SUSTAINABLE MINING AND GEOINFORMATION

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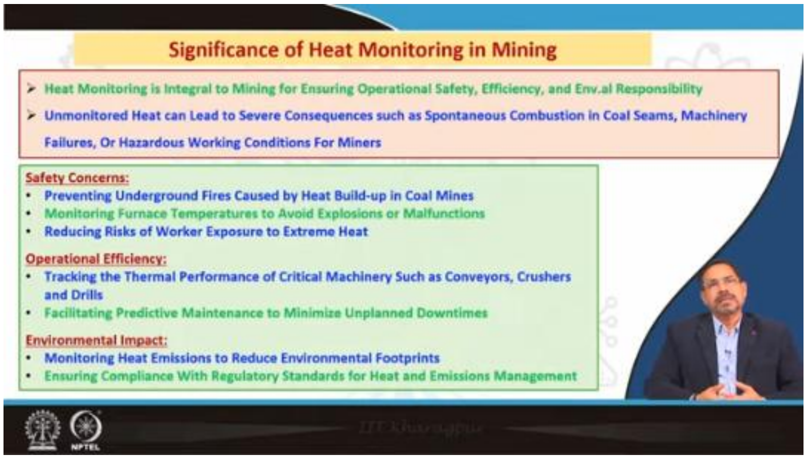
Week – 04

Lecture 19: Heat Detection and Monitoring

Welcome to the 19th lecture. Let us talk about heat detection and monitoring. So, this is the 19th lecture as far as the Sustainable Mining and Geoinformation course is concerned. So, let us discuss the concepts broadly—how remote sensing is applied for detecting heat in active mining operations. We will also discuss monitoring machinery, the furnace, and how to detect underground fires in coal mines. We will also take two case studies to see how thermal monitoring is applied for mine safety and better equipment efficiency. So, the purpose of studying heat anomalies or heat detection.

So, the purpose, relevance, and technological integration could be like this. The purpose is that heat detection and monitoring play an important role in modern mining operations, addressing critical aspects such as safety, efficiency, and environmental sustainability. Yes, as far as environmental sustainability, the safety of both life and property, and the efficiency of the mining environment are concerned. So, we need to implement effective or modern mining operations or management. So, detecting and monitoring heat is also part of modern mining operations.

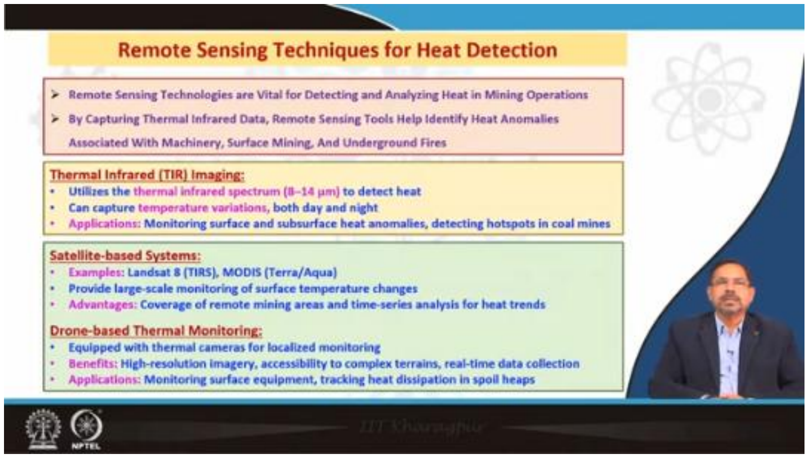
The mining industry operates under very difficult and challenging conditions where temperatures could be high. So, high temperatures can indicate potential risks such as machinery overheating, underground or subsurface fires, or other inefficiencies that can arise due to different processes. So, the technological interventions could be by leveraging advanced technologies such as the geoinformation we are discussing in detail here. So, these advanced geoinformation techniques help in identifying and mitigating heat-related issues efficiently and promptly, thereby aiding in advanced or smart mining operations. The significance of heat monitoring in mining: heat monitoring is integral to mining for ensuring operational safety, efficiency, and environmental responsibility.



So, unmonitored heat can lead to severe consequences if we do not monitor the anomalies or variations in terms of the heat or the heat content of any environment or system. It could cumulatively have disastrous consequences such as spontaneous combustion in coal seams or certain failures of the machinery or hazardous working conditions for the miners or workers who are working in a mining environment. So, safety concerns, as far as safety is concerned, are one of the significant aspects in terms of studying or monitoring the heat in the mining industry. So, safety concerns prevent underground fires caused by heat buildup in coal mines. So, if we monitor it regularly, it could prevent any kind of underground fires that can be caused by the accumulation of heat in coal mines and monitoring the furnace temperature to avoid explosions or malfunctions.

The temperature of the furnace also needs to be monitored regularly to avoid any kind of explosions, and it also reduces any risks to workers who are exposed to higher temperatures or extreme heat conditions. The operational efficiency—yes, if we monitor this, it will lead to efficient performance, or the performance of the machinery such as conveyors, crosshairs, or drills will be optimal. So, monitoring this thermal performance at regular time intervals is important. It also facilitates predicting maintenance to minimize plant downtimes. So, what are the environmental impacts?

The environmental impacts are monitoring heat emissions to reduce environmental footprints, thereby ensuring compliance with standard rules or regulations for heat and emission management. So, the significance—I will repeat—the safety concerns address any kind of operational efficiency or optimization in terms of operational efficiency, and also it addresses environmental impact criteria as far as rules and regulations are concerned. So, what are the techniques available as far as heat detection is concerned from remote sensing platforms? So, remote sensing techniques are vital for detecting and analyzing heat in mining operations by capturing thermal infrared data. This remote sensing helps in identifying heat anomalies, any change in the heat content which is associated with machinery heating, surface mining, or underground fires.

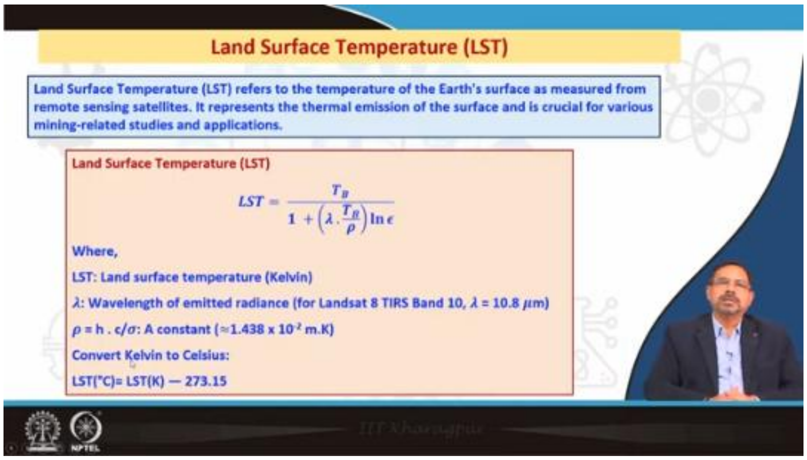


So, as far as remote sensing is concerned, thermal remote sensing or TIR imaging is very important because it utilizes the thermal infrared spectrum, which ranges between 8 to 14 micrometers, to detect heat. So, that is how thermal infrared imaging can capture temperature variations, both diurnal day and night, because it is independent of light. So, diurnal temperature variations can very well be captured using thermal imaging. Rather, it is advised that nighttime temperatures are free from various other external factors or disturbances. So, nighttime temperatures are usually preferred for any change or regular monitoring activities.

The applications include monitoring surface and subsurface heat anomalies and detecting hot spots in coal mines. So, satellite-based systems, such as those from Landsat 8's Thermal Infrared Sensor (TIR), which operates in the range of 8 to 14 micrometers, and thermal sensors in MODIS, both TERA and AQUA, are used. So, satellite-based systems provide large-scale monitoring of surface temperature changes. The advantages of remote sensing are that it covers a larger area, particularly in mining, and aids in time-series analysis for any heat changes, trends in heat content, or heat anomalies. Drone-based thermal monitoring, as we know, drones or UAVs also offer a different kind of close-range platform.

So, if we equip these platforms with thermal cameras, they are useful for imaging over relatively larger areas or mining sites. So, with high resolution. So, in comparison to satellites, drones or UAVs offer high-resolution images and access to complex terrains. So, wherever we cannot reach physically, these UAVs can mount a thermal camera. So, it will provide information about inaccessible terrains and also helps in real-time data collection.

So, the applications in terms of drone-based thermal monitoring could be monitoring surface equipment, tracking heat dissipation in spoil heaps. So, somewhere some heaps or dumps are there. So, how the heat is moving based on the conditions or the criteria or the environment present there. This kind of real-time monitoring and tracking, as well as identifying what kind of equipment is present in terms of monitoring and presence or absence, can be tracked using the drone-based thermal monitoring system. So, let us have a look at the equation as far as the LST or land surface temperature calculation is concerned using satellite data.



Land Surface Temperature (LST) is given by,

$$\mathrm{LST} = \frac{T_B}{1 + \left(\lambda \, . \frac{T_B}{\rho}\right) \ln \epsilon}$$

where,

LST: Land surface temperature (Kelvin)

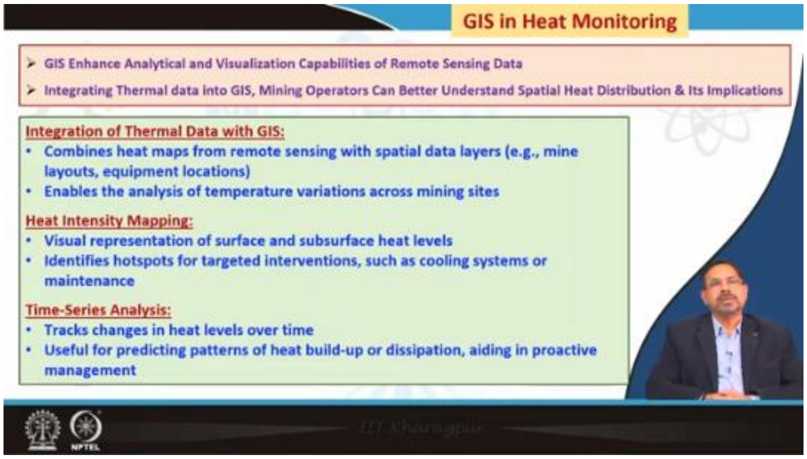
λ: Wavelength of emitted radiance (for Landsat 8 TIRS Band 10, $\lambda = 10.8\ \mu$m)

ρ = h. c/σ: A constant (≈1.438 x 10^{-2} m.K)

Convert Kelvin to Celsius: LST(°C) = LST(K) — 273.15

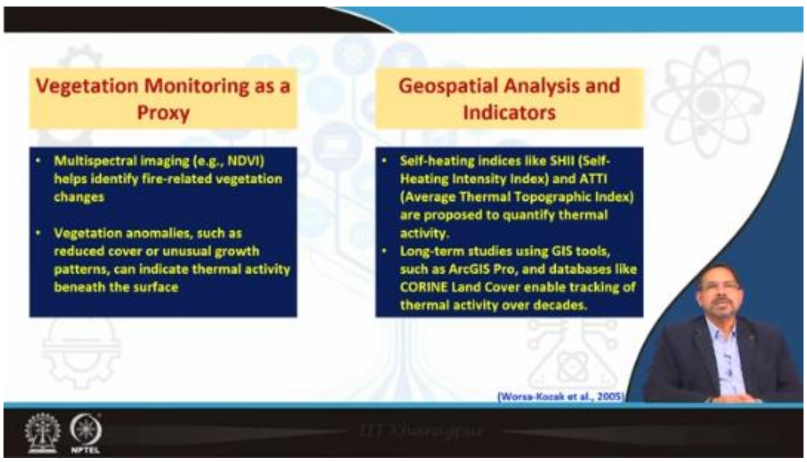
So, LST refers to the temperature of the Earth's surface as measured from remote sensing satellites. It represents the thermal emission of the surface and is crucial for various mining-related studies and applications. So, LST is represented using this formula before you, where LST stands for land surface temperature measured in Kelvin, which also has a conversion. So, you subtract 273.15, which will give you the land surface temperature in degrees centigrade. So, lambda represents the wavelength of emitted radiance.

So, as far as the Landsat 8-based thermal imaging remote sensing band 10 is concerned, this lambda is 10.8, which is the mid-value of 10.8 micrometers, the mid-value of that particular spectral band or bandwidth. So, GIS in heat monitoring enhances analytical and visualization capabilities of remote sensing data. It integrates thermal data into GIS, allowing mining operators to better understand spatial heat distribution and its implications. So, the integration of thermal data with GIS helps in combining the heat maps from remote sensing with any kind of spatial data layers, such as mine layout, equipment location, and all those things. It can be combined with the thermal data using or in the GIS platform, thereby enabling the analysis of temperature variations across mining sites. So, heat intensity mapping provides a visual representation of surface and subsurface heat levels. It also helps in the identification of hotspots for targeted interventions, such as cooling systems or maintenance, and we also do time series analysis using GIS.

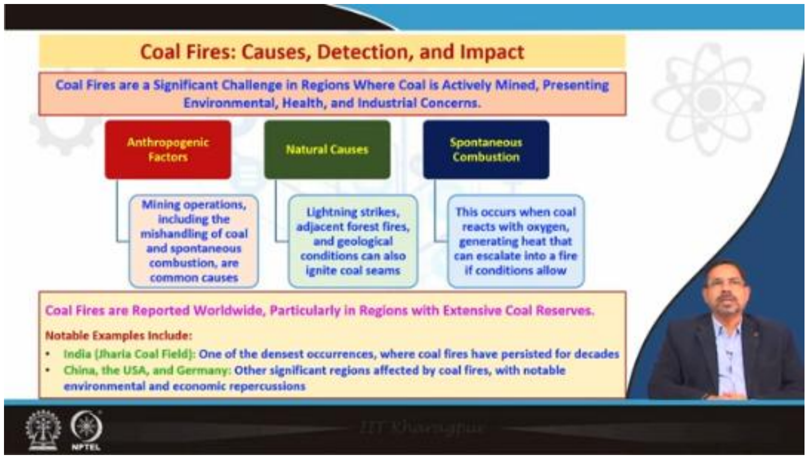


So, use the time series analysis helps in tracking any kind of changes in the heat content or the level of heat over time over you can have seasonal, you can have diurnal, you can have monthly or yearly. So, this helps us tracking or knowing the change of the variation in heat or the temperature over time scale. So, this is how it is useful for predicting any kind of pattern of heat buildup or dissipation. So, if we see it or if we know it across time then we understand the pattern of either heat buildup or heat dissipation. So, that is how it will help us in in doing any kind of modeling or prediction kind of analysis and that is why it could be useful for proactive management or proactive mining management.

So, let us see vegetation monitoring as a proxy. Yes, very often vegetation is monitored that gives us a proxy that is used as a proxy as far as any kind of heat anomaly or variation in heat is concerned. So, using normal multispectral imaging optical NDVI and other indices it helps in terms of identifying any kind of fire related vegetation changes. We can of course, use many fire events like normalized burn ratio and things like that that gives us indication about any fire related activities or fire related vegetation loss. So, any kind of vegetation anomalies such as reduced cover or unusual growth patterns can indicate thermal activity below the surface or beneath the surface.



Using geospatial analysis and indicators, yes many indices such as self-heating indices SHII. So, we call it self heating intensity index and ATTI the average thermal topography index these are proposed to quantify any kind of thermal activity. So, you take it across time A minus B or T1 minus T2 you will get an information about any kind of change in terms of the heat content. So, long term studies using GIS tools such as any kind of GIS platform and databases helps in tracking thermal activity over time period. The let us discuss about coal particularly the coal fires the different attributes in terms of causes detection and impacts as far as the disaster and the thermal or the heat anomaly is concerned.



So, coal fires are a significant challenge in regions where coal is actively mined. That is how it presents environmental concerns, health concerns, and industrial concerns. So, the atmospheric factors, natural causes, and spontaneous combustion—these all attribute to what you say are triggering factors as far as coal fires are concerned. So, the anthropogenic factors—mining operations, including mishandling of coal and spontaneous combustion—are common causes. Always, anthropogenic causes—that include the mishandling of coal—contribute to common causes as far as coal fires are concerned. The natural causes are important. Natural causes include lightning.

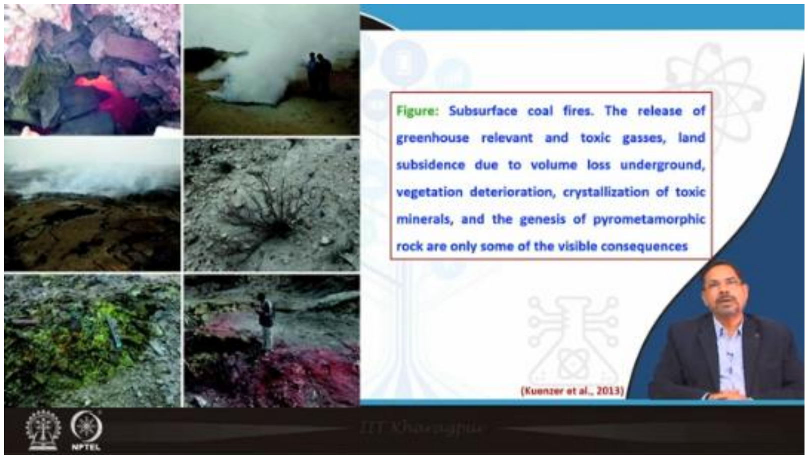
If lightning strikes adjoining forest areas or a forest fire happens, then the geological conditions around that may ignite the coal fire or the coal seams. And the third reason could be spontaneous combustion. This occurs when coal reacts with oxygen, generating heat that can escalate into fire if conditions allow. So, we need to see what the in-house or ambient conditions are. If these kinds of conditions are present or become suitable, then immediately the fire or the combustion happens in a spontaneous way. So, coal fires are reported worldwide, particularly in regions with extensive coal reserves.

So, notable examples include the Jharia coal field mines in Jharkhand, India. It is one of the densest occurrences where coal fires have persisted for decades. So, we have been hearing and reading here and there that coal fires in the Jharia coal field are one of the very important, what you say, disastrous activities, which persist for decades. So, we need to address them. So, also in the rest of the world—such as China, the US, Japan—other significant regions are affected by coal fires, with notable environmental and economic repercussions.

So, please have a look at these two false color composites on the left-hand side: March 30, 1998, Landsat 5 FCC of part of Jharia coal field. And on the right-hand side, it is

April 2nd, Landsat 7 FCC of the same region. So, it can be seen that the brownish-black areas on the left-hand side—what you call the FCC (false color composite)—show that the brownish-black areas are exposed coal, and the surface fires are seen as red dots over that. So, over the brownish-black areas, which are the exposed coal, you can see the red dots; those are the surface coal fires. On the right-hand side, the areas previously burned have been extinguished, and it is now part of the expanding urban area in the Dhanbad region.

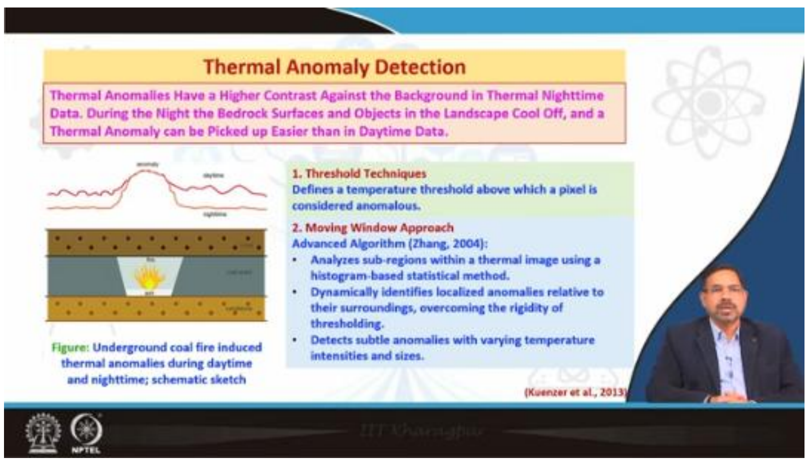
So, compared to 1998, the 2019 change shows that those areas have been extinguished as far as the coal burn—or coal fire—is concerned, and now some kind of settlement activity has come up over the same area. This has been reported by Cristobal et al. in their publication in 2024 this year. So, have a look at the other one: the upper left corner shows a subsurface coal fire in red color; the fire is ongoing. So, the release of greenhouse-relevant and toxic gases, land subsidence due to volume loss underground, vegetation deterioration, crystallization of toxic minerals, and the genesis of pyrometamorphic rock are only some of the visible consequences of the coal fire activity. So, these are the visible consequences. What are the techniques?



The techniques for monitoring coal fires include thermal data analysis, high-resolution optical imaging, greenhouse gas emission studies, and in-situ mapping. As far as thermal data analysis is concerned, we employ day-and-night thermal differences to isolate any kind of fire anomaly. So, any change with respect to A minus B in terms of temperature gives us the temperature anomaly that we relate to fire or any kind of coal-fire-based activities. And then, the pre-dawn winter imagery enhances detection due to maximum contrast. Here, this talks about the time—the period where we can have maximum contrast, which is the pre-dawn period in the winter season.

Because at that time, we have minimal hindrances as far as the atmosphere is concerned. So, high-resolution optical imaging is effective for identifying structural precursors such as cracks and fissures to fire spread. Also, mapping subsidence using interferometric techniques is limited due to sudden, unpredictable ground collapses. Greenhouse gas emission (GHG) studies provide efforts to quantify coal fire emissions for climate impact and trading schemes, but they have faced challenges in baseline establishment. In-situ mapping, we have other devices such as thermal cameras and radiometers, which provide localized data.

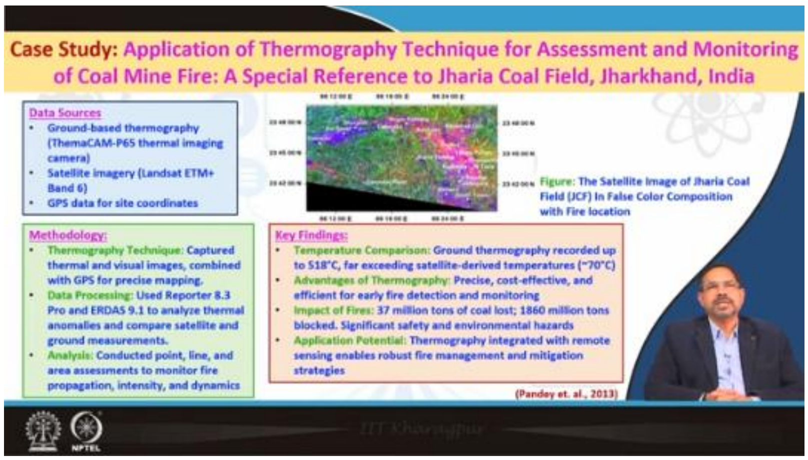
So, they are useful in observing the cracks, the vents, and the fissures, which is how they support high-resolution data for fire mapping. So, the thermal anomaly detection looks at the lower-left depiction, which talks about underground coal fire-induced thermal anomalies during daytime and nighttime. It is a schematic. So, if there is a fire underground, the temperature on top or above the surface gives you an anomaly—a higher temperature. So, the night and daytime difference shows that both times have a higher temperature, and in general, the same region has fluctuations in nighttime and daytime temperatures. But, over the coal fire areas, the daytime and nighttime temperatures are very high.



So, the thermal anomalies have a higher contrast against the background in nighttime thermal data. So, during nighttime, the bedrock surface and objects in the landscape cool off, and a thermal anomaly can be picked up more easily than in daytime data. So, we really need to use nighttime data to do any detection as far as thermal anomalies are concerned. And often, we use a threshold technique. So, threshold means beyond this point, what is the threshold, and above that, we will say that this is definitely a thermal anomaly.

So, we define this as a temperature threshold above which a pixel can be considered anomalous. So, those pixels can be branded as anomalous as far as the thermal or temperature is concerned. So, thermal anomaly pixels are branded. So, another is the moving window approach. So, advanced algorithms given by Zhang et al. in 2004 analyze sub-regions within a thermal image using histogram-based statistical methods.

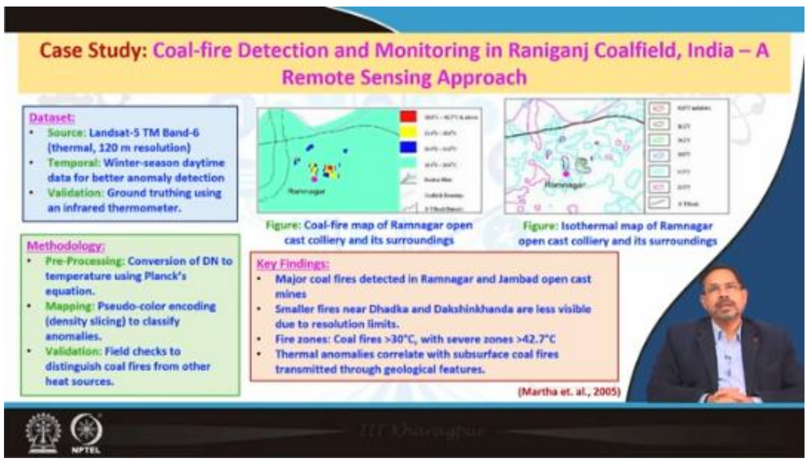
So, these identify dynamically localized anomalies relative to their surroundings, thereby overcoming the rigidity of thresholding. So, it helps in detecting subtle anomalies with varying temperature intensities and sizes. So, the moving window approach is based on a kind of histogram-based statistical method to detect the anomaly in comparison to the surroundings based on a threshold parameter. Now let us take two case studies. The first one is the application of thermography technique for assessment and monitoring of coal mine fires with special reference to Jharia coal field, which is located in Jharkhand state of India.



So, the data sources are ground-based thermography; the ThermaCAM P65 thermal imaging camera has been used. Satellite imageries, Landsat ETM band 6, and the GNSS data for site-level coordinates have been used. The methodology, as far as thermography technique is concerned, captured thermal and visual images combined with the GNSS-based input for precise mapping because we are integrating the localized or location-specific information into the data processing. So, the authors Pandey et al. in 2013 used Reporter 8.3 Pro and ERDAS 9.1 to analyze the thermal anomalies to compare the satellite and ground-based measurements. So, the analysis was conducted across points, lines, and areas to assess and monitor fire propagation, intensity, and dynamism.

So, the key findings if you can it can be seen over seen on a on the satellite image which we say the Jharia coal field mine in terms of a false color composite where the fire location have been mapped. So, it is it shows the temperature comparisons like ground thermography recorded up to 518 degree centigrade for exceeding satellite derived temperature of 70 degree. So, if you have ground based thermography survey it is giving you very accurate information whereas, in a satellite pixel since it is overall for a pixel of let us say 250 by 250 meter area or 500 by 500 meter area it gives you a average value. So, it could be it was little less. So, 70 degree centigrade.

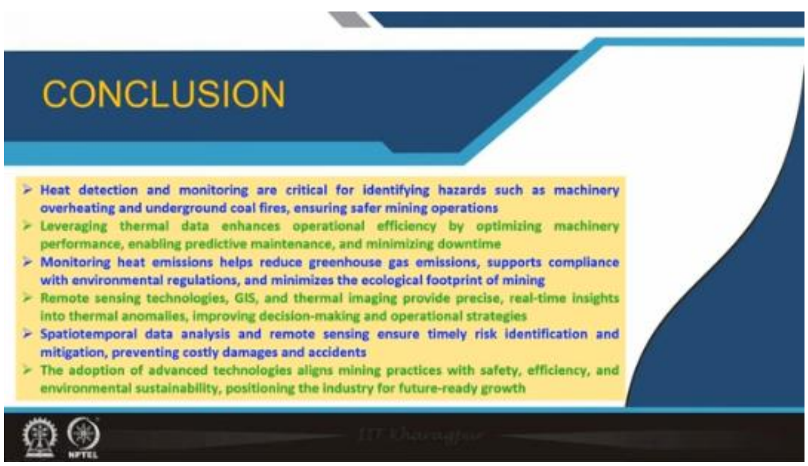
The advantage of thermography gives precise cost effective and efficient for early fire detection and monitoring whereas, 37 million tons of coal was coal loss could be identified. And the potential application in terms of thermography integrated with remote sensing enabled robust fire management and mitigation strategies helps in management of fire in coal field or coal areas. The second one taken from Raniganj coal field in India using remote sensing approach. The data particular Landsat 5 TM band 6 with 120 meter resolution and on the temporal period winter season day time data has been picked for anomaly detection and it has it was validated with ground truthing using the infrared thermometer. The methodology follows pre-processing and mapping and validation.



The key findings which can be seen from the two maps. The first one is the coal fire map of Ramnagar open cast colliery and its surrounding. And, on the right hand side or upper right side, you can see the isothermal map of the Ramnagar coal cast cavalry and its surrounding with a what you say polygons, vector polygons. The key findings, major coal fires detected in Ramnagar and jambot open cast mines. You can see on on the on the map.

The smaller fires near few regions are visible are less visible due to the resolution limit because the TM band 6 gives you 120 meter resolution the pixel size is 120 by 120 meter. So, because of that it could not be very well visible. The fire zones coal fires more than 30 degree centigrade with severe zones 42.7 degree centigrade could be detected and the thermal anomalies correlate with the subsurface coal fires transmitted through the geological features. So, this can be linked to understand the cause the drivers in terms of the fire or the fire events. These are the references which have been used for this particular discussion.

So, let us conclude with these 6 points. Heat detection and monitoring are critical for identifying any kind of hazards such as machine overheating or underground coal fires. And the thermal data using this is helpful in terms of operational efficiency by optimizing machine performance thereby enabling to say maintenance or minimizing the downtime. It also helps in monitoring heat emissions because of the heat emissions such as which is coming because of different greenhouse gases and the remote sensing techniques such as GIS, GPS and thermal imaging along with IoT provides real time data and the thermal anomaly helps in operational in deriving or formulating operational strategies. And, spatio-temporal data analysis and remote sensing ensures timely risk identification mitigation thereby optimizing the cost factor preventing the any kind of damage or accidents to life or property.



So, let us adopt advanced techniques to practice or to do a smart mining or to practice smart mining that ensure safety efficiency and environmental sustainability for a future ready growth. Thank you.