to assess vegetation health and monitor changes in plant cover over time. It is expressed as the difference between near infrared and red wavelengths, given by DVI = NIR minus red. Currently, modified cameras or GoPros are being utilized to produce a simple Difference Vegetation Index, making it easy to obtain and providing a general idea of vegetation health, as visible light wavelengths are not reflected nearly as much as near infrared.



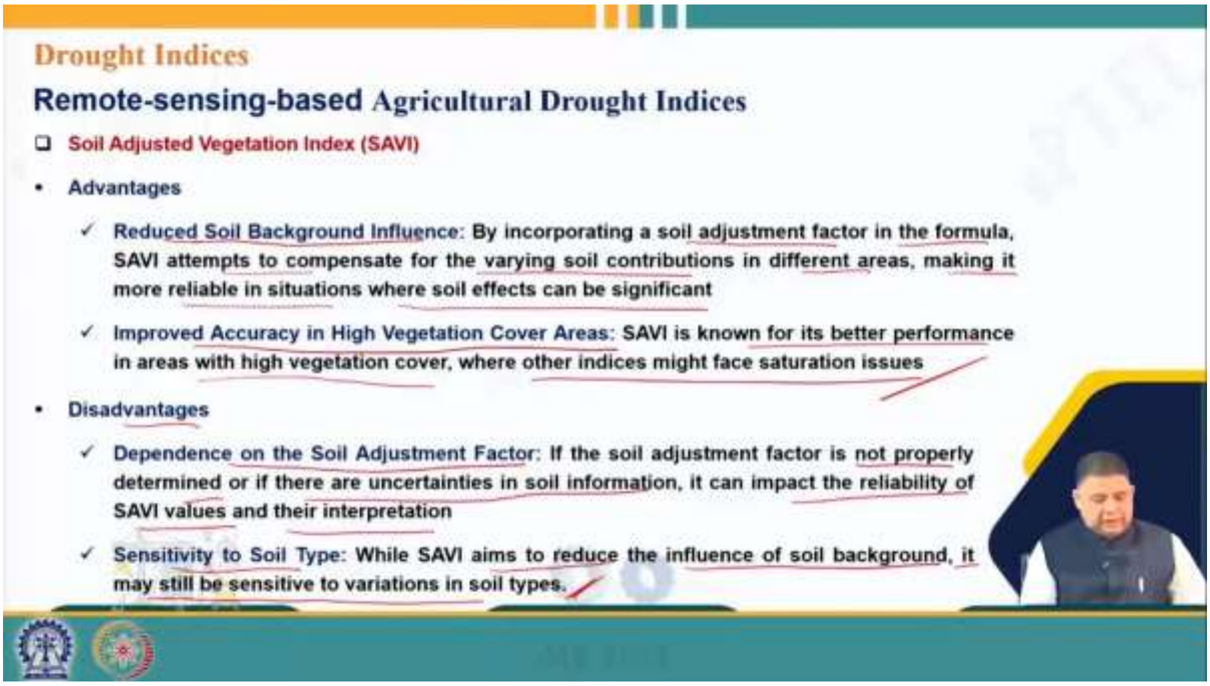
The advantages of DVI include its sensitivity to vegetation changes, particularly in distinguishing between healthy and stressed vegetation, which is crucial for assessment purposes. Calculating DVI is straightforward, as seen from the relationship formula. However, DVI is sensitive to atmospheric conditions, such as clouds, aerosols, and water vapor, like many vegetation indices. Additionally, susceptibility to soil background influence may impact DVI results. Variations in soil properties can influence reflectance in red and near infrared bands, potentially leading to misinterpretation of vegetation conditions. Therefore, soil background and atmospheric conditions should be considered when interpreting DVI results, although these challenges are typical for many remote sensing-based calculations. So, one advantage of DVI is its simplicity, as it is usually based on a straightforward calculation.



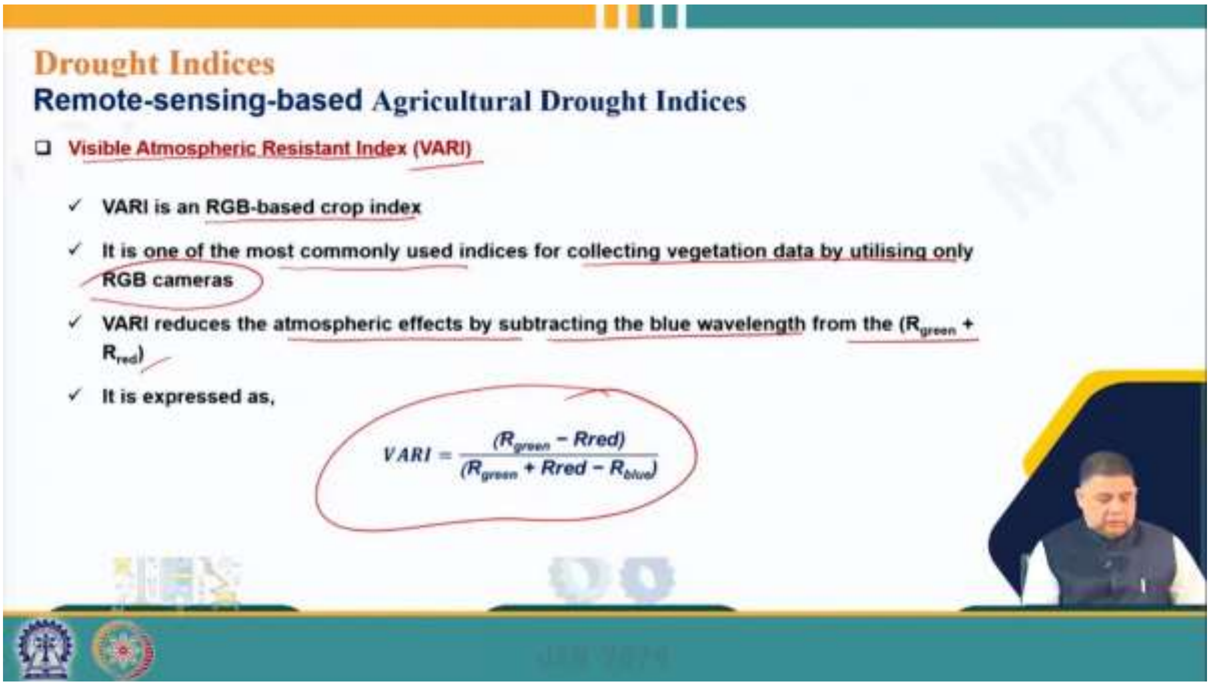
Moving on, let's discuss the Soil Adjusted Vegetation Index (SAVI), which attempts to minimize soil brightness influences by incorporating a soil brightness correction factor. As we've seen in previous examples, soil brightness presents a challenge, and SAVI addresses this issue by introducing a correction factor. This index is often utilized in arid regions where vegetation cover is low. SAVI is calculated using the relationship SAVI = (NIR - R) / (NIR + R + L * (1 + L)), where NIR represents pixel values for the near infrared, R represents pixel values for red, and L denotes the amount of green vegetation cover. The value of L varies depending on the amount of green vegetation cover present in the area. For areas with no green vegetation cover, L is 1; for areas with moderate green vegetation cover, L is 0.5; and for areas with very high vegetation cover, L is 0, equivalent to the NDVI method. Thus, the correction factor L is essential in the SAVI calculation.



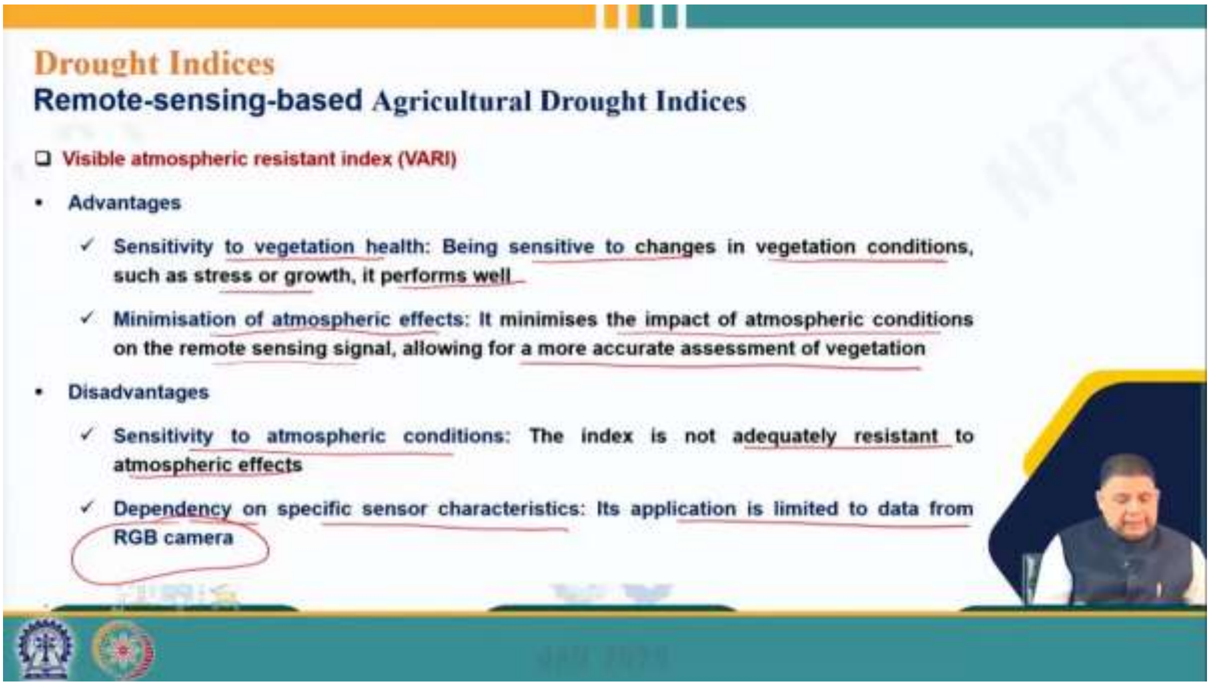
One advantage of SAVI is the reduced influence of soil background, addressing a drawback observed in earlier methods such as DVI or TCI. This correction factor allows for a more accurate assessment of vegetation health by minimizing the impact of soil brightness on the index values. So, by incorporating a soil adjustment factor into the formula, SAVI attempts to compensate for varying soil conditions in different areas, making it more reliable in situations where soil effects can be significant. This leads to improved accuracy, especially in areas with high vegetation cover, where other indices might encounter issues. However, a disadvantage of SAVI is its dependence on the soil adjustment factor. If this factor is not properly determined or if there are uncertainties in soil information, it can impact the reliability of the index values and their interpretation. Additionally, SAVI remains sensitive to soil type despite aiming to reduce the influence of soil background, presenting a challenge in its application across different soil types.



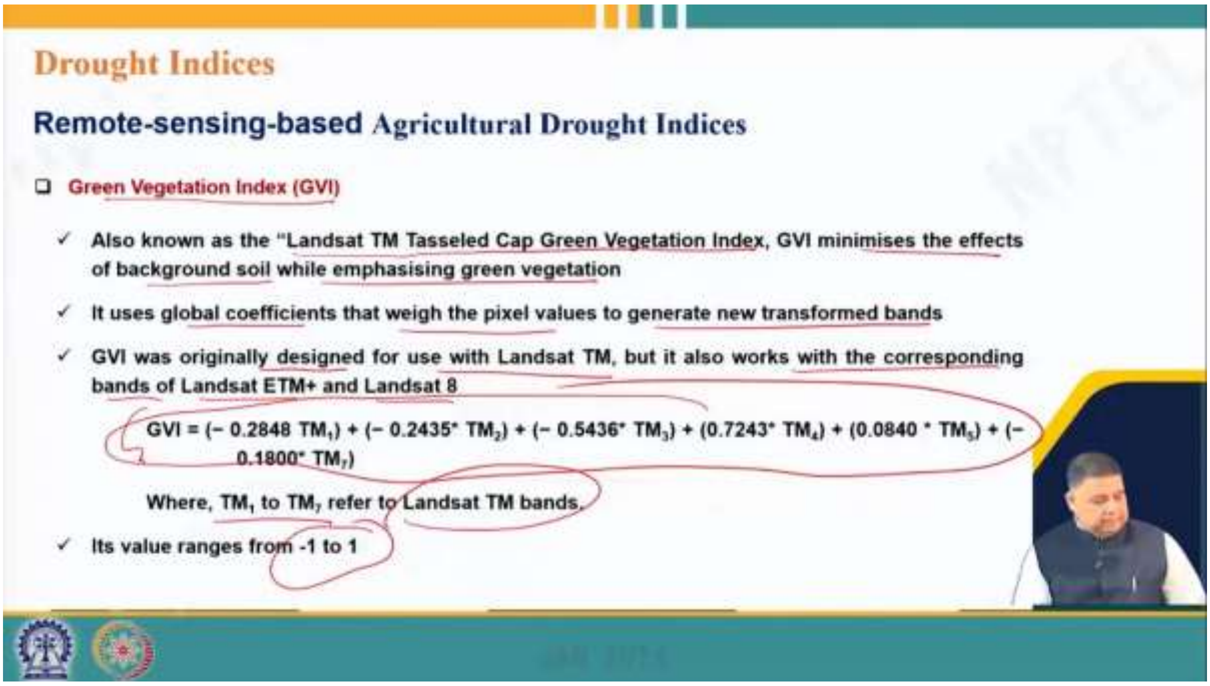
Moving on, let's discuss the Vegetative Atmospheric Registration Index (VARI), an RGB-based crop index commonly used for vegetation analysis using only RGB cameras. This means that even drones can be utilized for data collection. VARI reduces atmospheric effects by subtracting the blue wavelength from the sum of green and red wavelengths, calculated as (R_green - R_red) / (R_green + R_red - R_blue).



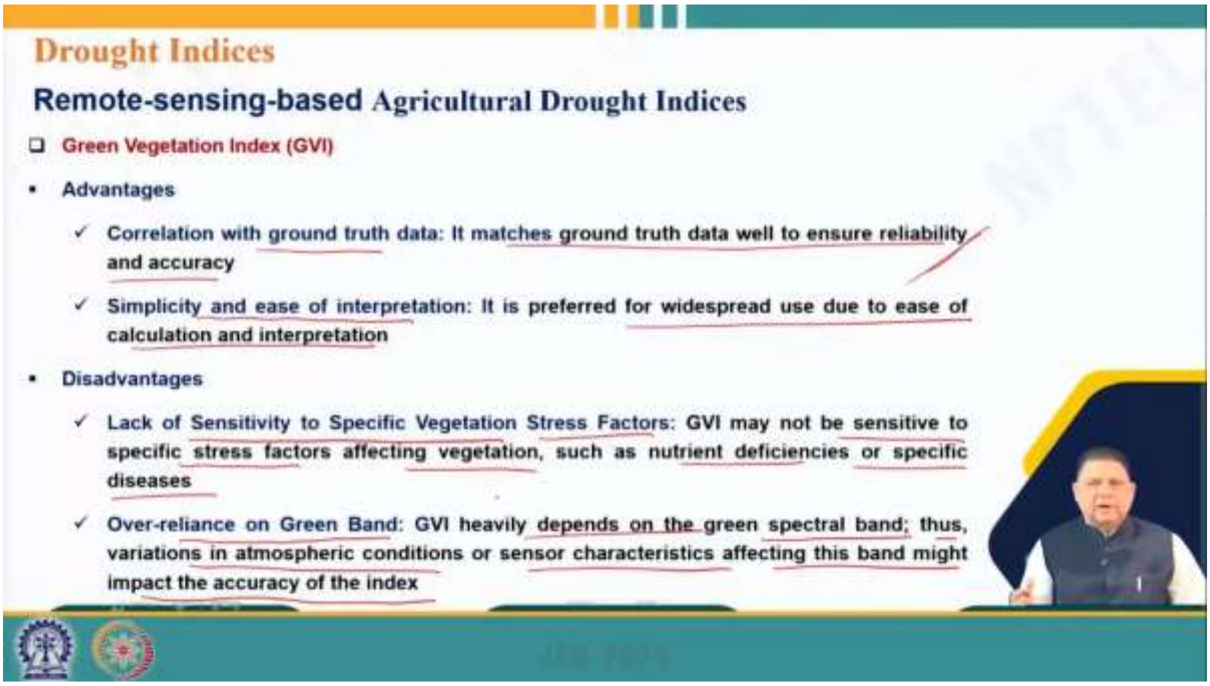
This index is sensitive to vegetation health and performs well in detecting changes in vegetation conditions such as stress or growth. Moreover, it minimizes the impact of atmospheric conditions on remote sensing signals, allowing for a more accurate assessment of vegetation. The disadvantages include sensitivity to atmospheric conditions. Therefore, it may not adequately resist atmospheric effects, which could be a drawback. Additionally, its dependency on specific sensor characteristics limits its application to only RGB cameras. Hence, VARI, or Variable Atmospheric Resistance Index, can only be used with RGB data; other types of data such as thermal cannot be utilized with this index.



Now, let's discuss the last index, the Green Vegetation Index (GVI), also known as the Lancet TM TESEL CAP Green Vegetation Index. This index minimizes the effects of background soil while emphasizing green vegetation. It utilizes global coefficients to transform pixel values and generate new bands. Initially designed for use with Lancet TM data, it also works with corresponding bands of Lancet ETM Plus or Lancet 8 satellites, which are more modern. GVI can be calculated using the relationship where TM1 to TM7 refer to Lancet thematic mapper bands. These bands cover the entire Lancet TM spectrum, and the index value ranges from -1 to 1.



As for its advantages, GVI correlates well with ground truth data, ensuring reliability and accuracy. So, obviously, in any remote sensing-based analysis, we always use ground truth data. GVI has been found to work well with ground truth data, and simplicity and ease of interpretation are preferred for widespread use due to the ease of calculation and interpretation. One disadvantage includes a lack of sensitivity to specific vegetation stress factors. It may not be sensitive to specific stress factors affecting vegetation, such as nutrient deficiency or specific diseases. Additionally, over-reliance on the green band is a concern. GVI heavily depends on the green spectral band; thus, variations in atmospheric conditions or sensor characteristics affecting this band might impact the accuracy of the index. So, these are the advantages and disadvantages. However, a large number of remote sensing-based agricultural drought indices have been developed, and they are being used effectively.



With this, we come to the end of this lecture where we have introduced remote sensing-based agricultural drought indices, which are being used quite often nowadays because remote sensing data is now basically the "in" thing as far as research goes. That's why these indices are very popular. Please give your feedback and also raise any questions or doubts you may have; we shall be happy to answer on the forum. Thank you very much.