

# SUSTAINABLE MINING AND GEOINFORMATION

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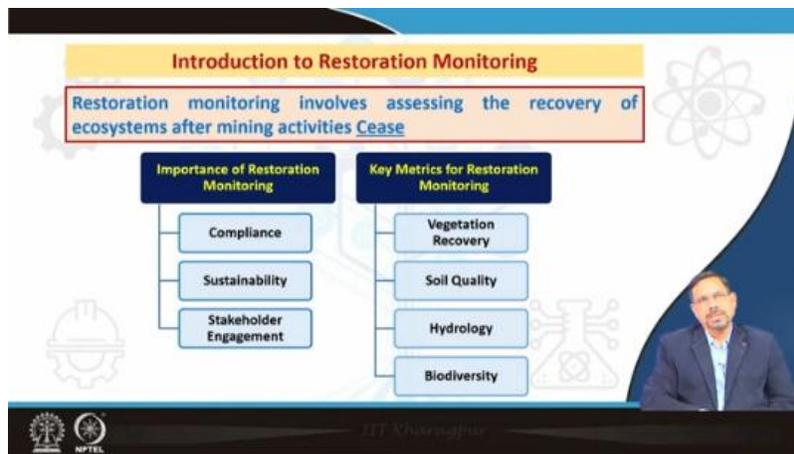
Week – 03

## Lecture 13: Restoration Monitoring

Welcome to the 13th lecture on Restoration Monitoring. In this course on sustainable mining and geoinformation, let us talk about sustainable resource restoration monitoring. So, what is the use and utility of restoration monitoring and its essence? Essentially, when an activity like mining is ongoing, we need to monitor the status of the land and that particular ecosystem before the mining activity has taken place and after the mining activity has been completed. That means it is a pre- and post-monitoring process to ensure that the land has been restored and the indicative parameters, like soil and vegetation, have recovered or nearly recovered compared to the pre-mining scenario.



So, let us discuss the concepts in three ways. One is techniques for monitoring land restoration and revegetation, which occurs post-mining. Then, we will talk about the utilization of geoinformation technology for tracking the progress of ecosystem recovery. We will also discuss two case studies evaluating the effectiveness of reclamation efforts in abandoned mining areas. So first, let us once again try to understand: what is restoration?



What is restoration? How can restoration be monitored? Restoration monitoring involves assessing the recovery of ecosystems after mining activities cease or stop. Essentially, it deals with comparing pre- and post-mining situations or scenarios. So, in an area or ecosystem, what were the conditions before the mining activity took place and after the mining activity has been stopped or ceased?

So theoretically saying, once the mining activity has done, the 100% recovery of the ecosystem may not be possible. Because in a kind of open-cast mining, you uncover the upper vegetation, the upper soil, you disturb the layers which are not required, means not having mineral ore, then those soil and the vegetation including all the properties, biodiversity, hydrological property, everything gets altered. So, in order to understand the restoration monitoring, we need to understand the importance of restoration monitoring and what are the key matrices those are required to understand the restoration monitoring process. The importance of resource monitoring could be to comply. It could be compliance with respect to the area, compliance with respect to the legal or regulatory activities in order to achieve sustainability, the principle of sustainable mining.

And also, we need to satisfy the different stakeholders who are our prime, what you say, the important elements of these activities. Then coming to key matrices, key matrices for restoration monitoring are visibly the vegetation recovery. So, whatever the vegetation present over that area, how much of that could be recovered? Then the soil quality, the recovery of upper soil is nearly difficult. So, but how much or what kind of scenario we are building on to recover the soil, particularly the upper soil and other layers as far as the soil is concerned.

So, in a sense the soil quality recovery. Third is the hydrological status of the area. And of course, the biodiversity, both the underground and above ground flora, fauna and

microbes. Yes, it will be disturbed, but to some extent, that means to what extent the biodiversity could be or can be restored, falls under the broader aspect of restoration monitoring. These are as I mentioned these are the important parameters to judge that how much we have achieved in terms of restoration post mining activity.

So, the remote sensing GIS, GPS, also cloud computation, IoT all this together which we have been discussing under the framework of geoinformation. This geoinformation has a definite role to play. They provide powerful tools for tracking and evaluating all these restoration efforts very efficiently over larger areas and over inaccessible terrains. So, as we know as far as the role or power of remote sensing goes it offers multispectral hyperspectral thermal imaging that have capabilities to monitor whatever changes has happened including contamination over larger areas over large over ecosystems which spread over larger areas. Key applications include as far as the restoration monitoring of mine is concerned are monitoring soil contamination, water quality assessment, air quality monitoring, land cover and vegetation analysis.

**Role of Geo-Information**

Remote Sensing (RS) and Geographic Information Systems (GIS) provide powerful tools for tracking and evaluating these efforts efficiently over large and inaccessible areas

<p><b>Role of Remote Sensing</b> Remote sensing offers multispectral, hyperspectral, and thermal imaging capabilities to monitor contamination over large areas</p> <p><b>Key Applications include:</b></p> <ul style="list-style-type: none"><li>• Monitoring Soil Contamination</li><li>• Water Quality Assessment</li><li>• Air Quality Monitoring</li><li>• Land Cover and Vegetation Analysis</li></ul>	<p><b>Role of GIS</b> GIS integrates spatial data from Remote Sensing with other datasets for comprehensive contamination mapping</p> <p><b>Key Applications include:</b></p> <ul style="list-style-type: none"><li>• Spatial Analysis and Modeling</li><li>• Contamination Hotspot Identification</li><li>• Temporal Monitoring</li><li>• Decision Support System (DSS)</li></ul>
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As far as the role of GIS goes, it integrates the spatial and non-spatial data. Mostly the spatial data can be derived from remote sensing sources. So, the key applications as far as restoration monitoring goes could be spatial analysis and modelling, contamination of hotspot contamination of hotspots for identification, then temporal monitoring and also coming out with a kind of decision support system that how much we have achieved as far as the restoration monitoring efforts are concerned. Now, let us have a look at the various applications in terms of sustainable mining. Friends, these five activities have been selected for discussion.

**Applications in Sustainable Mining**

- Vegetation Monitoring:**
  - NDVI and EVI for Quantifying Green Cover Recovery
- Reclamation Progress:**
  - Detecting Restored vs. Degraded Areas using Land Classification Technique
- Biodiversity Corridors:**
  - Mapping and Monitoring Wildlife Pathways to Ensure Habitat Connectivity
- Soil Health Assessment:**
  - Remote Sensing-based Estimation of Soil Organic Carbon and Erosion Risks
- Water Resource Management:**
  - Monitoring Mining-Induced Hydrological Changes and their Restoration

One is vegetation monitoring. As we know, the vegetation is one of the very important and clearly visible parameters over the earth's surface. So, in kind of any disturbance as far as the mining activities particularly open crust mining activities goes on, we need to very clearly monitor the vegetation whatever was there before and whatever is left after. So, the various indices particularly the vegetation indices such as normalized difference vegetation index, enhanced vegetation index stands for NDVI and EVI respectively. They are useful for quantifying how much of the green cover has been recovered over that particular land which has undergone mining or mining excavation.

Then coming to reclamation progress, understanding the reclamation progress that means detecting the restored areas vis-a-vis the degraded areas using land classification or land monitoring tools. So, we can very well see, we can very well evaluate that how much areas have been restored and how much could not be restored. That means restored area versus the degraded areas can be very well mapped, identified and mapped using these geo-information tools. Coming to biodiversity, sometime we call biodiversity corridor or habitat corridor also in connection to the activities such as biodiversity mapping and monitoring. Friends, what happens, as we know, biodiversity consists of the flora, fauna and microbes of any region. So, mapping and monitoring the wildlife pathways to ensure habitat connectivity is one of the essential parameters of restoration monitoring. If the situation before the mining activity has taken up, what was the situation? What was the wildlife movement, wildlife presence, wildlife activities, wildlife functional activities over an area? Then after that, how much is the activity still going on?

Because a disturbance phase has already happened. So, the flora, the fauna, how much they have been restored? How much the habitat has been connected? Habitat, perhaps we here dominantly considered with respect to the wildlife. So, the wildlife, in particular the

wild animals, how much they are moving along a corridor which is having a lot of connectivity with other habitats.

So how much that has been taken care. So, this all falls under biodiversity mapping, biodiversity monitoring as far as wildlife corridor and habitat connectivity is concerned. The fourth one is soil health assessment. So remote sensing and GIS and geoinformation based estimation of soil organic carbon and erosion risks. So, these the carbon content particularly the SOC soil organic carbon content of the soil is one of the indicators of the soil health and also, we can we need to study the risks in terms of the soil erosion of the upper or the top soil because it becomes loose it loses many of these properties so that is how it becomes fragile to erosion. So, these all we can understand we can study and try to understand this pre and post mining scenario as far as the health status is concerned. The fifth one is water resources management. Friends, monitoring the mining induced hydrological changes and their restoration is one of the very important aspects. The moment the soil, the composition, the layer has been altered, we are also altering the hydrological property, the hydrological behavior of the hydrological characterization of the soil and the materials which is disturbed or altered.

So, restoring them from hydrological point of view is extremely important because that depends in terms of the flora, the fauna or the microbes which live below ground and which also live above ground also depends on the hydrological property of the soil. So, monitoring the hydrological property or the water resources characterizing the water resources of the soil of the land of that particular region is very very important in order to understand the sustainable mining. Then let us look at the techniques for monitoring land restoration and what are the re-vegetation that has happened post mining. So, we can do it in terms of soil quality and soil quality index and also vegetation monitoring. Let us look at the soil quality which in terms of the physical parameter, the chemical parameter and biological parameters can be studied.



As far as the physical parameters are concerned, the soil quality includes bulk density, soil texture, and field moisture. However, the chemical parameters include organic carbon content, pH level, electrical conductivity, nutrient availability, etc. As far as the biological parameters are concerned, soil respiration, microbial biomass, and enzyme activities give us key indications about the soil quality. So, some of these soil quality indices have been generated and developed, which are based on geo-information tools. One of them is the Reclaimed Mine Soil Quality Index.

This index quantifies the soil recovery of restored sites. For a soil quality index, FSQI acts as a benchmark for comparing restoration efforts to natural ecosystems. So, what happens? Many times, we select the adjoining natural ecosystem as the benchmark, and then we take all these properties as the benchmark for soil, vegetation, water quality, and all these things, considering an adjoining area that is a natural and undisturbed ecosystem. And then we compare all these indicators with the disturbed area where mining activity has been done or has ceased, okay, is over.

So, that gives us a good methodology and benchmark for comparison and contrasting. Now, let us look at vegetation monitoring: species richness and abundance. These two are indicators as far as vegetation and biodiversity are considered. The number of species present in a defined area is the indicator or is defined as the species richness of that area, and how abundantly they are present—that means— how many individuals of one particular species there are—talks about the abundance. So, these reflect the ecosystem property as far as biodiversity is concerned. So, in the post-mining scenario, in terms of vegetation monitoring, we need to take a comparative stock of the species richness and abundance status of that particular region.

That is how we can say that yes, how much change has occurred, which reflects the biodiversity monitoring or recovery. Another is biomass production and litter accumulation. Both of them are very crucial as far as nutrients are concerned, as well as carbon or primary productivity, which is one of the most important properties in photosynthesis or vegetation material. So, we need to understand that if we study biomass production, we can understand the carbon sequestration behavior of a region's vegetation. This situation can be compared with pre- and post-disturbance or adjoining natural ecosystems versus disturbed ecosystems.

So, we can assess changes in carbon sequestration. Species richness and abundance primarily describe the structural properties of vegetation, whereas carbon, photosynthesis, or primary productivity are important indicators of vegetation functioning. So, if we study biological richness or biodiversity and carbon, we are primarily examining the structural and functional aspects of vegetation, allowing us to understand how much change has occurred in the post-mining scenario. Then, the faunal community indicators—there are various ways to understand community composition in terms of pre- and post-disturbance for animals, microbes, and litter dynamics, which we just discussed. We can observe how much soil organic carbon deposition has occurred and similar factors. We talk about vegetation recovery monitoring using geospatial technologies.

**Vegetation Recovery Monitoring Using Geospatial Technologies**

- Analysis of Vegetation Cover Changes Using NDVI**
  - Tracking vegetation regrowth patterns
  - Differentiating between disturbed and naturally vegetated areas
- Species Mapping Through Hyperspectral and Multispectral Remote Sensing**
  - Detecting invasive species in reclaimed mining areas
  - Assessing biodiversity levels post-reclamation
- Tracking Forest Regrowth and Canopy Development**
  - Long-term monitoring of forestry restoration projects
  - Quantitative canopy density measurements

So, we have focused on vegetation cover change, species mapping through hyperspectral and multispectral remote sensing, and also tracking forest regrowth and canopy development. These three are very important for understanding or monitoring vegetation recovery using geospatial tools. Vegetation cover change—we use various vegetation indices to track vegetation growth and regrowth patterns in areas affected by pre- and

post-mining conditions. This helps us differentiate between disturbed ecosystems and undisturbed or natural ecosystems in terms of vegetation area or composition. Let us talk about species mapping. These days, species mapping is achieved through hyperspectral remote sensing and multispectral remote sensing.

So, assessing the biodiversity level post-reclamation, how many species were there? Mostly, is it in terms of forest species, monoculture species, or species in terms of 4, 5, 7? We have a very good spectral signature, and pre- and post-reclamation can be very well compared. As far as if the species number, richness, and diversity go very high, then perhaps we may lose some of the spectral signatures to compare and contrast. So, if there is a dominant composition of few species, then it is good to monitor using satellite data. The other point is in terms of detecting invasive species. Invasive species are species that are not native to any region.

These species are foreign to a particular region. They grow very fast. They give tough competition to the native species. So, they are called invasive species because they grab light very fast. They grab nutrients very fast.

They also grab, or their water-use efficiency is very high in comparison to the original native species of a region. So, if we detect invasive species, that will give us an indication of how much the area has become disturbed to accommodate many invasive species or how much invasive species are present over a reclaimed mining area. The third one is tracking forest regrowth and canopy development. Long-term monitoring of forest restoration projects and quantitative canopy density measurements—these activities can be tracked using geospatial technologies. Quantitative canopy density measurement.

Yes, in the canopy density, we go in terms of percentage. So accordingly, we have open, medium open, and dense kinds of canopy that can very well be quantified using satellite data. And these kinds of studies are very useful in terms of forest canopy density or forest cover density in the long term and thereby useful in these kinds of restoration monitoring activities. Let us talk about soil quality assessment. So, monitoring soil erosion and sediment deposition, detection of soil organic matter and nutrients, contamination mapping, and remediation.

**Soil Quality Assessment**

**Monitoring Soil Erosion and Sediment Deposition**  
 Satellite imagery combined with DEMs maps areas of high erosion or sediment buildup  
 Applications:  
 • Designing sediment control measures  
 • Evaluating landform stability post-reclamation

**Detection of Soil Organic Matter and Nutrients**  
 Thermal and Hyperspectral imagery detect soil organic content and nutrient deficiencies in rehabilitated soils  
 Applications: Assessing fertility restoration in reclaimed lands

**Contamination Mapping and Remediation**  
 RS identifies areas of contamination from mining processes and assesses the effectiveness of remediation efforts  
 Applications:  
 • Monitoring the spread of heavy metals and other pollutants  
 • Evaluating cleanup success

As far as soil erosion monitoring and sediment deposition go, satellite imagery combined with digital elevation models is useful in mapping areas with different erosion levels, from low to high, even if the sediment buildup is erosion. So, the applications could be designing sediment control measures, evaluating landform stability after reclamation activity has taken place, that means post-reclamation evaluation of the landform. Detecting soil organic matter and nutrients, thermal and hyperspectral imagery detects soil organic content and nutrient deficiencies in rehabilitated soils. The use of hyperspectral imagery is very essential or has the power to detect the composition or minor variations in the composition of the soil, particularly the soil organic content and nutrient variation. Because when we do spectroscopy or imaging using the narrow channels in the EMS (electromagnetic spectrum), we have much more, we have the spectra that is accounted for by small variations as far as soil organic content and nutrient variation are concerned in the soil.

So thermal, and thermal also with respect to emissivity. So thermal remote sensing application in studying and detecting soil organic content and nutrient deficiency is very important. Applications could be assessing fertility restoration in reclaimed lands. Geoinformation identifies areas of contamination from mining processes and assesses the effectiveness of remediation efforts. The application could be monitoring the spread of heavy metals and other pollutants, evaluating cleanup successes.

So, identifying the contamination from mining processes is very important as far as mining restoration is concerned. Now, let us go to the third one, which is water resources rehabilitation, that could be understood in terms of surface water quality analysis and hydrological restoration tracking. So, satellite data along with the imagery from UAVs is very useful in monitoring surface water quality parameters such as turbidity, chlorophyll

content, and various contamination levels present in surface water bodies. The applications include evaluating the impact of acid mine drainage and assessing the recovery of aquatic ecosystems. As far as hydrological restoration tracking is concerned, time series data is very useful for studying water levels and flow pattern analysis.

**Water Resource Rehabilitation**

**Surface Water Quality Analysis**

Satellite and UAV imagery are used to monitor turbidity, chlorophyll content, and contamination levels in surface water bodies

**Applications:**

- Evaluating the impact of acid mine drainage
- Assessing the recovery of aquatic ecosystems

**Hydrological Restoration Tracking**

Time-series data on water levels and flow patterns analysis and modeling indicate hydrological recovery in mined regions

**Applications:**

- Evaluating the impact of acid mine drainage
- Assessing the recovery of aquatic ecosystems

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That is how it is useful in modeling hydrological recovery in mined areas. The applications could include evaluating the impact of acid mine drainage. And assessing the recovery of aquatic ecosystems. So, studying the variation in moisture levels, water quality, turbidity, chlorophyll content, and contaminant levels are all very important as far as water resources rehabilitation parameters are concerned. So, landform and topographic recovery, biodiversity and habitat restoration, carbon sequestration and climate regulation, mine waste rehabilitation and monitoring.

**Landform and Topographic Recovery**

- DEMs are utilized to track topographic changes, such as slope stability and landform regrading
- Evaluating erosion control effectiveness and for Tracking terrain reshaping after mining

**Biodiversity and Habitat Restoration**

- Map suitable habitats for wildlife reintroduction and biodiversity assessments
- Planning wildlife corridors and to Monitoring species population dynamics

**Carbon Sequestration and Climate Regulation**

- Estimating carbon storage changes in reclaimed lands through LIDAR and remote sensing
- Evaluating microclimatic variations post-restoration using thermal sensors
- Mapping changes in GHG emissions from restored mining areas

**Mine-Waste Rehabilitation Monitoring**

- Mapping tailings storage facility recovery using radar and multispectral imagery
- Assessment of cover vegetation and toxicity reduction on waste dumps
- Evaluating effectiveness of phytoremediation techniques with geoinformation tools

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These are the five broad indicators of monitoring as far as rehabilitation is concerned. So, let us take two case studies. The first one is the assessment of land degradation and restoration in coal mines of central India using time series data analysis. The objective of

this study was to assess land use changes and land degradation in coal So, Sohagpur and Bishrampur coal mines during the period from 2001 to 2020, which is a two-decadal analysis.

**Case Study: Assessment of Land Degradation and Restoration in Coal Mines of Central India: A Time Series Analysis**

**OBJECTIVE**  
Assess land use changes and land degradation in Sohagpur and Bishrampur coal mines (2001-2020)

**LAND USE AND LAND COVER CHANGES (LULC)**

- Decrease Observed in Forests, Water Bodies and Sparse Vegetation
- Increase Observed in Coal Mines/Overburden Dumps, Settlements and Agriculture

**STATISTICAL AND REMOTE SENSING ANALYSIS**

**Indices Used:**

- NDVI (Normalized Difference Vegetation Index): Monitored vegetation health
- NDBI (Normalized Difference Built-up Index): Measured urbanization and mining expansion

**Findings:**

- Sohagpur: Moderate improvement in NDVI (vegetation) and weak to moderate correlation with NDBI
- Bishrampur: Consistent decline in NDVI with a weak relationship to NDBI

**ECO-RESTORATION EFFORTS**

**Methods Implemented:**

- Levelling of land and addition of topsoil
- Plantation of multi-purpose native species (e.g., Teak, Sal, Neem)
- Focus on afforestation and vegetation restoration.

**Outcomes:**

- Moderate improvements in soil parameters
- Uniform growth observed in planted species like Teak and Sal

(Thakur et al., 2022)

So, the land use and land cover change has been studied, and a decrease was observed. It is expected that the forest, water bodies, and sparse vegetation have decreased. Whereas, an increase was observed as far as coal mining, overburdened dumps, settlements, and agricultural activities are concerned. So, the naturalness, which is indicated by the presence of a lot of forests or vegetation, The water bodies and vegetation, whether in sparse or dense condition. So, these have decreased at the cost of the overburdened dumps, which emerged from the coal mining activities in that area.

And also, some settlement areas have come up, and accordingly, some agricultural areas—these sparse vegetation and forest lands—have been converted to agricultural land to cater to the population that has grown in or around those areas. So, the statistical and remote sensing analysis done here includes NDVI and NDBI, where V stands for vegetation and B for built-up. So, these two indices have been used to monitor vegetation health and urbanization activities as far as mining expansion is concerned. So, the findings for the Sohagpur and Bishrampur areas show moderate improvement in NDVI and a weak to moderate correlation with NDVI, whereas a consistent decline in NDVI with a weak relationship was observed in Bishrampur. So, various eco-restoration efforts based on this study could include leveling the land and adding topsoil.

So, one of the most important parameters is the restoration of topsoil. Then, the plantation of multi-purpose native species—whatever native species are present—if planted, they will try to regenerate an ecosystem that perhaps existed years before the mining activity started. And then, focus on afforestation and vegetation restoration. So,

the restoration activity should focus more on afforestation. The outcomes include moderate improvement in soil parameters and uniform growth observed in planted species like teak and sal.

So, once the vegetation restoration activities have taken place, there will be definite improvement in the soil condition, the soil parameters—both quality and quantity—and also the hydrological parameters. So, in the long run, it will lead to the restoration of natural conditions as they were before the mining activity was implemented. Another case study on land restoration measures in highly affected hilly mining watersheds using remote sensing and GIS. The objective here is to mitigate soil erosion and restore the ecology in mine-affected areas of Saranda forest in Jharkhand. So, the methodology followed in this study is as follows.

**Case Study: Land Restoration Measures in Top Hilly Mines Affected Watershed using Remote Sensing and GIS**

**OBJECTIVE**  
Mitigate Soil Erosion and Restore Ecology in mining-affected areas of Saranda forest, Jharkhand

**METHODOLOGY**  
Data Collection: Remote sensing (CartoSat-1, LISS IV), soil and rainfall data.  
Mapping & Modelling

- LULC Mapping: Classified forest, agricultural land, water bodies.
- Soil Erosion Estimation (USLE Model): Estimated erosion risk.
- Surface Runoff Estimation (SCS Curve Number Method): Analysed surface runoff.
- Soil Conservation Potential Mapping (AHP Technique): Prioritized areas for intervention.
- Buffer Zone Delineation: Phillips Model to control sediment flow into water bodies.

**RESULTS**

- Proposed 81 check dams, 152 graded bunds, and 9 nala bunds.
- Bench terracing and staggered trenching recommended for steep slopes.
- Buffer zones around mines to reduce sediment flow and improve water quality.

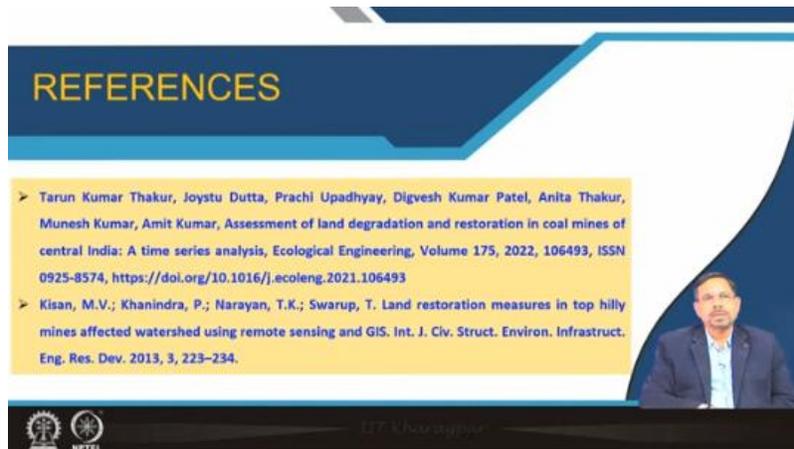
(Kisan et al., 2013)

CartoSat-1 and LISS IV data were used—very high-resolution data—and soil and rainfall data were collected and utilized. Land use and land cover were mapped, where forest, agricultural land, and water body categories were classified. The soil loss equation-based model was implemented to estimate soil erosion risk, and surface runoff estimation was done using the SCS curve number method to analyze surface runoff. As far as soil conservation potential mapping is done, the AHP (Analytical Hierarchical Process)-based technique was used, which helped prioritize areas for implementing intervention activities. The buffer zone was delineated using the Phillips model to control sediment flow into water bodies.

So, the major results obtained are: 81 check dams have been proposed to minimize soil loss. 152 graded bunds and 9 nala bunds were proposed as restoration measures to improve soil loss conditions and runoff conditions. Bench terracing and staggered trenching were recommended for steep slopes to slow down and minimize soil and

sediment loss as well as runoff. Buffer zones around mines were proposed to reduce sediment flow and improve water quality. These kinds of studies using geo-information technology help us identify restoration measures and their exact locations.

Here, 81 check dams, 152 graded bunds, and 9 nala bunds were proposed, and the locations can also be shown very clearly using geoinformation and GIS-based modeling approaches. So, that is the beauty of implementing geoinformation technology as far as restoration monitoring is concerned, particularly for improving soil erosion status, including surface runoff. So, these references were used for this study. So, to conclude, geoinformation techniques provide a systematic approach to monitoring ecological recovery as far as mining areas are concerned. The indices and tools used for vegetation monitoring could include vegetation indices such as NDVI and EVI.



## REFERENCES

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## CONCLUSION

- Geoinformation techniques provide a systematic approach to monitoring ecological recovery in mining areas.
- Techniques like NDVI, hyperspectral imaging, UAVs, LIDAR, and GIS enable detailed tracking of vegetation, soil, hydrology, and biodiversity.
- These methods ensure compliance with environmental regulations, promote biodiversity, and support sustainable reclamation efforts.
- Integration of spatial data facilitates informed decision-making for long-term ecological stewardship and sustainable mining practices.





Hyperspectral imaging helps us in picking up various spectral signatures as far as vegetation species are concerned. UAV, LiDAR, and GIS enable detailed tracking as far as vegetation, soil, hydrology, and biodiversity are concerned. These methods ensure

compliance with environmental regulations, promote biodiversity, and support sustainable reclamation efforts. Integration of spatial data facilitates informed decision-making for long-term ecological stewardship and sustainable mining practices. So, this is about the application and utility of geoinformation techniques.

For restoration monitoring over mining areas as far as pre- and post-activities are concerned. Thank you very much.