SUSTAINABLE MINING AND GEOINFORMATION

Prof. Mukunda Dev Behera

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

Indian Institute of Technology Kharagpur

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Lecture 39: Life Cycle and Associated Environmental Impacts

Welcome to Lecture 39. Let us discuss the various matrices, particularly to achieve sustainable mining using geoinformation. In our initial lectures and discussions, we first talked about the technology—geoinformation technology, various remote sensing, GIS—and then we also covered sensors and sensor technologies. Then, in the second phase, we discussed the various mining-related activities and how they benefit from geoinformation technologies. In the third phase, we discussed the 17 Sustainable Development Goals and how some of them relate to mining or mining industries and how they benefit from geoinformation tools. So, this lecture and the 40th lecture will discuss, in a cumulative sense, how sustainability matrices for the mining industry can be achieved using geoinformation technology.

So, as all of us know, the concepts we are going to cover here are: Sustainable mining, which aims at balancing resource extraction with environmental preservation and long-term societal benefits. So, this is the essence of sustainable mining. So, on one hand, we need to extract mining resources. But then, we need to maintain a critical balance between the extraction of mining resources and environmental preservation, environmental management, environmental quality maintenance, and it must align with long-term societal benefits.

So, this can be optimized by using various approaches, such as life cycle approaches. So, in this 39th lecture today, we will discuss more about sustainability matrices and take a few examples of how they have been achieved or could be achieved using geoinformation tools. These four parts—particularly the inputs, land disruption, output, and closure—were presented in a 2018 publication by Gorman et al. These are the key environmental sustainability parameters related to the mining industry that can benefit from geoinformation technologies. So, the first inputs, as far as the inputs are concerned, are majorly water use in terms of reduction and recycling.

So, in this mining sector, in the mining industry sector, lot of water are used, but we need to really think of reducing the water use, optimizing the water use and also recycle the water use, where we know that geothermal has a great role to play. Second in terms of input is the energy. So, here also we need to in terms of the to achieve the key environmental sustainability parameters as far as energy is concerned we also need to reduce and use alternative that means the renewable energy instead of hydrothermal and coal. So, we can mean instead of the non-renewable we can shift to renewable to the utility of renewable energy resources. The third is the reagents in this we use lot of reagents and need to reduce and come or think out think of the substitutes of the reagents.

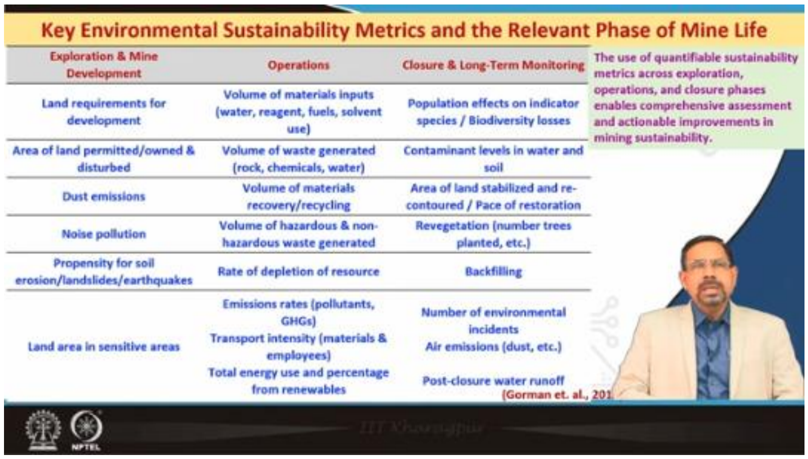
Now, let us move to the second component the second part that is the land disruption. So, here the biodiversity is the first component as far as biodiversity is concerned both in terms of flora, fauna and also we add the microbes to it. So, all this gets disturbed disrupted when a mining activity is taken in an area. So, that we understood that we also need to achieve means we need to take care of this environmental variable as far as or in order to attain the sustainability.

The second is soil along with the biodiversity. Lot of disruption happens to the soil erosion soil contamination soil and many other ways we disturb and disrupt the soil. The third is prevention of seismic effect. The moment we go in terms of resource extraction in mining, we are prone or the area is prone as far as lot of seismic activity is concerned because we create a vacuum. So, that also falls under this land disruption category and there are critical areas which also can be identified or can be managed sustainably as far as the geoinformation technology is concerned. Now the next part is the output when these activities happens in terms of mining industries it disturbs or it enhances I would say it manipulates as far as the greenhouse gases are concerned.

So, in a sense, it interferes with the climate or climate change activities, as we know greenhouse gases contribute toward the warming of the Earth's temperature. So, any kind of these activities in the mining sector contributes to the alteration or manipulation of available greenhouse gases, and in a sense, it also contributes to climate change. Now, the second one is acid waste or sometimes we say acid mine drainage. So, a lot of these means flow in terms of spillover or something similar. So, this also needs to be taken care of, and geoinformation helps by providing a good situation in terms of a geospatial platform.

The third is pollution. So, as far as pollution is concerned in the mining industry, we all know that the surrounding ambient air, water, and soil all get polluted. So, these are some of the negative impacts as far as mining industries are concerned, and geoinformation is extremely useful in providing a situation or helping in terms of taking preventive and corrective measures. Now, during or after the closure of mining—once the mining extraction is over—we need to do a lot of remediation and reclamation activities, and these also need to be monitored at regular intervals. So, here, geoinformation technology helps by providing useful information that aids in monitoring the remediation and reclamation activities post-mining or after the closure of the mine.

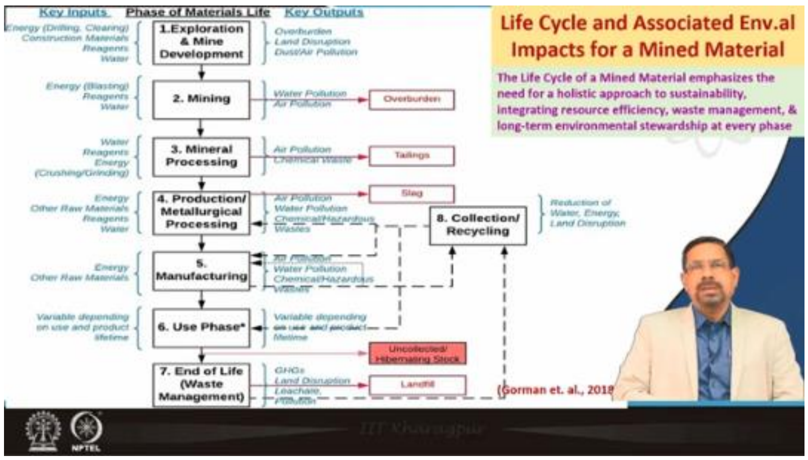
Now, in detail, if we take this as far as the key environmental sustainability matrices are concerned and the relevant phase of mine life. So, here, what I want to say is that the use of quantifiable sustainability matrices across exploitation operations and closure phases enables comprehensive assessment and actionable improvements in mining sustainability. So, here, let us see in terms of a lot of exploration and mine development activities, and in the middle column, we have put the various operations that involve this, as well as closure and long-term monitoring. As we just mentioned, in terms of exploration and mine development, we have various land requirements as far as the land is concerned for developmental purposes. The area of land permitted or owned for disturbance—we say this the moment we refer to disturbance for mining-related activities.



The dust emission, noise pollution, propensity of soil erosion, landslides, earthquakes, and the land area in sensitive areas. So, let us see as far as the land requirements for development are concerned, several operations such as the volume of material input, including water, reagents, fuel, and solvent use, are all involved. During closure or after closure, we go for long-term monitoring of the effect on the population. Indicators of species biodiversity loss all help in terms of bringing or coming out with a kind of environmentally sustainable matrix. Similarly, as far as dust emission is concerned, during operation, the volume of materials recovered and recycled. So, the area of the land stabilized and recontoured, the pace of restoration—these things can be very well monitored and measured using geo-information technologies.

The propensity of soil erosion, landslides, and earthquakes. So, the rate of depletion of resources, particularly in terms of backfilling, can benefit from geo-information. Let us see the last row that talks about land area in sensitive places over the mining region. So, emission rates, particularly pollutants, greenhouse gases, transport intensity with respect to material transport and the employees or workers, total energy use, and the percentage of energy from renewable sources. So, these things fall under the category of operations.

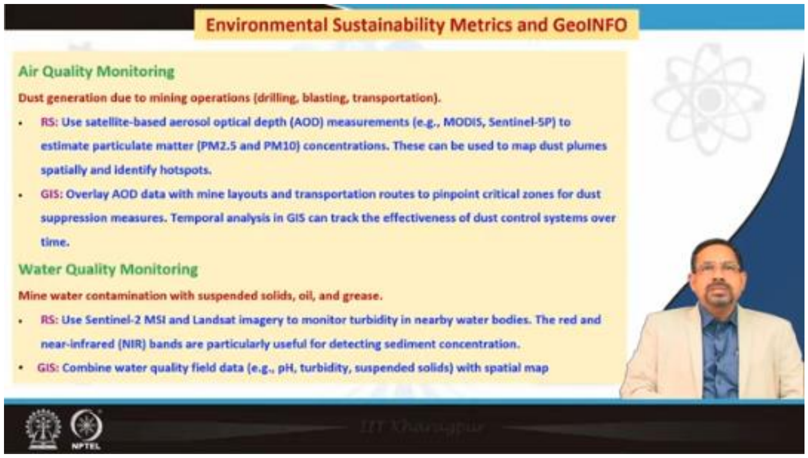
Now, with respect to post-closure, the number of involved incidents, air pollution emissions as far as different air pollutants are concerned, and then the post-closure water runoff. So, all these things can be very well monitored using geo-information, and they act as environmental sustainability matrices as far as the relevant phase of mine life is concerned. Now, let us move to the next term called the life cycle. So, the life cycle and associated environmental impacts for a mined material. The life cycle of a mined material emphasizes the need for a holistic approach to sustainability, integrating resource efficiency, waste management, and long-term environmental stewardship at every stage.



So, on the left hand side one flow diagram that includes the key inputs and the key outputs with respect to different phases of materials life. So, let us see what are the different phases of materials life. The first one is the exploration and mine development. Here the input is we need energy as far as drilling, cleaning, construction material, reagents also in terms of the water. And with respect to this exploration and mine development, the output are overburden, land disruption, the dust and air pollution.

The third one let us I am skipping one each because it is the similar way. So, let us move to the third one after the mining when we see the mineral processing. Here also the input could be water, the reagents, the energy and also lot of crushing and grinding activity. So, key outputs we can see the air pollution or lot of chemical waste that go in terms of tailing. Now, the fourth one that deals in terms of the material life talks about production metallurgical processing.

So, here also energy other raw materials resins and water are the key inputs, but the output in terms of air pollution, water pollution, chemical and hazardous waste which gets released in terms of slag. So, this flow diagram has been given by Gorman et al that talks about the life cycle and finally, what we need to understand that through all this including manufacturing use phase and end of life in terms of waste management and post closure. Everywhere the remote sensing, the GIS or in totality the geoinformation technology has a role to play and this together helps in terms of achieving the sustainability in mining sector or we say it helps us in terms of calculating a kind of sustainability card over the mining region. Now let us see the environmental sustainability matrices one by one and the geoinformation benefits. So, what we can see as an example lot of these things we have already discussed but let us see as far as matrices are concerned of for achieving the environmental sustainability of mining.

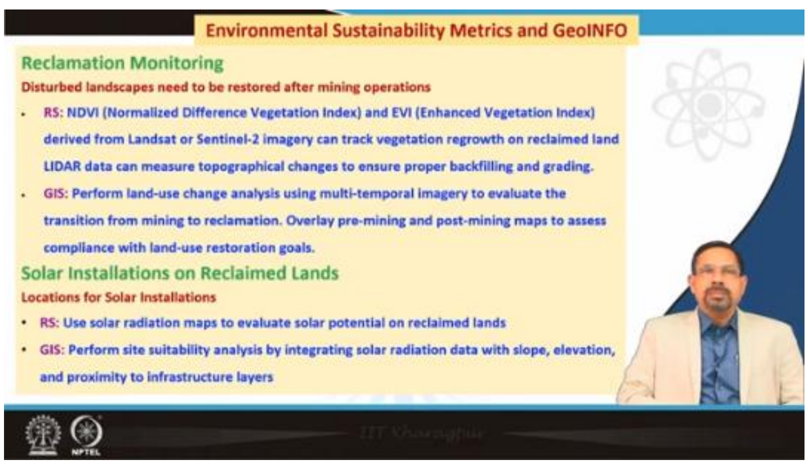


So, let us see a few one by one. First is the air quality monitoring in terms of the lot of dusts as we know are generated due to mining operation including drilling blasting transportation all these things. So, these we can very well monitor using the satellite based data particularly the aerosol depth coming from MODIS or we have already discussed from Sentinel 5P that is the TROPOMI sensor. So, this also helps us in terms of recording or assessing and periodically monitoring as far as the particulate matter 2.5, 10 and various concentration sizes concerned. This can be used to map the dust plumes spatially and identify the hotspots.

So once we get the data from the satellite in periodic interval, then it is left to us what kind of analysis we do. There are many various analysis based on the rose wind the wind variation across the across the year we can see how much in which part of the year how much is the dust deposition or the what is the direction of the dust in terms of the dust plumes over temporal and spatial scale. So, we know which direction and how much and which part of the year. So GIS here helps in terms of overlaying this aerosol optical depth data with various mine layout and transportation route and can very well pinpoint the critical zones for dust suppression measures. Once for a mining sector, we have this already over a GIS platform, it helps us in terms of generating dust control mechanisms or installing dust control systems over time.

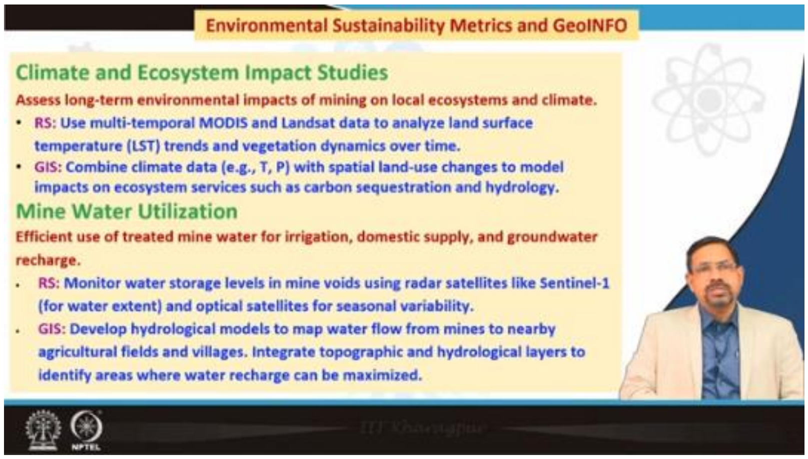
In a sense, this helps in terms of achieving the environmental sustainability in mining sector. Now let us move to the next one the water quality monitoring mine water contamination with suspended solids oils and grease. So, these are various things are involved as far as the mining activity concerned lot grease contamination and lot of suspended solids. So, here also remote sensing is useful in terms of monitoring the turbidity in the nearby water bodies. The red and NIR bands are particularly useful for detecting the sediment concentration in terms of the deposition where and how much.

So, GIS also helps in terms of linking any kind of ground-based observation sample you take, pick samples to analyze, and link it to the spectral signature in terms of the pH, turbidity, and suspended solids with the spatial map. So, in that way, the water quality due to mining activities can be very well monitored in order to achieve sustainability. Next is the reclamation monitoring. As far as mining activity is concerned, there is a lot of disturbance in terms of landscapes that need to be restored after the closure of mining operations. So, here various indices in terms of NDVI, EVI, and many more are really useful to understand how much was the pre and how much is the post.



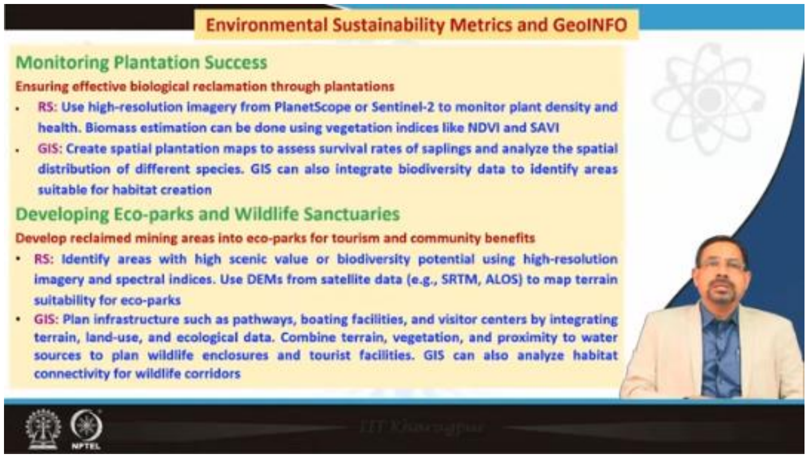
So, now we have satellite data since 1972, over more than 52 years. So, at frequent and regular intervals, that can be very well used to monitor the pre and post as far as any kind of disturbance over the landscape is concerned. So, this can very well benefit from GIS-based analysis. Now let us move to the reclamation. One of the reclamation methods, as far as mine closure or deposition of some of the dumps is concerned, is the installation of solar power plants or solar panels.

So, particularly on the reclaimed area, the solar panels can be very well installed. So, in this sense, remote sensing helps in terms of evaluating where the land area can be reclaimed. And that means, indirectly, it shows how much area is available based on other studies in terms of illumination and the directional property of solar radiation availability. We can very well calculate and see, and the geoinformation analysis can very well provide information in terms of site suitability analysis for the installation of solar panels or solar cells. Now, moving to the next one: climate and ecosystem impact studies.



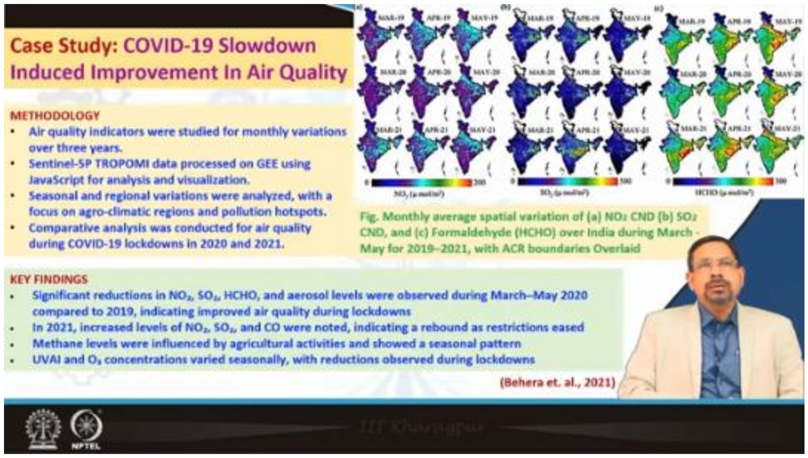
So, here in terms of the long term environmental impacts of mining on local ecosystems and climate. As we already know that if we use lot of satellite data that can give us in terms of the air pollutants, the AOD, the LST. So, this information over time can help in terms of combining with other climate data such as temperature and precipitation and then we can relate it with respect to the change in terms of vegetation loss or the land use or the land cover changes and we can model and come out with various maps that can have implications as far as ecosystem services such as carbon sequestration or hydrology is concerned. Now the next one is mine water utilization.

So, efficient use of the treated mine water for irrigation, domestic supply and ground water recharge. So, lot of satellite data particularly the microwave data which is coming are available from various satellites including Sentinel-1 are good in terms of delineating the water extent and the seasonal variability. The GIS develop hydrological models to map water flows from mines to nearby agriculture or fields and villages. So, this when we integrate with other variables in terms of topography or hydrology layers, it is useful in order to identify areas where water recharge can be maximized. the plantation monitoring so many places as a reclamation activities or you say biological reclamation activities the plantation is one of the best tool so we mean the environmental or the mining sector the mining people they try to they plan plantation so as so as it can arrest many things



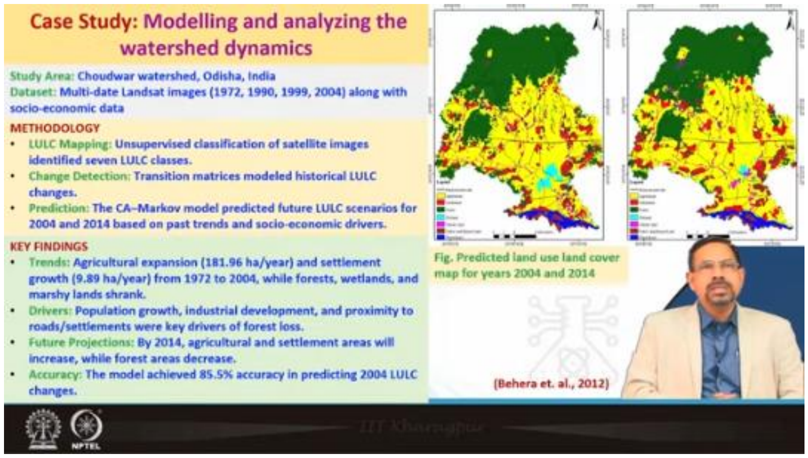
So, here the remote sensing with high resolution data coming from various sensors, Sentinel-2, PlanetScope, they help in order to understand that how much vegetation is where, what is their plant density, what is their health and in terms of vegetation content, so that helps. And then we can also plant the gap fill plantation, how much less is there are where the density is very less in terms of the vegetation distribution, there also the gap filling plantation can be done and using various indices NDVI, SAVI service oil adjusted vegetation indices these activities are practiced in regularly we have already discussed in some of our previous classes. Now, developing eco parks and wildlife sanctuaries develop reclaimed mining areas into eco parks for tourism and community benefits. So, many many areas over the mining mining region or the mining ecosystem can be very well identified and and in terms of a site suitability analysis we can propose that these are the areas could be more suitable for developing eco park for in order to maintain a balance as far as the ecosystem or the environmental aspect is concerned. or wherever we can also if possible based on the area availability some wildlife sanctuaries can be proposed.

So, these actually help or contribute in totality as far as the mining industry is concerned as the sustainability matrices studies. Now let us look at a few case studies. The first one is the COVID-19 slowdown-induced improvement in air quality. This study has been done by our team, but here mostly the M. Tech students were involved. They have been studying this during the autumn semester in 2020, the year when we had the corona lockdown impact. So, what we did is we tried to understand the various changes in the air quality parameters, which we have taken as the air quality indicators for the variation over a monthly time scale for 3 years, using the Sentinel TROPOMI, that means, Sentinel-5P, the data sensor known as TROPOMI. Using the cloud computation platform, the Google Earth Engine, which uses JavaScript for analysis as well as visualization, with this study in terms of comparative analysis, all the students tried to find out the air quality parameters and their variation.



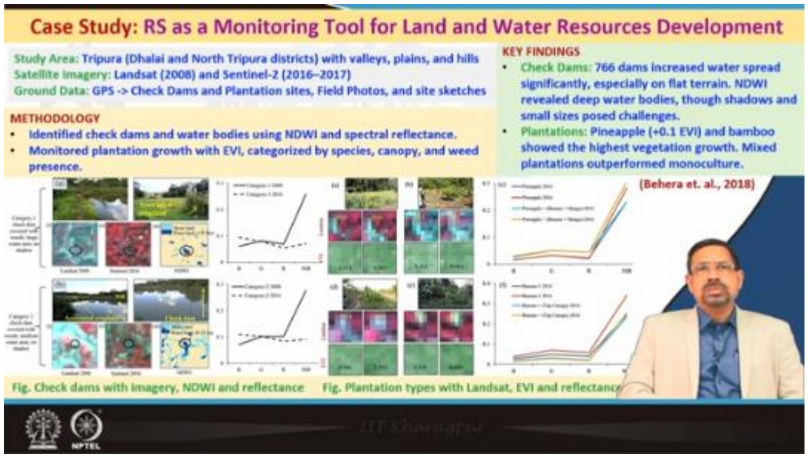
Here, three consecutive images have been shown. You can see the nitrous oxide, the sulfur dioxide, and also the formaldehyde. This is over India during March to May for the period of 2019 to 2021. So, 2019 March, April, May; 2020 March, April, May; and 2021 March, April, May. So, this actually gives very good information as far as how much damage or how much change in terms of the air quality parameters, particularly nitrous oxide, sulfur dioxide, and formaldehyde, has happened. Using a similar approach over the mining area, we can study the change in terms of the air quality variation.

So, what is the take-home message? The key findings are a significant reduction in nitrous oxide, sulfur dioxide, and formaldehyde, and fewer aerosol levels were observed during March to May 2020 in comparison to 2019. Similar studies have found this is because of the slowdown as far as the corona or COVID-19-related lockdown was concerned. Now let us move to another study where we try to see, this is also from our lab, we try to see the modeling and analyzing the watershed dynamics. Here, essentially, the multi-date data has been picked: 1972, 1990, 1999, and 2004. So, over a time scale, we try to understand how much change in terms of various land use and land cover classes has happened.

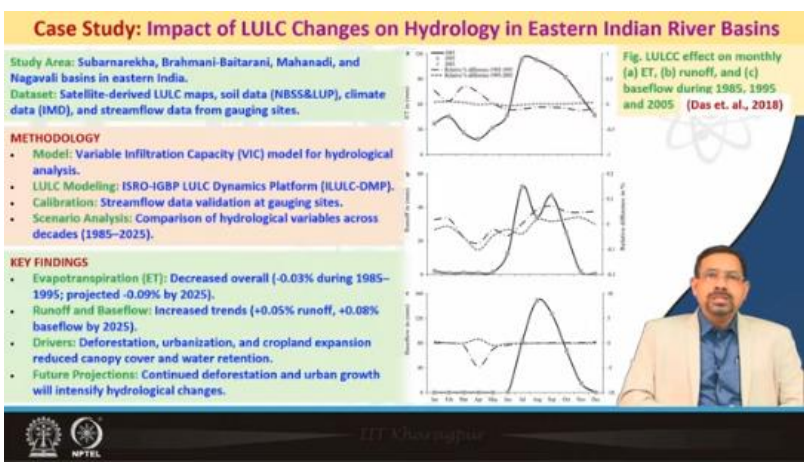


Then, once we understood this, we tried to frame a kind of transition matrix and then model, as far as the land use land cover change is concerned, and we have chosen the CA-Markov model. So, the CA-Markov model gives the direction and the magnitude of the change in terms of various land use land cover classes, and we try to predict it for 2000 based on 2014. From 2004 to 2014, we predict for the next scenarios, and it was giving us good accuracy. So, what we found was that by 2014, agricultural and settlement areas will increase while the forest cover decreases. This is a regular finding people are getting because when we think of expanding agriculture, we only have those barren areas or some forested areas left where we can convert them for agricultural purposes. So, this is a finding, and in a similar way, over mining regions, we can study and take different time period data.

We analyze it, interpret it, then come out with a kind of transition matrix. Then, we can also see what the change is in terms of direction and magnitude, and we can predict for the future. Once we have that kind of map, it helps us in terms of planning to achieve sustainability. So, in a similar way, remote sensing is used in terms of monitoring. So, we need to monitor post-closure of mining, post-closure as far as mining activity is concerned. So, here, through this, we have used several indices, particularly the NDWI (Normalized Difference Water Index), NDVI, and a lot of ground visits also. Then, what we did was we tried to see how much change has happened because of some development, land and water developmental activity, or say, the intervention activities. So, through this, we can very well understand and say that yes,



you have a variation as far as the spectral signature is concerned because of any activity or change in any activities on the ground in terms of land use and land cover. So, that can be very well captured using the satellite signature, and with intelligent—what you say—careful analysis, we can very well say what the intervention-related benefits or changes are that can be captured. Then, we also tried to see how much the hydrology is affected because of this land use land cover change. So, we used here a model published by Das et al. in 2018. So, here, what we try to do is we try to select the satellite-based outputs in terms of land use land cover change, and also we try to integrate the climate data coming from the Indian Meteorological Department and streamflow data coming from different gauging sites available on our CWC or the Central Water Commission webpage.



So, then what we did we try to run a model that depends on the variable infiltration capacity. So, variable infiltration capacity is directly connected in terms of the change in the land use or the land cover. So, we try to see here how much is the impact or how much is the variation as far as the evapotranspiration the runoff or the base flow is concerned because of the change in the vegetation cover and then we try to predict it. So, what we can see from or take from this example or this case studies that because of any alteration in the land use land cover over the mining areas which there are there the the surface hydrology is going to affect. And this kind of studies using geoinformation is means is very very operational or very well benefit in terms of the mining area is concerned to achieve sustainability.

So, these are the references we have used to prepare these slides and further discussions and let us conclude. The life cycle of a mined material emphasizes the need for a holistic approach to sustainability, integrating resource efficiency, waste management and long term environmental stewardship at every phase. key environmental sustainability parameters such as water use reduction, biodiversity protection and pollution control. They all highlight the importance of multi-stakeholder initiatives to drive the responsible mining practices. So, in totality geo information is very useful to quantify the sustainability matrices and also it helps to bridge the gap between the mining operations and the sustainability goals by enabling effective monitoring, analysis and planning mechanism. Thank you very much.