

SUSTAINABLE MINING AND GEOINFORMATION

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Week – 01

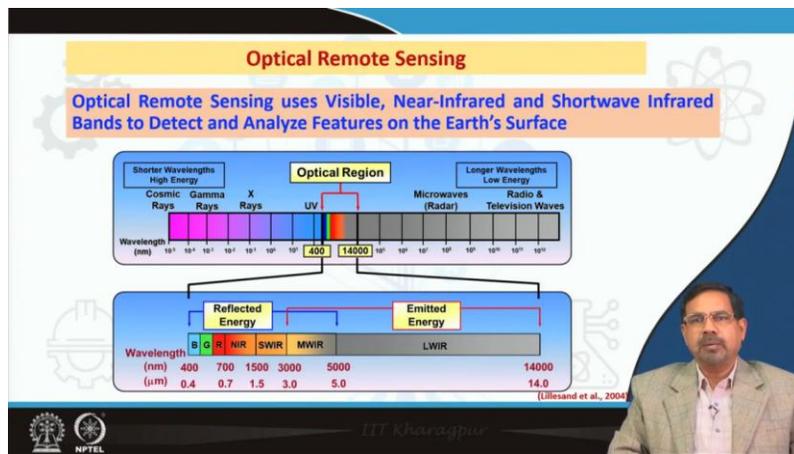
Lecture 02: Optical remote sensing

Welcome to the second lecture on Optical Remote Sensing. We have been talking about sustainable mining and geoinformation, and the concepts we are going to cover are optical remote sensing principles, particularly panchromatic, multispectral, and hyperspectral applications in mineral exploration, detecting surface materials, and identifying vegetation cover. And one or two case studies also let us see examples that talk about the use of optical imagery for mapping mine areas and monitoring environmental changes. As far as optical remote sensing is concerned, it uses the visible, near-infrared, and shortwave infrared (SWIR) bands to detect and analyze features on the Earth's surface. The portion of the electromagnetic spectrum here depicts the optical region.

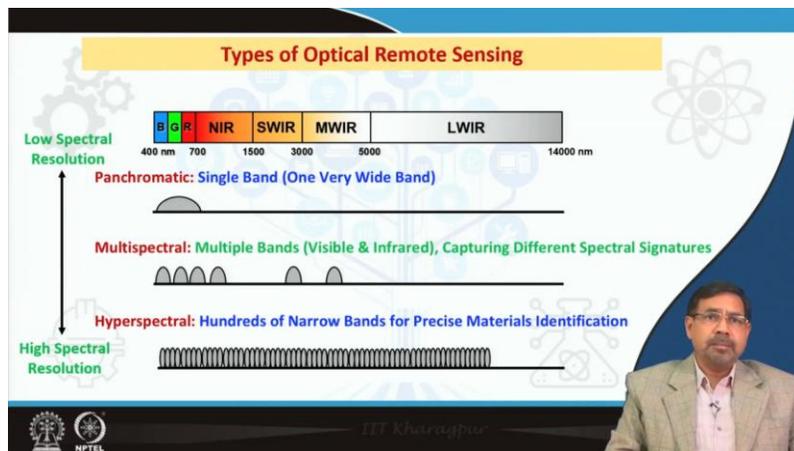
CONCEPTS COVERED

- Optical Remote Sensing Principles (Panchromatic, Multispectral, Hyperspectral)
- Applications in Mineral Exploration: Detecting Surface Materials and Identifying Vegetation Cover
- Case Studies: Use of Optical Imagery for Mapping Mine Areas and Monitoring Environmental Changes

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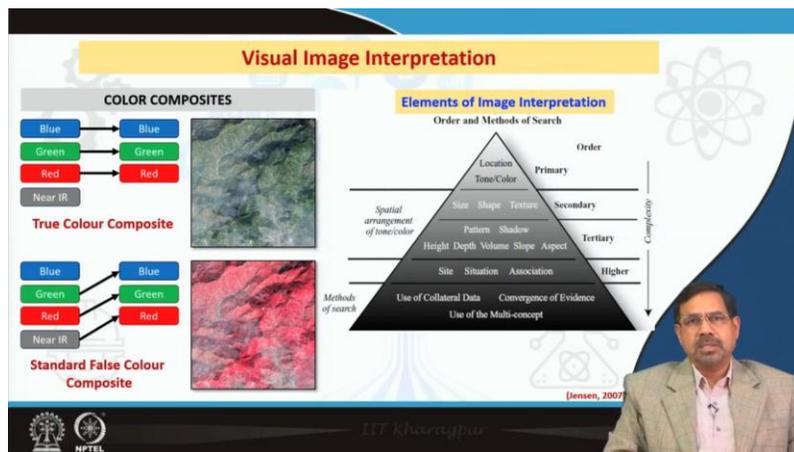
Mostly, we consider the visible region to be between 390 to 760 nm, but the optical region we use for remote sensing is shown between 400 to 14,000 in terms of nanometers. And the reflected energy, particularly the blue, green, red, NIR, and shortwave infrared, as well as part of the middle infrared, is utilized. As far as the types of remote sensing are concerned, we can broadly divide them into three categories: panchromatic, multispectral, and hyperspectral, based on spectral resolution. In Lecture 1, we discussed spectral resolution. And here, we are categorizing them into three broad groups based on low to high spectral resolution.



The panchromatic type uses one very wide band, meaning a single band, mostly displayed in grayscale, covering the entire visible range. You might remember black-and-white cameras, as they work on the principle of panchromatic imaging, having a single band. The multispectral type, as the term 'multi' suggests, has multiple bands in both the visible and infrared regions, capturing different signatures of the Earth or surface features of our interest, particularly in mining. Coming to the hyperspectral type, it uses hundreds of

narrow bands for precise material identification. What happens is, within the same electromagnetic spectrum, we use many narrow bands.

So, we get the small variation in terms of the spectral reflectance curve, which may be coming from or because of a particular mineral or ore present on the earth's surface, which is of interest to the mining sector. So, friends, based on the spectral resolution, optical remote sensing can be divided into three categories: panchromatic, multispectral, and hyperspectral. Hyperspectral has hundreds of narrow bands, such as AVIRIS. So, let us move to the next topic, which talks about visual image interpretation. Visual image interpretation is very basic; the moment we get a satellite image, we see it either in natural color, meaning the colors we usually see on Earth, or in false color or pseudo color, also called false color composite or pseudo color composite. So, friends, why is this necessary, and what is its requirement?



Now, to understand this, on the left-hand side, we know that blue, green, and red are the three primary colors. The whole range of colors our eyes can see or visualize must be composed in these three color planes or guns, combined in different proportions. So, if we are seeing or if the data captured in the blue portion of the electromagnetic spectrum is placed under the blue plane, and the data captured in the green part is placed under the green plane, and red under the red plane, that means it will give us a true color or natural color composite, the way we see the Earth's surface. So, that means the green color of vegetation will look green, and the soil will look slightly brighter.

But that is not the case when we talk about multispectral or hyperspectral imaging, where we deal with more than three bands. So, for visualization purposes, we only have the option to assign all those bands at once across the three planes: original blue, green, and red. That means we have to assign pseudo-colors, meaning the information captured in the near-

infrared region must be visualized because our naked eye cannot perceive the information captured in that part of the electromagnetic spectrum. So, we need to assign a pseudo-color. What do we mean by assigning a pseudo-color?

The range of brightness, let us say it is an 8-bit data from 0 to 255. So, we are assigning 0 as the minimum and 255 as the maximum as far as the red color is concerned. So, in that case, the blue is representing the green part of the data, the green is displaying the red data, and the red is displaying the NIR data. That means the data has been taken against the green, red, and NIR parts of the electromagnetic spectrum. It is represented or displayed using the blue, green, and red regions respectively, giving us not a true color but a false color. And this particular representation is standard, where the green—meaning the vegetation—is shown as red color, called the standard false color composite.

All other color combinations, all other representations, are called false color composites except this color composite combination. Now, let us understand the right-hand side depiction that talks about the elements of image interpretation order and methods of search. When the data is there—when the false color composite (FCC) is there, the image is there—then as an interpreter, we need to interpret it to extract the feature of our interest. Here, the feature of our interest is the mining feature. So, on the left-hand side, we are talking about the spatial arrangement of tone or color, and on the right-hand side, we have represented the complexity. When we come from the top—that is, the location or the true tone or color—first, based on the color variation, we say that these are different features based on the different color variations.

Then, at the next or secondary level, we go up to the size, shape, texture, pattern, and shadow—these are the elements of image interpretation. Further, at the higher or tertiary level, we also associate different neighboring features to that so we can do a good job in terms of image interpretation, which falls under the visual image interpretation category. To do that, we also need to have a background understanding of the spectral reflectance curve; only then can we do a good job in terms of visual image interpretation. The next thing is the band ratio or the spectral indices. Friends, what do we understand by band ratio or the spectral indices? What happens when we have several images taken using different parts of the information? We have an option to play around with that in terms of additive or cancellation effects as far as the common features are concerned.

Band Ratio and Spectral Indices

Mineral Detection Indices			
Index	Formula	Purpose	Application in Mining
Clay Mineral Index	$SWIR1 / SWIR2$	Detects Clay Minerals	Identifies Clay-Rich Mineral Deposits
Ferrous Minerals Index	$SWIR1 / NIR$	Detects Ferrous Minerals	Maps Iron-Bearing Deposits
Iron Oxide Index	Red / Blue	Highlights Iron Oxide Areas	Indicates Potential Ore Deposits

Environmental and Vegetation Indices			
Index	Formula	Purpose	Application in Mining
Moisture Stress Index	$SWIR1 / NIR$	Assesses Moisture and Vegetation Stress	Monitors Vegetation Health around Mines
NDVI	$(NIR - Red) / (NIR + Red)$	Monitors Vegetation Cover	Tracks Impact of Mining on Vegetation
NDBI	$(SWIR1 - NIR) / (SWIR1 + NIR)$	Identifies Built-up Areas	Maps Infrastructure Growth in Mining Zones
SAVI	$(NIR - Red) / (NIR + Red + L) \times (1 + L)$	Enhances Vegetation Signals in Sparse Areas	Useful for Reclamation in Mining Regions

By comparing two spectral bands, these techniques allow for the enhancement of specific features in an image that may not be apparent in the individual bands alone

(Jensen, 2007)



So, taking advantage of that using different spectral bands, different band ratios have been established for different kind of applications. As far as the mineral detection indices is concerned the clay mineral index which takes the formula of short wave infrared 1 upon short wave infrared 2 It helps in detecting the clay minerals and have application as far as identification of clay rich mineral deposits are concerned. Similarly, the ferrous mineral index which has the formula of short wave infrared 1 upon NIR, it has the potential to detect the ferrous minerals and thereby is helpful in mapping of iron bearing deposits. Similarly, the iron oxide index that takes the formula of red upon blue it highlights the iron oxide areas indicating the potential ore deposits are the iron ore deposits.

So, friends this is so easy to narrow down the search or come out with a kind of indication based on the satellite derived spectral indices. Now, the environmental and the vegetation indices. some of them are here in terms of the moisture stress index the NDVI the very basic and primitive one the and normalized difference vegetation index the NDBI the normalized difference built up index the SAVI the soil adjusted vegetation index. Here in this set of formula we are also coming out with A minus B upon A plus B kind of formula. So, NIR minus rate upon NIR plus rate that goes as NDVI it helps in monitoring the vegetation thereby tracking the impact of mining on vegetation.

Similarly, the SAVI that takes L as one of the constants coming from the ground based measurement for different soils enhances the vegetation signals in sparse areas. So, thereby it is useful for reclamation in mining regions. By comparing two spectral bands, these techniques allow for the enhancement of specific features in an image that may not be apparent in the individual bands alone. So, that is why the requirement of more than one band is concerned. And friends here I would like to tell you another point. Here is always the input is more than 1 band, but the index is 1.

So, that means more than one band. Since it deals with the number of bands, it also falls under the criteria of spectral enhancement, okay? So, the number of input bands. So, two bands input or three bands input, but the output is one, okay? So, it plays or alters the number of spectral bands. So, that is why it is also repeated and also referred to as spectral enhancement.

Now, coming to optical remote sensing in sustainable mining, we have listed here five broad points: mineral exploration and mapping, environmental impact monitoring, land use and land cover classification, safety and hazard monitoring, and rehabilitation and restoration. So, in terms of mineral exploration and mapping, it helps in identifying mineral types and distribution through spectral analysis, as different minerals will have different spectra. So, that is why mineral exploration and mapping is a well-practiced process using optical remote sensing, thereby helping in sustainable mining. Mineral exploration and mapping also support efficient resource targeting and reduce the need for ground-based surveys. So, it minimizes the cost and energy as far as ground-based surveys are concerned.

Optical Remote Sensing in Sustainable Mining

- Mineral Exploration and Mapping**
 - Identifies Mineral Types and Distributions through Spectral Analysis
 - Supports Efficient Resource Targeting and Reduces Ground-Based Surveys
- Environmental Impact Monitoring**
 - Detects changes in Vegetation, Soil, and Water around Mining Sites
 - Assesses effects like Soil Erosion, Deforestation, and Water Contamination
- Land Use and Land Cover Classification**
 - Maps Land Cover Types (Forest, Water, Urban Areas) for Sustainable Land Management
 - Monitors Mining-Induced Land Use changes and Habitat Disruptions
- Safety and Hazard Monitoring**
 - Detects Surface Deformations and Instability for Early Warning on Landslides or Subsidence
 - Aids in Maintaining Safe Operational Conditions by Tracking changes in Terrain
- Rehabilitation and Restoration**
 - Monitors Post-Mining Reclamation and Restoration Success
 - Tracks Vegetation Regrowth and Soil Stability, supporting Long-Term Environmental Recovery

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So, once you prioritize that these are the areas where the presence of this mineral is higher or the content is higher, then it proceeds with the ground-based survey. So, that means it reduces the efforts in terms of ground survey. Second, environmental impact monitoring detects changes in vegetation, soil, and water around the mining sites. It also assesses the effects, such as soil erosion, deforestation, and water contamination.

These are all required as far as sustainable mining is concerned. So, changes in the different vegetation properties can also show the change in vegetation behavior, change in soil properties, and change in the water around the mining sites. Now, a similar concept helps us understand land use and land cover classification, which maps water, forests, urban areas, and aids in sustainable land management. It also monitors mining-induced land use

changes, which lead to habitat disruption, alteration, or new formations. The fourth aspect is safety and hazard monitoring, which detects surface deformations and instability for early warnings on landslides and subsidence.

This is one of the very important properties as far as optical remote sensing utilities are concerned. We also study surface deformation and instability. Thereby, it aids or helps in maintaining safe operational conditions by tracking changes in terrain stability and terrain deformation. The fifth one is rehabilitation and restoration. So, it helps in monitoring post-mining reclamation and restoration, successfully tracking vegetation regrowth and soil stability, thereby supporting long-term environmental recovery.

For rehabilitation and restoration, optical remote sensing acts as a useful data source. By analyzing temporal datasets, we can compare pre-mining and post-mining situations, thereby effectively planning and channeling reclamation and restoration processes. Now, the challenges: what are the different challenges in optical remote sensing for mining? The challenges could be grouped under two headings: one is environmental, and the other is technical. Friends, as far as environmental concerns go, there could be obstructions due to cloud cover, mostly during the monsoon season when visibility is minimal, limiting data collection and analysis. This is also a limitation of optical remote sensing. And the penetration depth.

Challenges in Optical Remote Sensing for Mining

Environmental Limitations

- **Cloud Cover:** Cloudy Weather or Monsoon Seasons can Obstruct Visibility, Limiting Data Collection and Analysis
- **Limited Penetration Depth:** Optical Sensors are Surface-Sensitive and cannot Penetrate Vegetation, Soil, or Water effectively, unlike Radar
- **Seasonal Variations:** Changes in sunlight and vegetation cover across seasons can lead to inconsistent data, impacting monitoring accuracy

Technical Limitations

- **Resolution Constraints:** High-resolution optical data is often expensive, and low-resolution data may miss small-scale features
- **Cost:** Hyperspectral and High-resolution Multispectral Imagery can be Costly, Limiting access for smaller Projects
- **Data Processing Complexity:** High Data Volume, Storage needs, and Complex Algorithms make processing and analysis challenging, Requiring specialized skills and Infrastructure

Dr. Khantappa

So, optical sensors are surface-sensitive and cannot penetrate vegetation, soil, and water effectively, unlike radar. So, most of the signals that are coming from the object are dominantly from the upper part of the object. Okay, so we say it is mostly a surface phenomenon with limited penetration depth. Coming to the third one, seasonal variation—the changes in sunlight and vegetation cover across seasons—can lead to inconsistent data, impacting monitoring accuracy. That is why we always use anniversary data in terms of

change detection. where the sun angle and the vegetation cover are nearly taken care of or nearly constant. Then, the second type of challenge or limitation is technical.

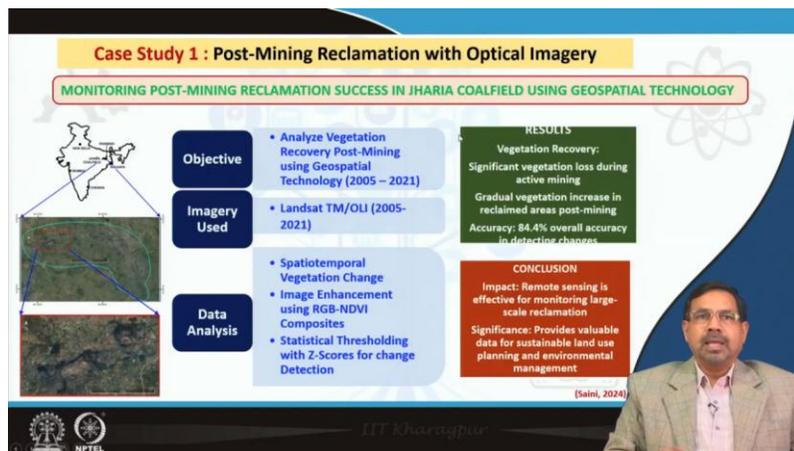
Technical in terms of resolution, in terms of processing complexity, data processing complexity, and also the cost. Coming to the resolution constraints, high-resolution optical data is very expensive, and low-resolution data may miss some small-scale features. So, we need to have a very cautious, careful decision about what the appropriate scale or resolution we need is. So, we should not waste time in terms of taking very high-resolution data, and we should not lose information by taking very low-resolution data. So, I have been understanding the resolution, the spatial resolution concept—the criteria—it helps us in choosing the right kind of data for this kind of analysis.

Then, cost: hyperspectral is a little costly in comparison to multispectral. And the data processing complexity. Yes, the data—we have to deal with high-volume data and data storage, and also the complex algorithms. That is why skilled manpower and infrastructure are needed. What about the future trends? The future trends in optical remote sensing for mining could be advances in hyperspectral technology and integration with other sensors.

The slide is titled "Future Trends in Optical Remote Sensing for Mining" and is divided into two main sections. The first section, "Advances in Hyperspectral Technology", lists two bullet points: "Increased Spatial and Spectral Resolution: Modern Hyperspectral Sensors Provide more detailed, Accurate Data, Improving Mineral Identification and Environmental Monitoring" and "Enhanced Mineral Mapping: New Technologies allow better discrimination of subtle spectral differences, aiding in more precise mineral detection." The second section, "Integration with Other Sensors", lists three bullet points: "LIDAR (Light Detection and Ranging): Combined with Optical data, LIDAR adds Topographic details, valuable for analyzing Mine Structures and Land Deformation.", "Radar (Synthetic Aperture Radar - SAR): SAR provides Ground Penetration, allowing for subsurface analysis and all-Weather Monitoring, Complementing Optical Limitations", and "Multi-sensor Platforms: Using UAVs or satellites equipped with both optical and non-optical sensors enables more comprehensive and precise mining assessments, especially for monitoring environmental impact." The slide features a blue and yellow color scheme, a logo of a stylized atom on the right, and a small inset photo of a man in a suit in the bottom right corner. Logos for NPTEL and IIT Kharagpur are visible at the bottom left.

So, in terms of the advances in hyperspectral technology, increased spatial and spectral resolution will be very useful because it would offer more detailed accurate data thereby improving the mineral identification and environmental monitoring. Whereas the enhanced mineral mapping if we use new technology that allows us in terms of better discriminating between and among the minerals thereby adding more precise mineral detection. And coming to the next part is the integration with other sensors. Yes, we will also see when we learn a bit more about the microwave the lidar and others the sense the data coming from other platforms. So, we always try to live in a hybrid sense so that we get maximum or we derive the optimum from different sources.

So, we can combine it with the optical data particular LiDAR for more of the structure of the topographical details so also for with the radar data the SAR data. And then multi sensor platforms using UAV satellite equipped with both optical and non-optical sensors enables more comprehensive and precise mining assessments especially for monitoring the environmental impact. So, these are the challenges as far as the integration, but friends we all need to do because different data sets have different unique information if we do not work on the data merging or the information or the feature extraction from different sources then perhaps we may not have the complete information in hand. So, we need to deal with that also. Then, one or two case studies.



So, case study 1 post mining reclamation with optical imagery. We try to take the case studies from our own study site Indian sites from different mining areas. So, monitoring post mining reclamation success in Jharia coal field. The word Jharia is very well known to all of us who are working in the mining sector ah using the geospatial technology. look at this has been taken from Saini publication given in the reference 2024 this year itself and the upper left location talks about the ah where the jharia mining is located down below you have the natural color composite

And, this is a pre and post kind of analysis. So, we are trying to monitor the post mining reclamation as far as the Jharia coal field is concerned using the geospatial technique. So, the objective is clear. To monitor that 2005 and 2021 that means a kind of 16 or 15 years data ah has been ah means gap has been maintained. So, 15 years what is the change happened over 15 years has been ah monitored in this study of case study.

So, for that the Landsat TM and OLI data has been taken and the analysis is as far as the analysis is concerned spacio temporal vegetation change has been done image enhancement using RGB NDVI composite. So, then you get better ah spectral visibility.

and statistical thresholding with Z score for the chain detection. You you define a threshold so that you will know that beyond this threshold is a change or below this threshold is a positive or a negative that way you this ah you decide. So, this is the technique has been followed here in this case study by Saini in this year.

And, then the result shows that the there has been a significant vegetation loss during active mining whereas, gradual vegetation increase in reclaimed areas post mining. So, this is also a good symptom because we expect lot of vegetation loss during active mining, but post vegetation if we are implementing a. successful reclamation process then the vegetation increase will be there vegetation will again come up on those areas after the post mining. So, this has been done with an accuracy of 84.4 percent with a overall accuracy. So, friends unlike other mathematics or other kind of things here in remote sensing we always talk in terms of the accuracy.

So, and that is also related to the scale. As far as USGS is concerned, any studies in terms of mapping, if it is at a 1:20,000 to 50,000 scale, should have a minimum of 85 percent accuracy. So, that means 15 percent inaccuracy is acceptable. So, that also we need to understand—it is never absolute, the mapping. We are monitoring these things, and we always try to show them in terms of their accuracy.

So, different statistics are involved in terms of representing the acceptance level in terms of accuracy. So, the conclusion. In fact, remote sensing is effective for monitoring large-scale reclamation and significantly provides valuable data for sustainable land use planning and environmental management. This is a successful story of remote sensing application for monitoring the post-mining reclamation in Jharia coal field. And then, coming to case study 2, that talks about vegetation mapping with optical imagery.

Case Study 2: Vegetation Mapping with Optical Imagery

DETECTION AND MAPPING OF VEGETATION STRESS USING AVIRIS-NG HYPERSPECTRAL IMAGERY IN COAL MINING SITES

OBJECTIVE: Identify and map vegetation stress caused by coal mining using high-resolution hyperspectral data (Jharia Coalfield, India)

DATA SOURCES: AVIRIS-NG hyperspectral imagery, NIR spectrometer ground data

VEGETATION INDICES (VIS):

- Tested 18 narrow-banded Vis
- Selected top-performing indices: NDVI, NSI-2, SR-1, SWST-3, SRWI, NWI-2, CSVI, HMSSI, ARI-1

STATISTICAL VALIDATION:

- Used Separability (S) and Coefficient of Determination (R^2) for index selection

RESULTS

- **High-Stress Zones:** Found near coal stockyards, haul roads, and pit sites
- **Low-Stress Areas:** Located farther from mining activities
- **Performance Comparison:**
 - Vis-based model: AUC of 0.69 (higher accuracy)
 - ENVI AST tool: AUC of 0.61
- **Validation:** Field NIR spectral data showed a negative correlation with the vegetation stress index

CONCLUSION

Impact: Hyperspectral imagery effectively monitors vegetation health at a fine scale

Significance: Results can inform environmental impact assessments and support sustainable mining practices

(Kayet et al., 2024)

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Dr. Khushboo

So, detection and mapping of vegetation stress using AVIRIS-NG—this is hyperspectral data having 224 spectral bands—in the mining or coal mining sites. So, here, the 18 narrow-banded vegetation indices have been selected, have been tested, and the top-performing indices have been identified. They are found to be NDVI, SI2, and a few more, and the statistical validation has been done. So, at the end, what are the results we got? The results are: high-stress zones have been identified; they are found near the coal stockyards, haul roads, and the pit sites. The low-stress areas have been identified, located further from the mining activities. And the performance has been compared, where it was found that vegetation index-based models—the AUC (area under curve) is 0.69, good accuracy—whereas the ENVI AST-based tool says that it is 0.61. So, in different ways, it has been found.

So, the take-home message is that the high-stress zones could be very well identified and mapped using the higher spectral resolution, which we call hyperspectral resolution data, and the low-stress areas have also been identified and mapped. So, as far as the conclusion is concerned, the hyperspectral imagery effectively monitors vegetation health at a very fine scale with good accuracy. So, significantly, these results can inform environmental impact assessments and support sustainable mining practices. And for this discussion, we have used these four references: Jensen, which all of us know, then the publication from *Advances in Space Research*, then the Lillesand and Keifer book, which all of us know. And another publication from Saini V.

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So, these two are the two Indian examples from Indian sites. So, to conclude this particular Lecture 2 on optical remote sensing, these are the five broad points we discussed. Optical remote sensing is a vital tool in mining, aiding in mineral exploration, environmental monitoring, and land reclamation. Techniques like panchromatic, multispectral, and

hyperspectral imaging allow for detailed analysis of surface features, vegetation health, and mineral deposits. While challenges such as cloud cover, resolution limitations, and high costs exist, integrating optical data with technologies like LiDAR and RADAR enhances its effectiveness.



Case studies highlight, confirm, and demonstrate the value of remote sensing in monitoring post-mining reclamation and vegetation stress, thereby supporting sustainable mining practices and environmental management. Yes, in the future, advancements promise even more precise and comprehensive data for these applications. So, just to conclude, optical remote sensing data are very widely available. They are relatively easy to interpret, unlike the LiDAR and microwave datasets, because this is so handy since our eyes see it every other day as far as the natural color composite is concerned. But the natural color composite has the limitation of displaying data beyond the visible range.

So, we must also understand the false color composite combinations and understand the spectral reflectance behavior. So, that we can also understand the visual interpretation techniques and then the feature extraction of the features which are of interest to the mining sector. Thank you very much.