SUSTAINABLE MINING AND GEOINFORMATION

Prof. Mukunda Dev Behera

Centre for Ocean, River, Atmosphere and Land Sciences (CORAL)

Indian Institute of Technology Kharagpur

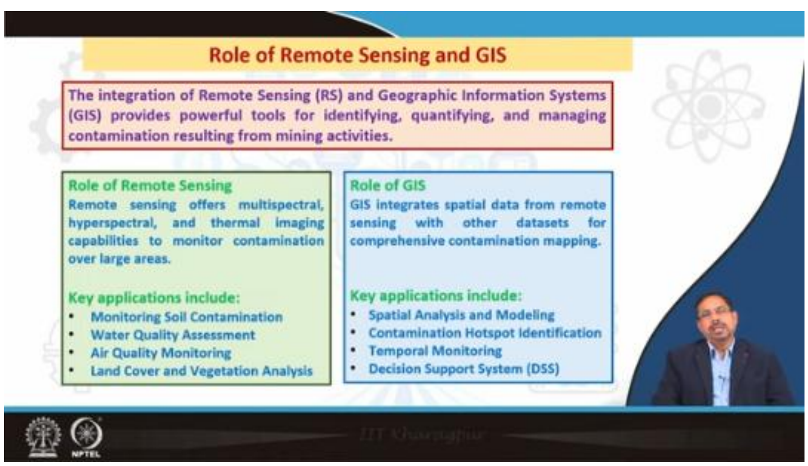
Week – 03

Lecture 14: Contamination Mapping and Geo-Assessments

Thank you. Welcome to the 14th lecture on contamination mapping and geo-assessments. Friends, let us discuss mapping contamination of water and soil using geo-enforcement techniques such as remote sensing and GIS. In this, we will try to understand how to detect toxic spills, acid mine drainage, and a few other effects that arise due to contamination in water and soil. Second, we will also discuss geospatial assessments for identifying high-risk areas and talk about the spread of contamination.

We will also take a few case studies that use satellite data to monitor contamination near and around mining sites. With this, let us get introduced to the term contamination and what you understand by contamination mapping. Contamination mapping involves tracking and analyzing pollutants across soil, water, and air environments using geoinformation or geospatial data. To assess and mitigate environmental hazards, here in this particular case, we are studying environmental hazards around the mining sector or mining industries, so contamination plays a crucial role in helping sustainable mining to minimize environmental damage as well as monitoring pollution, thereby ensuring compliance with the rules and regulations

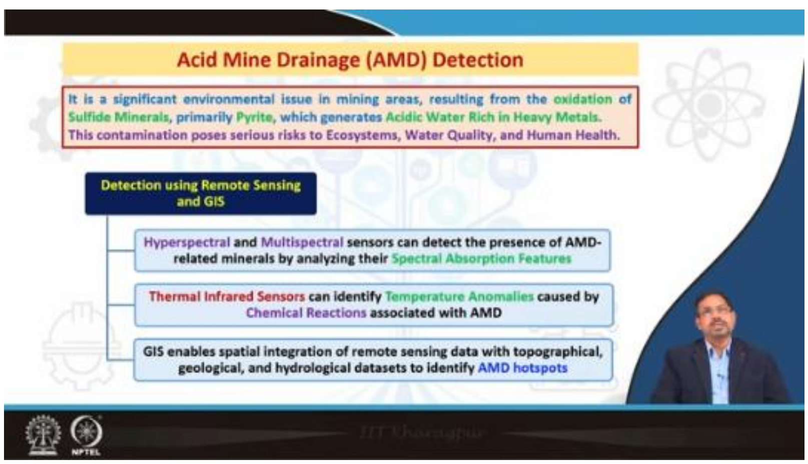
given by the State Pollution Control Board or monitored by the Central Pollution Control Board, and we have several rules and regulations that need to be complied with. So, what is the importance of contamination mapping, particularly in mining activities? In the mining industries, pollutants are generated, such as heavy metals, acid mine drainage (abbreviated as AMD), and several toxic spills. Understanding contamination and contamination mapping helps us mitigate environmental risks and thereby protect mining ecosystems or the surrounding ecosystems. In contamination mapping, monitoring, and management, remote sensing, GIS, and in general, geoinformation play a critical role in providing data and analyzing the situation. The integration of remote sensing and geographic information systems provides powerful tools for identifying, mapping, and managing contamination resulting from mining activities.



We all know the role of remote sensing and GIS. Hyperspectral, thermal, microwave, and as far as the role of GIS is concerned, it integrates both the spatial information. So the information or the data which comes from remote sensing sources is spatial in nature. It is integrated using other properties, integrating those that have other properties in terms of attribute data or non-spatial data using a geographic information system, or we call it GIS. So this provides, or this helps—the GIS helps in comprehensive contamination mapping.

So, as far as remote sensing is concerned, the applications in terms of contamination mapping could be monitoring the contamination, particularly soil contamination, assessing water quality, air quality, and also the changes in land and vegetation cover. And by taking this information into the GIS domain, several key applications in the contamination domain are possible, such as spatial analysis and modeling. Contamination hotspots can be identified where the maximum probability or occurrence of contamination exists. We can define that as the hotspot. It can be identified and monitored on a regular basis.

So, when we have all this information, it can be put together in the form of a decision support system, or sometimes we also call it the SDSS, Spatial Decision Support System, where we can see it in the form of maps or images—what has happened where in terms of contamination maps—and that helps us in monitoring. So, let us move to the next one, which is Acid Mine Drainage, sometimes abbreviated as AMD. So, detecting acid mine drainage is significant in terms of In terms of mining area management, this AMD results from the oxidation of sulfide minerals, primarily pyrites, which generate acidic water rich in heavy metals. So this contamination poses serious risks to ecosystems, water quality, and human health.



Detection using remote sensing and GIS, as far as the acid mine drainage is concerned. The hyperspectral and multispectral sensors can very well detect the presence of these acid mine drainage-related minerals by analyzing variations in their spectral absorption and reflectance properties. The thermal infrared sensors can identify temperature anomalies caused by chemical reactions associated with the acid mine drainage. And the GIS helps, as we already mentioned, in the integration of this spatial data along with the non-spatial data. Including many other related datasets such as hydrological and similar parameters that help to identify the acid mine drainage hotspot areas.

Now, the techniques available for contamination mapping—we have been discussing multispectral and hyperspectral imaging—as far as multispectral and hyperspectral imaging is concerned, they are very useful in detecting the contaminants. Identifying specific wavelengths absorbed or reflected by toxic elements such as heavy metals and organic compounds helps us in monitoring and managing the contamination. Now, coming to the indications, the presence of AMD (acid mine drainage) indicators helps in differentiating between different minerals or metals. Such as iron oxides and sulfates, which are commonly associated with AMD, we can differentiate them using different spectral properties. These iron oxides and sulfates will have different spectral behavior—sometimes we call it spectral properties, spectral reflectance properties, or spectral absorption properties. And these properties are useful in differentiating the different metals or minerals, and that is how they help in providing indications about the acid mine drainage.

The applications could be monitoring water discoloration caused by high metal concentration. So, if the water has a higher concentration of metals, that will be reflected in its color. This change in the color of the water can be captured using satellite remote sensing, and it could be due to contamination by heavy metals flowing from mining activities. And also, this contamination leads to vegetation stress. So, the water which has a higher concentration of heavy metals will affect the vegetation in terms of its nutrition, growth, and other activities.

So detecting this vegetation stress, the detection of vegetation stress is possible if we can detect whatever contamination is present, particularly heavy metal contamination in the soil or water. Now, the role or the advantages of using microwave or synthetic aperture radar data. So the advantage of using SAR data is that, as we all know, it has cloud penetration potential. It is weather-independent. That is why the utilization of SAR data helps in all-weather monitoring of contamination.

So the key uses are assessment in terms of subsidence or structural changes in mine sites, which can be linked to contamination. And also mapping flood-prone areas near tailing ponds that could be affected or could have been contaminated by heavy metals coming from the mining sector. Thermal infrared imaging utility. So, the utility could be identifying heat anomalies caused by chemical reactions in contaminated soil or water. So, that is how, based on thermal properties, the variation in temperature or heat anomalies can be detected.

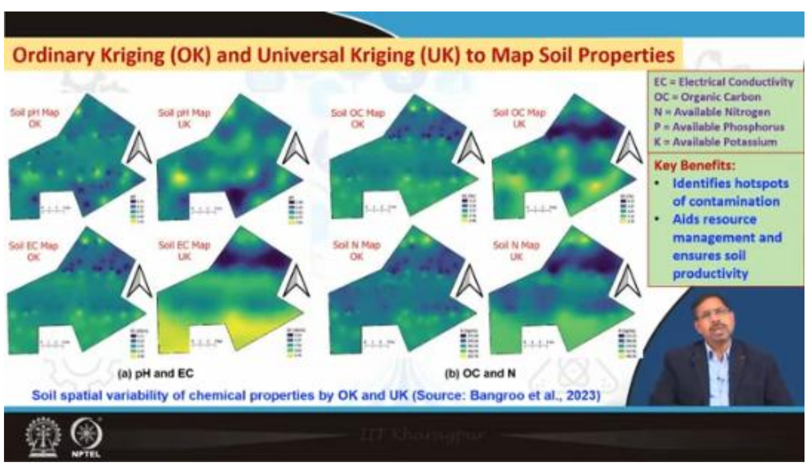
Waste dumps can be detected because they will have differentiation in heat properties due to exothermic oxidation behavior. And also, pollution plumes can be tracked, which will be linked to air or water bodies. So the utilization of SAR and thermal data helps in identifying, mapping, and monitoring contamination. The techniques for water and soil contamination mapping. So let us discuss water contamination monitoring.

So use of reflectance indices. So we have a lot of bands, the raw bands and we also come out with a lot of indications or indices based on the reflectance bands. So, these help the indices though some of the reflectance based indices helps in mapping the algal blooms. So, the algal blooms they come or they come over the water bodies so that can be linked that can be related because of the contamination by nutrients or runoff or runoff of different heavy metals from mining sector.

So, studying the reflectance indices we can also study the contamination behavior as far as the water the algal blooms over the water bodies are concerned. Spectral analysis for identifying discoloration caused by metal leaching. As we know, because of the contamination, the color of the soil, the water will be changed. And that can be very well captured by spectral analysis because they will have a different spectral behavior than the original or the raw water body or you say uncontaminated water body or the soil. So this can be mapped, this can be identified because of difference in the spectral reflectance behavior which can be linked to the leaching of leaching biomaterial by different metals.

The thermal imaging to detect plumes of warm and polluted water as we just mentioned using thermal imaging the anomalies in heat can be captured and that can be linked and attributed to the plumes of warm and polluted water. The soil contamination analysis. Combining spectral data with GIS to identify hotspot of heavy metal deposition, multi-temporal analysis for monitoring degradation over time, and mapping the changes in soil organic content also can be linked to industrial pollutants. So, friends, the hotspot as far as the heavy metal deposition can be very well analyzed using GIS. The multi-temporal data can be used to analyze the degradation and monitor the degradation over time and the organic content, the soil organic content can be linked or the variation in the soil organic content can be linked

to different industrial or you say here the mining industry pollutant sources and that can be very well mapped and attributed to contamination of soil. We have different methods available. One such is the kriging. So, in geostatistics, what we do, we have, let us say, over a region, over a mining, over a district, you have 10-15 locations where mining activities is going on. And you have difference in terms of the topography, difference in terms of the elevation, the aspect slope and all these things.



And then we have the location of different mining areas where all these pollutions are happening or the contamination is happening. So we have some information about the soil, the water in terms of the location. So if we have 10, 15, 20 based on the heterogeneity, we have the option of extrapolating these data points to come out with a spatial spread map representation. So here we have shown the difference in terms of the two types of kriging. One is ordinary, another is universal kriging.

abbreviated as OK and UK as far as a few soil properties is concerned. So, we have shown here the pH property, the organic carbon property, the electrical conductivity property and the soil available nitrogen property. So based on this we can very well see that both the using the two different techniques ordinary and universal they are giving different type of interpolation. So it depends on what kind of algorithm they are using. and how much it is acceptable to us, it depends again to us, that needs to be validated based on our data sets coming from other sources.

So, the key benefits in terms of extrapolating geostatistically this kind of point information to a spatial map are that we can very well identify the hotspots of contamination. And this kind of extrapolation using geostatistics helps in resource management, and that is how it ensures soil productivity and maintains the soil's naturalness. Application in terms of detecting specific contaminants. So, as far as the AMD is concerned, the characteristic formulation of sulfuric acid is due to the oxidation of sulfide minerals. This can be detected using the color indices from satellite imagery to identify, let us say, red or yellow iron oxide deposits.

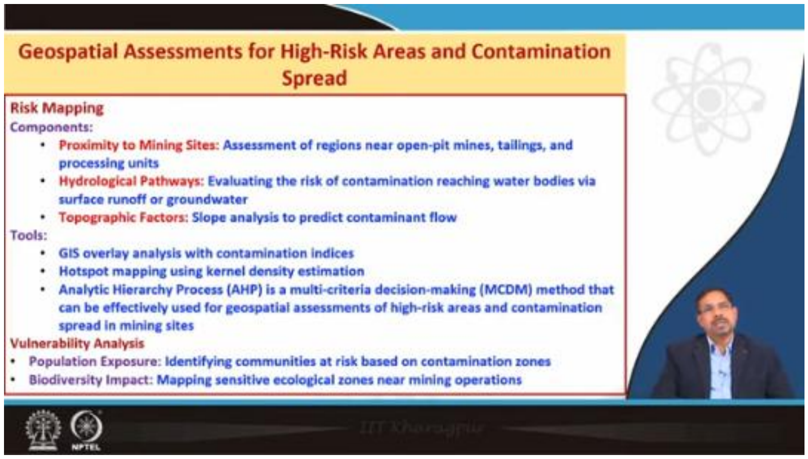
So, this color variation, as far as the red and iron oxide deposits are concerned, can be very well done using relevant satellite bands or the indices that are generated using them. And also, the turbidity mapping. Once the turbidity level of the water bodies is affected because of contamination, that can be very well mapped because higher turbidity means higher reflectance. No turbidity—clear water has less reflectance, which means more absorption.

So, keeping that in mind, that rule or rule of reflectance, as far as water is concerned, we can very well map the turbidity percentage, the turbidity content as far as the water bodies are concerned.

The heavy metals in soil—yes, we have a few techniques such as spectral mixing and unmixing. So, soil types and contamination based on the various contamination levels, we can very well play the trick of mixing and unmixing; we can apply the mixing and unmixing algorithm. Let us say we have different variations in terms of the metal iron oxide. And if you have 10%, 20%, 30% kind of variation in terms of deposition or contamination. And then, other variations can be very well studied, very well modeled, and very well discriminated using spectral unmixing algorithms.

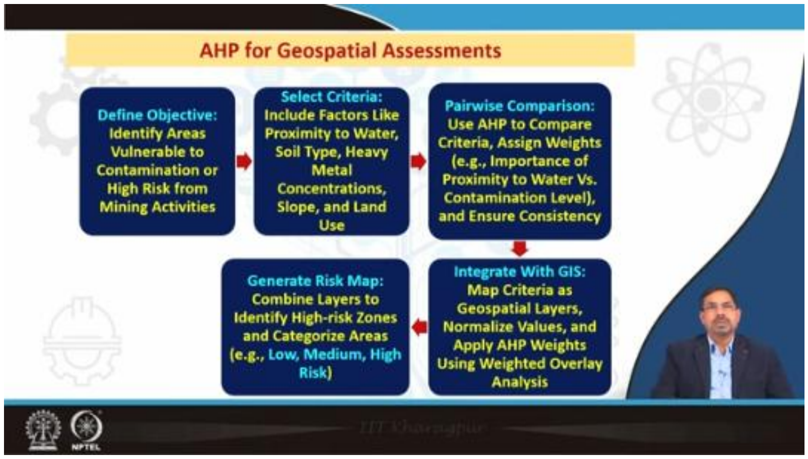
And this information combines with remote sensing and laboratory-based calibration. So we have lab-based calibration in terms of spectral absorption and spectral reflectance, indicating the percentage of that particular heavy metal present in the soil. So we have a control as far as the lab data is concerned. So once that is calibrated with the environmental properties and the materials present in the environment, as far as water or soil is concerned, that will give more information regarding the spill or contaminant detection. So, the monitoring techniques detect certain changes in water reflectance and temperature from the spills.

Yes, if the change—if you see on day one there is clear water, and on day two there is a difference in the reflectance due to contamination or variation in temperature—that can be very well detected using geopharmacy technology. And if we do it in terms of a time series, then we can very well analyze the spread, the rate, and the rate of change in terms of contamination. And high-risk areas, identification, and the contamination spread. So as far as the risk is concerned, yes, we can do some kind of proximity analysis around the mining sites that helps us assess regions near the open-pit mines, the tailings, and the processing units. Even the hydrological pathways—the water bodies, drainage channels, drainage orders, surface runoff, and groundwater—the contamination across these sectors can be very well evaluated in terms of the risk factor involved.

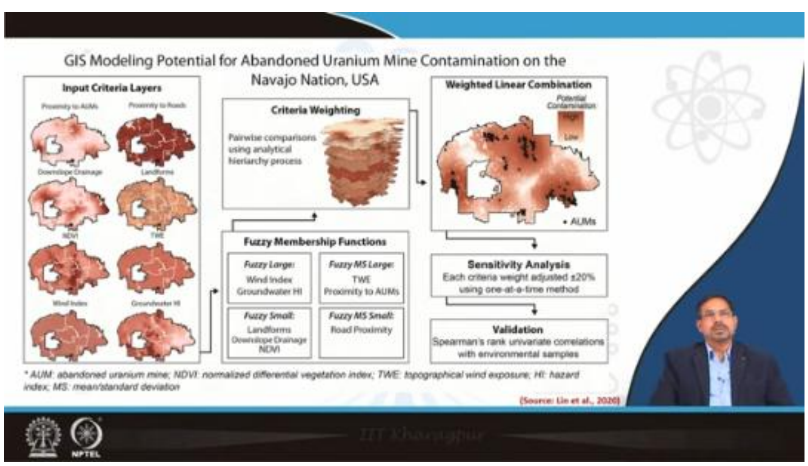


And the topography can also be taken into consideration as far as the contamination flow is concerned because it will always follow a gradient; it will flow along a gradient. So, the risk mapping considers the proximity analysis, the hydrological pathway, and the topographic factor as far as the spread or the spill of the contaminants is concerned. So the tools—we have the tools in terms of GIS overlay analysis as far as the contamination indices are concerned. And as far as the hotspot mapping is concerned, we put everything together and come out with a multi-criteria decision-making process, such as using AHP, the Analytic Hierarchical Process. And then we weigh or assign some kind of weight to different variabilities under different conditions and situations.

And that is how we identify the high-risk areas or low-risk areas in terms of contamination risks. The spread in mining sites is concerning, so the vulnerability analysis in terms of population exposure, biodiversity impact, and all these factors can be studied. The identification of communities at risk can be examined, and the mapping of ecologically sensitive zones, as far as contamination is concerned around or due to mining operations, can be thoroughly studied. Additionally, the vulnerability factors can be analyzed using the AHP (Analytical Hierarchical Process). We know that we use this AHP to assign weights, analyze the situation, and accordingly provide weightage. To define and identify vulnerable areas to contamination or high-risk zones from mining activities, we then select the criteria. The criteria could include proximity to water, soil types, heavy metal concentration, and topographical factors like slope, aspect, and variation, as far as land use categories are concerned.

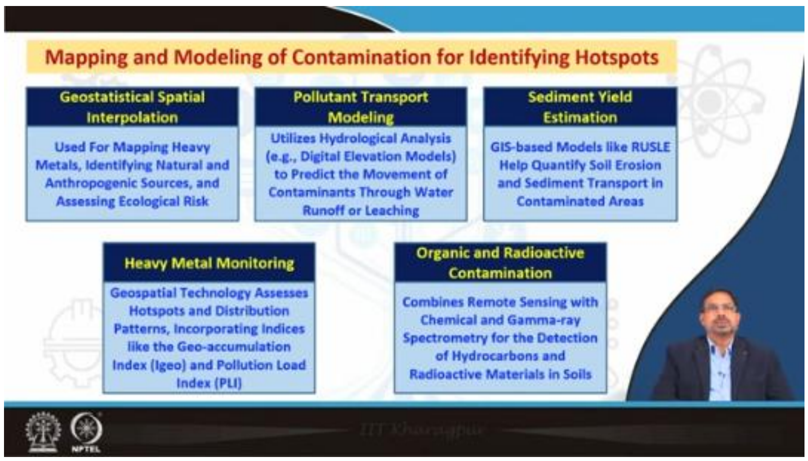


Using pairwise comparisons, we apply the Analytical Hierarchical Process to compare criteria. We assign weights based on the importance of proximity to water versus contamination levels and ensure consistency. Then, we generate the risk map in terms of low, medium, and high risk by combining the different information layers, which helps us identify high-risk zones in terms of maps. Furthermore, when integrated with GIS using different geospatial layers, it provides inputs and information to develop various management protocols or activities to address problems with different risk vulnerabilities. One such study I reference here is GIS modeling potential for abandoned uranium mine contamination on the Navajo Nation in the USA. On the left-hand side, you can see the input layers in terms of proximity to roads, drainage, landforms, NDVI, TWE (Topographical Wind Exposure), Wind Index, and water, particularly the groundwater factor.



These factors have been considered because they have a bearing and are linked in terms of the modeling potential calculation. The criteria have been discussed, and fuzzy membership functions have been assigned. Then, based on the weighted linear combination, the potential abandoned uranium mine contamination areas could be identified. This work was done by Lin et al. and published in 2020.

So, mapping and modeling of contamination for identifying the hotspot. So, geospatial geostatistical interpolation the pollutant transport modeling this is very important because we need to understand that which direction the pollutant will be transported will move will flow. So, the movement to predict the movement of the contaminants through water runoff or leaching or you say the air is very very important. So, and then we also discuss about the sediment yield estimation. heavy metal monitoring and organic and radioactive contamination.



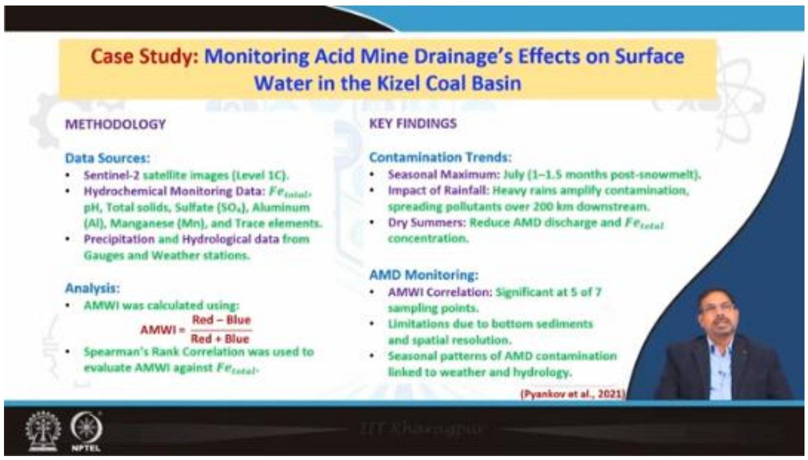
So, this organic and radioactive contamination combines the remote sensing with chemical and gamma ray spectrometry for the detection of hydrocarbons and radioactive materials in soils whereas the heavy metal monitoring uses the geospatial technology in assessing the hotspots and the distribution patterns incorporating indices like geoaccumulation index Igeo and pollution load index such as PLI. A case study coming that estimates the foliar dust concentration in an iron ore mining areas given by Kayet et al. published in 2019. So in Kiriburu and Meghahatuburu iron ore mines in Saranda forest in West Singhbhum district of Jharkhand this particular study has been taken.

So the Kayet et al have used the remote sensing data from Landsat 5 TM and Landsat 8, so 2005 and 2016. And then also used some hyperspectral data coming from EO1 Hyperion, 2005-2016. And some field information was done using the leaf spectra vis-a-vis using the spectroradiometer. And the dust accumulation was detected using the PC particle counter and the GPS was used to collect the location of the sampling or the point where it has been collected. And the sample was also utilized for the PCE based particle dust accumulation calculation.

And then in the lab, the dust weights were collected. So the leaves having the dust accumulation were cleaned and they were then taken the weight. So, based on this they have found or derived a kind of spectral analysis of dust vegetation index. So, in an environment or in a situation where the leaf is covered with different concentration of or different quantities of dust in comparison to a leaf having no dust deposition. So, that kind of correlation has been derived and also some vegetation indices was used in terms of deriving the correlation and also the accuracy assessment has been done using the error matrix.

And the results, the vegetation health and DOS distribution could be found out. So, the DOS reduced, what happens? If the leaf having dust deposition, it will reduce the NIR reflectance at the cost of increase in the red reflectance. So in comparison to a clean leaf which is having no dust deposition, The leaf which is having dust deposition will differ in the spectral behavior in terms of loss of reflectance in NIR part of the electromagnetic spectrum and increase in the reflectance in the red part of the electromagnetic spectrum.

So, this can be very well studied in comparison to a dust free canopy environment and the spatial analysis could be done and then the distance from mining mine and transport activity has been calculated in terms of buffer and a kind of inversely proportional relationship has been established as whether the dust level deposition and the activities. So, this kind of study using geo-information helps in estimating the foliar dust deposition around the mining areas. Then another case study done by another study done by Piankov et al published in 2021 in Kaizhel coal basin on acid mine drainage. So, what they have done they have used the satellite data particularly Sentinel-2 data and the hydrochemical monitoring data and also use the precipitation and hydrological data. and came out with an index called AMWI, that is Acid Mine Water Index.

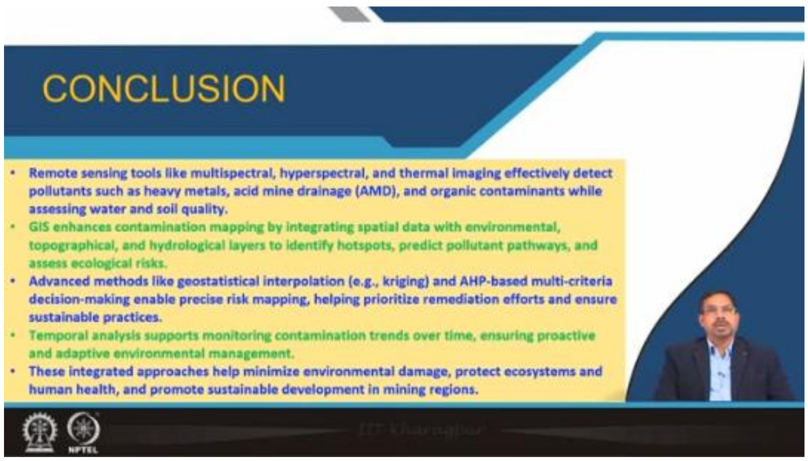


So, the formula is red minus blue over red plus blue.

$$AMWI = \frac{Red - Blue}{Red + BLue}$$

So, this AMWI index helps in providing what you might call discrimination as far as acid mine drainage is concerned. Both will have variations across the seasons. So, seasonal maxima and the impact of rainfall. And also, during the dry summer, this AMD can be very well studied using AMWI.

This index has shown a very good correlation, significant at 5 out of 7 sampling points. So, using indices such as AMWI, the acid mine drainage effect can be studied around mining activities. So, we have used these references for the discussion. We conclude that remote sensing tools like multispectral, hyperspectral, and thermal have a definite role to play. GIS helps in integrating the data, both spatial and non-spatial. And geostatistical tools such as Kriging-based interpolation and multi-criteria decision-making, such as AHP, help in extrapolating the information, the data point data, and also in modeling some of the vulnerability and risk scenarios.



And continuous or temporal monitoring helps in identifying trends, thereby enabling proactive environmental management. So, these integrated approaches of geoinformation help in minimizing environmental damage, protecting ecosystems and human health, and thereby promoting sustainable development. So, friends, mining contamination in the mining industry is definitely benefited by using geoinformation tools for mapping, identification, analysis, and modeling studies. Thank you very much.