SUSTAINABLE MINING AND GEOINFORMATION

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Week – 04

Lecture 18: Disaster Management

Welcome, let us talk about disaster management as far as the course on sustainable mining and geoinformation is concerned. Today, we will be covering the following concepts, particularly the use of satellite remote sensing and GIS in predicting and managing mining-related disasters such as landslides or tailing dam failures. We will also discuss the early warning systems and risk assessments for disaster-prone mining regions, and we will have two case studies that we will talk about regarding the applications of geospatial tools in disaster response and recovery planning in mining areas. As well as a kind of land surface temperature-based analysis that talks about the disaster or gives indications about some kind of irregular events or activities. So, to predict mining-related disasters, remote sensing, GIS, and the family of tools, including everything which we bundle together under geoinformation.

So, geoinformation tools play a crucial role in predicting and managing mining-related disasters such as landslides and tailing dam failures. These tools offer real-time monitoring and, more importantly, a kind of spatial analysis you get in terms of 2-dimensional or 3-dimensional space that occupies X, Y, and Z dimensions. And also, the data visualization: you visualize the data from different aspects, from different angles, from different solar illumination viewpoints. So, it helps us in this way; it helps us in decision-making and effective planning. So, what are the different disasters that could occur in the mining sector or mining industries?

So, one is the landslide. So, predicting landslide activities in mining areas in the mining industry is very important because if we can predict the landslide in advance, then we can take preventive measures. So, the high-resolution imageries and the digital elevation models derived from various data sources, as we already know now, with respect to digital photogrammetry, the LiDAR-based data cloud points, the SAR interferometry-based elevation. So, these all help in giving us information about the slope stability. And in terms of the differential mode, we get whatever changes are happening in terms of the slope, in terms of the elevation, in terms of deformation.

So, that gives us an idea about any imminent landslide event that could occur. Next, we come to tailing dam monitoring. Satellite-based SAR, or synthetic aperture radar, identifies deformations in dam structures that precede failure. So, if there is any deformation in the structure of a dam, that can be very well identified using differential SAR interferometry. This technique helps in preventing any kind of failure activities.

The third one is ground subsidence. We have already discussed this in different events as far as subsidence study is concerned, but this is also one of the mining-related disasters. So, ground subsidence can be studied or analyzed using time-series SAR interferometry data or LiDAR data clouds. This data helps in tracking the subsidence that can be caused by different underground mining excavation activities. The fourth one is hydrological assessment. In terms of hydrological assessment of disasters related to hydrology, it identifies any changes in water level, moisture content, and flow patterns near mining areas. GIS helps in simulating, predicting, and attributing the trend cumulatively. The impact of any kind of weather or extreme weather events can also be clubbed together, providing a different assessment as far as the hydrology of the mining area is concerned. Thereby, it aids in designing mitigation strategies or decision-making processes. Now, let us see the use of remote sensing as a data source in predicting and managing mining-related disasters.

First, we we have put it under 3 one is monitoring land deformation if there is any change in the land in terms of subsidence or in terms of any movement. So, this movement or deformation needs to be monitored and remote sensing helps in that. Third second is identifying the hazardous zones. So, the moment we talk about the zones. So, the the the hazards.

So, we can categorize the mining area in terms of various risk or having hazard or risk hazard zonation can be done and third is disaster event monitoring. So, this also any kind of disaster even can be monitored using satellite remote sensing. So, coming to the monitoring and deforestation, what are the datasets we usually use? the SAR synthetic aperture radar and InSAR the synthetic aperture radar interferometry techniques. So, these two techniques help in detecting the ground deformation as we already know about the accuracy it can go up to millimeter level accuracy helping identifying the areas which are at different risks of subsidence, different risk of deformation that could lead to bigger events like landslides.

The satellite images coming from the optical sensor such as Sentinel-2 and Landsat, IRS in Indian Remote Sensing Satellites. So, these optical data they detect the vegetation loss water logging areas and other early signs of instability. So, registration loss is a sign of instability it it leads to what you say it is triggered by some other event down below below because of mining or other activities or because of other things such as fire or or what you say the degradation related activities. Then the second one is water logging, water logging and similar kind of activities they they sometime offer indication of instability in mining areas. So, detecting these kinds of instabilities very important and satellite imagery helps in that.

Coming to thermal imagery, where heat anomalies can be very well identified, which could indicate stress or any kind of potential failure zones in tailing dams. So, any kind of fluctuation or anomalies due to variation in heat content, temperature—all these things can be very well captured using thermal imaging. Coming to disaster event monitoring, yes, we have with us the drones or UAVs, unmanned aerial vehicles. So, these platforms provide very rapid and high-resolution imagery, particularly post-disaster. So, if we have this kind of information post-disaster, it can help in terms of recovery planning, relief distribution, and effective damage assessment. So, multispectral and hyperspectral imaging assist in identifying contamination spread from any tailing dam breaches or other activities.

So, hyperspectral and multispectral imagery helps in identifying the spread of contamination or any other tailing activities with respect to GIS. So, as we already know, the geographic information system integrates spatial and non-spatial attribute data, thereby helping in managing mining-related disasters. So, GIS integrates both these datasets. It also helps in visualization and analysis, thereby enabling decision-makers and managers to assess any kind of risk and plan mitigation measures or strategies. So, let us talk about hazard mapping. Yes, hazard zone or hazard risk zone mapping and monitoring are very important. So, overlaying geological, hydrological, land use, and land cover data—

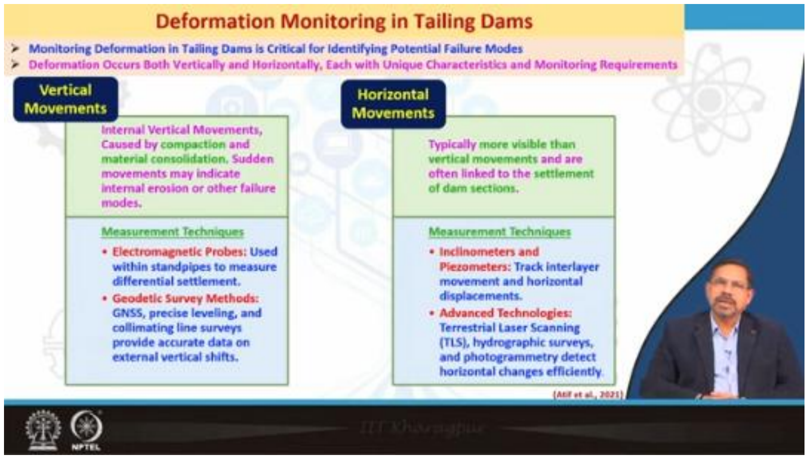
And many other attributes or layers—we say information layers—that serve as proxies or indicators to hazards can be integrated together to identify risk zones as far as landslides, floods, land subsidence, or similar hazards are concerned. So, hazard mapping is also done to provide information on tailing dam vulnerability using maps of various parameters such as slope, drainage patterns, and historical failure data. So, historical failure data is very important because it already gives an indication that failures have happened here before, providing clues about what went wrong. So, accordingly, it prepares or gives important intelligence for GIS integration or GIS-based analysis. Then, risk assessment and modeling—yes, predictive and multi-criteria analysis.

So, we need to do some kind of prediction, and GIS helps in that by imitating the pattern or the trend or the attributes or the causes or the drivers that are linked to this kind of disaster activity. And using multicriteria analysis, we combine various factors including environmental, social, and economic factors that are present or available around the locality, around the mining areas, to prioritize the risk areas—low to high kind of gradation—both quantitative and qualitative can be done for effective management and relevant interventions. Now let us talk about the DSS decision support system. So, real-time data integration linking GIS with IoT sensors in mining areas enables continuous monitoring of critical parameters. So, in terms of decision systems, decision systems help in enabling us to make any decision or provide any decision based on science, based on scientific evidence, and based on the inputs we provide to that.

So, real-time data integration links GIS and Internet of Things-based sensors in mining areas, which enables continuous monitoring of critical parameters such as water levels and other seismic activities. Emergency response planning: GIS facilitates the development of evacuation routes and resource allocation plans. So, that is how it helps in planning any kind of emergency response. Mining-induced seismic events, or mining-induced seismicity, result from fracture initiation, propagation, and rock mass movement. So, this could happen during large-scale excavation, and that is why it is triggered by tectonic and many kinds of mining-induced traces.

These mining-induced seismic activities are observed globally, mostly in underground mining and tunneling across various rock types such as granite, which is a kind of very hard rock we all use, and coal, a kind of very soft rock. So, this kind of rock—any kind of this rock—is observed mostly in underground mining. So, the risks are delays in production, equipment damage, and any kind of structural collapse in terms of drifts or stops. So, rock bursts and mine roof collapses pose significant threats to miner safety. Let us talk about the impact or the magnitude of the impact.

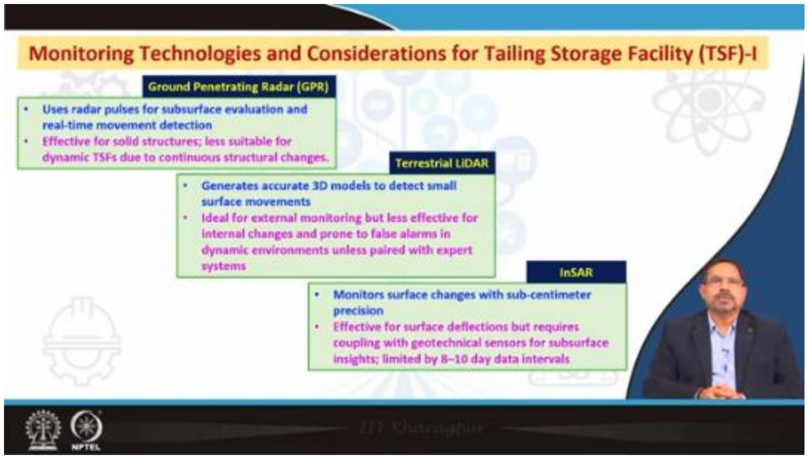
So, events with a magnitude of 3.0 on the seismic scale can cause severe damage within a 100-meter radius, including rock falls and structural instability. So, depth, excavation size, production rate, geological discontinuities, and ambient tectonic stress—these factors all contribute significantly to influencing any kind of seismic activity. So, monitoring mine-induced seismic activity is a must, using geoinformation tools, which are very helpful. So, deformation monitoring in tailing dams is critical for identifying potential failure modes. Deformation occurs both vertically and horizontally, with unique characteristics and monitoring requirements. So, let us see what the vertical movement properties and the horizontal movement properties are.



As far as vertical movement is concerned, internal vertical movements are caused by compaction and material consolidation, and also by sudden movements that may indicate internal erosion or other kinds of failures. So, how do we measure this kind of vertical movement? In mining environments, we also use electromagnetic probes within standpoints to measure differential settlements, and another method is the geodetic survey. So, using GNSS—the Global Navigation Satellite System. Precise leveling and collating line surveys provide accurate data on external vertical shifts.

So, we have already discussed GNSS, differential GNSS, where you have the Arctic and other modes, and a roving activity, you have a base station. So, we have discussed all this in terms of accuracy as far as the geodetic survey is concerned. So, accurate data provides more precise information about vertical shifts. Now, let's talk about horizontal movement, which is typically more visible than vertical movement and often linked to the settlement of dam sections. So, measurement techniques such as inclinometers and piezometers are used.

So, these instruments track inter-layer movement and horizontal displacements. And the advanced remote sensing technology, such as TLS (terrestrial laser scanner), hydrographic surveys, and photogrammetry-based analysis, detects horizontal changes more efficiently. So, both horizontal and vertical movement, in terms of deforestation monitoring as far as tailing dams are concerned, is important and can be done using these kinds of measurement techniques, including instruments or satellite and geoinformation-based approaches. So, what are the monitoring techniques in terms of tailing storage facilities, sometimes abbreviated as TSF? So, we have GPR (ground-penetrating radar), terrestrial LiDAR, and SAR interferometry in terms of image or data-providing tools and approaches.

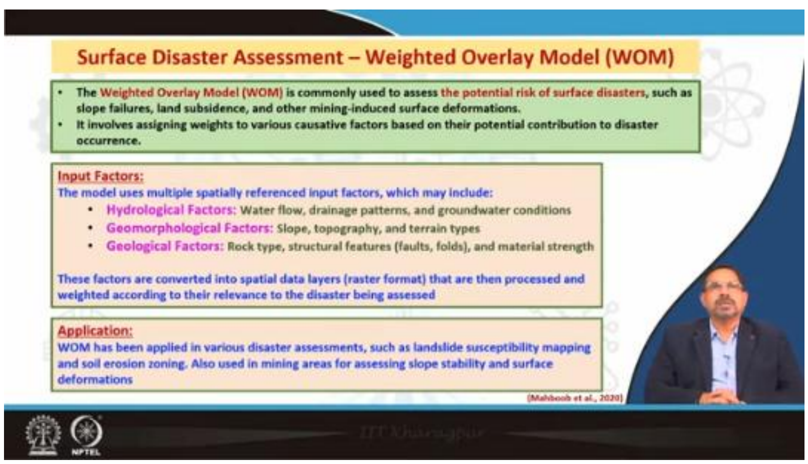


So, in terms of ground-penetrating radar, it uses radar pulses for subsurface evaluation and real-time movement detection. It is very effective because this instrument has more precision as far as the measurement is concerned. And it is effective for solid structures but less suitable for dynamic TSFs, like tailing storage facilities, due to continuous structural changes. So, it is more important or effective for solid structure measurement than for continuous flow measurement. So, the second one is terrestrial LiDAR.

Yes, terrestrial LiDAR generates accurate three-dimensional models to detect small surface movements. So, these small surface movements are ideal for external monitoring, but they are not as effective for internal changes and are also prone to false alarms in dynamic environments unless paired with expert systems. So, we need to use the three-dimensional models generated using the data clouds from the TLS (terrestrial laser scanner). So, that needs to be used in terms of 3D models very effectively. Now, coming to SAR interferometry, InSAR monitors surface changes with sub-centimeter precision.

So, that is how they are effective for surface deflections, but they require coupling with geotechnical sensors for subsurface insights. And this is limited by 8 to 10-day data intervals; this data interval limitation is due to the temporal resolution or the repeatability of the satellite that is mounted with a SAR sensor. The next four are total station automation. Yes, the total station we use tracks surface movements by comparing fixed survey points over time. We also use real-time monitoring systems that combine piezometers, weather stations, ultrasonic, seismic, and ferretic sensors for holistic monitoring of the TSF (tailings storage facilities).

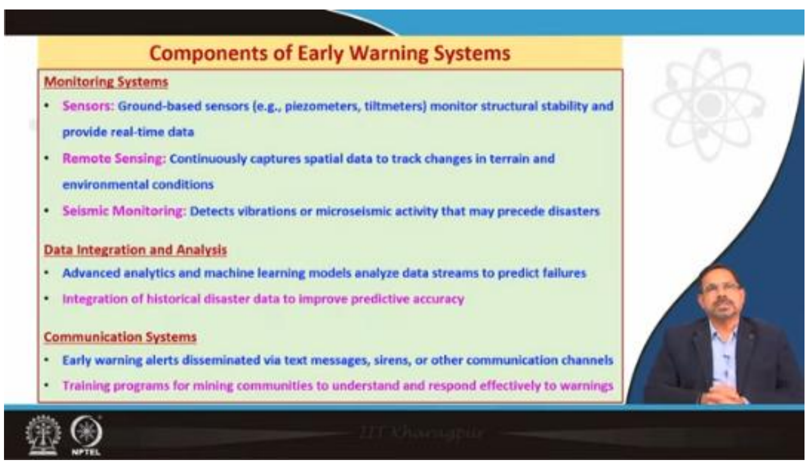
Coming to seismic sensors, seismic sensors detect tremors, earthquakes, and operational vibrations that affect dam stability. As far as the mine IoT-based systems are concerned, they connect sensors, machines, and operators for automated monitoring of deformation, rainfall, and other parameters. So, these methods are available for monitoring the TSF. Now let us talk about surface disaster assessment using the weighted overlay model (abbreviated as WOM). The WOM is commonly used to assess the potential risk of surface disasters such as flow failure, land subsidence, and other mining-induced surface deformations.



It involves assigning weights to various causative factors based on their potential contribution to disaster occurrence. So, input factors—yes, the input factors based on the model—use multiple spatially referenced input factors, which may include hydrological, geomorphological, and geological factors. The hydrological factors, such as water flow, drainage patterns, and groundwater conditions, fall under the hydrological factors. As far as geomorphology is concerned, slope, topography, and terrain types fall under the geomorphological categories. And, as far as the geological factors go, rock type, structural features such as faults and folds, and material strength fall under the geological factors.

So, these factors are converted into spatial data layers raster or the grid format that are then processed and weighted according to their relevance to disaster. So, that is why the model is weighted overlay model. So, we assign a weight based on their importance in terms of contribution to surface disaster ok. So, the application of weighted overlay model. So, WOM has been applied in various disaster assessments such as landslide susceptibility mapping and soil erosion zoning.

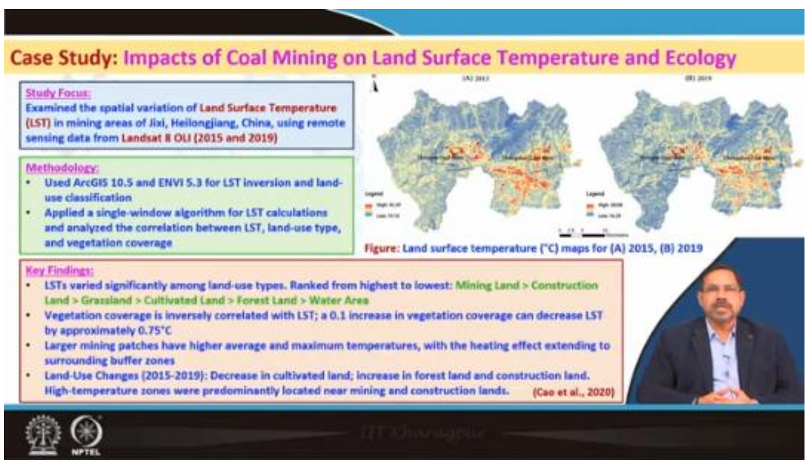
Also used in this model is also used in mining areas for assessing slope stability and surface deformation. So, this Mahboob et al in 2020 have used this model and for surface disaster assessment using this weighted overlay model and this was published their study has been published in the year 2020. So, the components we have various components as far as the early warning systems is concerned the early warning system as far as disaster is concerned. So, it could be the monitoring systems in a in terms of monitoring systems we should have sensors the remote sensing-based images and then the seismic monitoring. So, the sensors such as ground based measurements are concerned the ground-based sensors such as phasometer, tiltmeter etc they monitor any kind of structural stability or instability and provide the real time data.



The satellite remote sensing continuously captures the spatial data and track changes in terrain and the environmental conditions, seismic monitoring detects the vibration or the micro seismic activity that may precede the disasters. So, these data sets when we integrate, so this if we integrate and analyze in terms of using advanced analytics and machine learning tools the failure can be predicted. The failures if we can predict the failure as far as any disaster is concerned then we will be able to take what you say preventive measures in advance. Now, coming to the other component of early warning system that is the communication systems. Early warning alerts disseminated via text messages sirens or other communication channels.

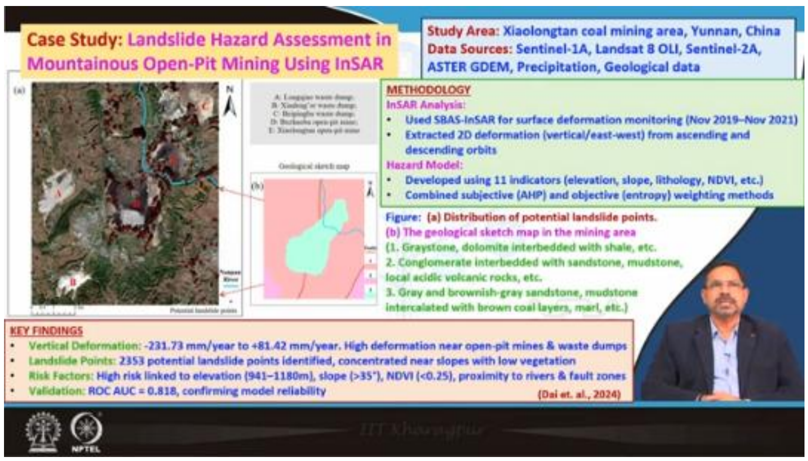
Once we understand that a kind of disaster might happen or there is a chance that it could happen. Then we need to communicate this message at the right place and at the right time. So, this can be in terms of text messages on mobile phones or whatever display devices the workers or the people working in the mining are using or in terms of a siren, so that they will understand that something very hazardous or dangerous is happening, and they will leave the place, vacate the place, prepare for it, or use any kind of communication channels. So, training programs for mining communities help them understand and respond effectively to such warnings.

Let us see two examples. The first one is by Cao et al. Here we are trying to see the change or the realization of the land surface temperature using Landsat 8 OLI, ASTER, or many other remote sensing data sources. We can very well visualize the land surface temperature. This study was done by Cao et al. in 2020, using two sets of images over two time periods: 2015 and 2019.



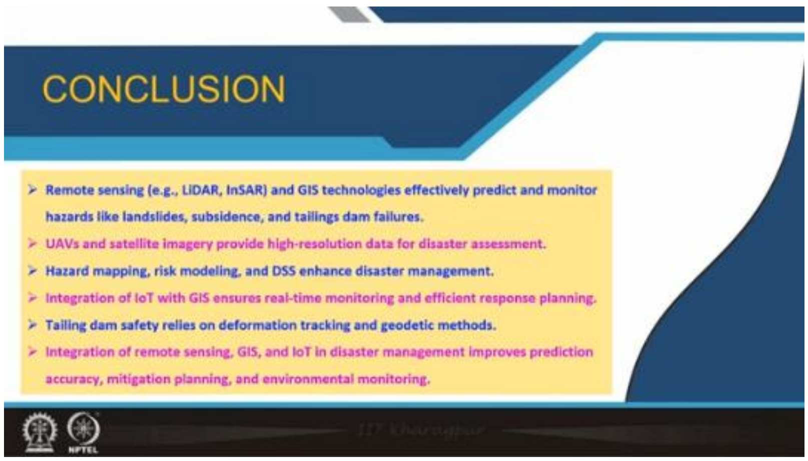
They found a change in the land surface temperature over the coal mining region. So, if we find this kind of temperature variation, we will be prepared to understand what it means. Then, if we correlate the regions or attributes to that, we will understand if it has any chance of leading to any kind of disaster, and we can be prepared in advance. This study revealed that LST varied significantly among land use types, ranked from highest to lowest. Mining land was very high, construction land next, then grassland, cultivated and forest land, and water body areas were the coolest. This kind of variation in land use type or ranking helps in understanding any symbols or indications related to disasters over a mining risk site.

The second case study on landslide hazard assessment in mountainous open-pit mining uses SAR interferometry. This study was conducted by Dai et al. in 2024 over a study area in Yunnan, China. They used data sources from Sentinel-1A, Landsat-8 OLI, and Sentinel-2A. Sentinel-1A is the microwave or SAR, and Sentinel-2 is optical. They also used ASTER GDEM. The digital elevation model, along with precipitation and other geological data, contributes to the hydrological and geological components, respectively.



The methodology in SAR interferometry-based analysis was done using SBAS technology, as discussed in Lecture 17. This helps measure surface deformation accurately. The hazard model used 11 indicators, including elevation, slope, lithology, etc., to develop a model combining AHP (Analytical Hierarchical Process) and entropy-based objective weighting methods. On the left-hand side, the distribution of potential landslide points can be identified. Key findings from Dai et al.'s study include vertical deformation. The deformation ranges from -231.73 mm/year to +81.42 mm/year. Very high deformation, both upward and downward, was observed near open-pit mines and waste dumps.

A total of 2,353 potential landslide points were identified using this hazard model, with risk levels ranging from high to low in landslide hazard zonation. The model was validated using AUC (Area Under Curve), showing good accuracy with an AUC value of 0.818. This indicates high reliability for the model. These references confirm that remote sensing technologies like LiDAR, InSAR, and GIS are effective for predicting and monitoring hazards such as landslides, subsidence, and tailing dam failures, which are common in mining industries. Hazard mapping, risk modeling, and decision support systems enhance disaster management potential in mining operations.



The integration of IoT with GIS ensures real-time monitoring and other benefits, which helps in efficient response planning for the mining industry. Thank you very much.