

# SUSTAINABLE MINING AND GEOINFORMATION

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Week – 04

## Lecture 20: Gas and Particulate Matter Monitoring

Welcome, let us discuss gas and particulate matter monitoring in the 20th lecture of this course on sustainable mining and geoinformation. So, the concepts we are going to cover are the various techniques available for monitoring greenhouse gas emissions and particulate matter in mining operations. We will also discuss the utility of satellite data for air quality monitoring around mining regions. And also, at the end, we will take one case study that talks about the assessment of environmental health risks from gas and particulate emissions in near mining areas in real time as well. So, what are the different applications and benefits of geoinformation in gas and particulate matter in the mining industry?

**CONCEPTS COVERED**

- Techniques for Monitoring Gas Emissions and Particulate Matter in Mining Operations
- Use of Satellite Data for Air Quality Monitoring around Mining Regions
- Case Study: Assessing Environmental Health Risks From Gas and Particulate Emissions Near Mines

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### Applications and Benefits of Geoinformation in Gas and PM in Mining

- **Emission Detection:** Identifies gas emissions and hotspots in mining areas
- **Pollution Mapping:** Tracks PM dispersion and health impacts on nearby populations
- **Impact Assessment:** Measures the effect of mining on air quality
- **Policy Support:** Provides data for regulatory compliance and mitigation planning
- **Wide-Area Monitoring:** Enables efficient monitoring over large mining areas
- **Enhanced Safety:** Allows non-intrusive monitoring in hazardous locations



So, the six important applications in terms of geoinformation for gas and particulate matter detection studies in the mining sector could be: first, emission detection—here we identify gas emissions and thereby prioritize hotspots of gas emission in mining areas. In terms of pollution mapping, geoinformation helps in tracking particulate matter dispersion and health impacts on nearby populations. In terms of impact assessment studies, using geoinformation tools, we can measure the effect of mining on air quality. Such information is useful in terms of policy prescriptions and compliance as far as regulatory guidance is concerned, and that is how they plan any kind of mitigation in the mining sector. Now, coming to the fifth one: wide-area monitoring.

Yes, satellite remote sensing, because of its large area coverage, enables efficient monitoring over larger areas that extend as far as the mining operations are concerned. And that is how it ensures and enhances safety, allowing non-intrusive monitoring in hazardous locations. So, let us see what the key gases and particulate matter of concern in the mining industry are. So, that is why they need to be studied. The first one, let us talk about methane.

### Key Gases and Particulate Matter of Concern

**Methane (CH<sub>4</sub>)**

- Released during coal exploitation.
- A potent GHG with a significantly higher (x 20) GWP than CO<sub>2</sub>
- Contributes to Ozone layer Depletion when emitted in excess

**Carbon Dioxide (CO<sub>2</sub>)**

- Emitted directly during Mining operations, & Combustion of Coal Gangue
- Major contributor to climate change

**Other Hazardous Gases**

- Sulfur Dioxide (SO<sub>2</sub>): Released from the spontaneous combustion of coal gangue
- Hydrogen Sulfide (H<sub>2</sub>S): Toxic gas that can be released during Sulfide oxidation

**Dust and Particulate Emissions**

**Particulate Matter (PM):** PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub> based on particle size

- Mining Operations: Dust generated during drilling, blasting, and material handling
- Coal Gangue and Tailings: Waste materials produce dust when exposed to wind




Methane is released dominantly during coal exploitation. It is a potent greenhouse gas a greenhouse gas with a significantly higher global warming potential than carbon dioxide nearly 20 times as far as 20 times global warming potential compared to one unit of carbon dioxide if it is taken in terms of 100 years. The methane contributes to ozone layer depletion when it is emitted in excess quantity. Let us talk about carbon dioxide which is emitted directly during mining operations and combustions of coal gangue. So, the gangue we say in terms of the wastes which is released or which is left over during the coal exploitation.

So that is how the carbon dioxide is a major contributor to climate change and all of us know the concentration of carbon dioxide is increasing day by day at an alarming rate exceeding 425 ppm in as far as carbon dioxide concentration in atmosphere is concerned. The other hazardous gases sulfur dioxide released from the spontaneous combustion of coal gas the hydrogen sulfide which is a toxic gas that also can be released during sulfide oxidation. So, these gases they form or they are released from the mine in terms of different activities. Let us have a look at the dust and the particulate matters such as particulate matter 10, 2.5, 1 based on their size of the particles. Mining during mining operation the dust are generated from various activities such as drilling, blasting and handling of different types of materials the coal guns and tailing activities.

So, the waste materials produced during produce dust when exposed to wind out of the coal guns and the tailing and the different tailings. So, what are the use or how we use the ground sensors and also the remote sensing for this sort of air pollution monitoring over a mining area. So, monitoring gaseous pollutants the emission intensity can be measured or quantify quantified in terms of the levels of methane, sulfur dioxide, carbon dioxide and other pollutants. And this ground based sensors they also track the changes over time interval to identify trends or any violation as far as the rules or the regulatory guidelines are concerned. Coming to the particulate matters as far as the dust concentration and distribution ground-based sensors are concerned the dust concentration distribution are major in terms of the spatial spread and intensity of the dust generated by the mining activities and identify high risk areas for pollution mitigation.

**Use of Ground/RS for Air Pollution Monitoring**

**Monitoring Gaseous Pollutants: Emission Intensity Measurement:**

- Quantifies levels of CH<sub>4</sub>, SO<sub>2</sub>, CO<sub>2</sub>, and other pollutants
- Tracks changes over time to identify trends or violations of regulations

**Dust Concentration and Distribution**

- Measures the Spatial Spread/ Intensity of dust generated by mining activities
- Identifies High-Risk areas for Pollution Mitigation

**Satellite-Based Air Quality Systems:**

**Sentinel-5P (TROPOMI)**

- Monitors Pollutants such as NO<sub>2</sub>, SO<sub>2</sub>, CH<sub>4</sub>, ozone, CO
- Offers Global coverage with a Spatial Resolution of 5.5 x 3.5 Km and daily Revisit Times

**MODIS**

- Detects Aerosols and their Optical Properties, valuable for PM and Dust Monitoring





Dr. Manoj Kumar

Let us have a look at the satellite-based air quality monitoring or measuring systems. We have the Sentinel-5P sensor, which is mounted on board the Sentinel satellite. The sensor name is TROPOMI. So, it is the 5P. It monitors various pollutants such as nitrogen dioxide, sulfur dioxide, methane, ozone, carbon monoxide, and many others. Thereby, this satellite data or the data from the TROPOMI sensor offers global coverage with a spatial resolution of 5.5 by 3.5 kilometers on a daily revisit time. So, look at the spatial resolution. This is, of course, a bit coarse—5.5 by 3.5 kilometers—as far as the size or the resolution is concerned. The temporal resolution is very high; it has a daily revisit frequency.

So, let us also go back to MODIS. These two MODIS sensors, TERRA and AQUA, were launched into orbit in 2000 and 2001, respectively. These sensors detect aerosols and their optical properties. These properties— aerosol and optical properties—are available for particulate matter and dust monitoring. So, the multispectral analysis that we usually use for pollution detection—what are the principles? So, as far as the principle is concerned, we have different substances. They have distinct spectral properties based on their physical and chemical characteristics. So, these properties of different substances are significant in terms of their spectral signature or their reflectance behavior.

### Multi-Spectral Analysis for Pollutant Detection

**Principle**

- Different substances have distinct spectral properties based on their physical and chemical characteristics
- Multi-spectral sensors capture images across multiple wavelength bands, highlighting pollutant types

**Process:**

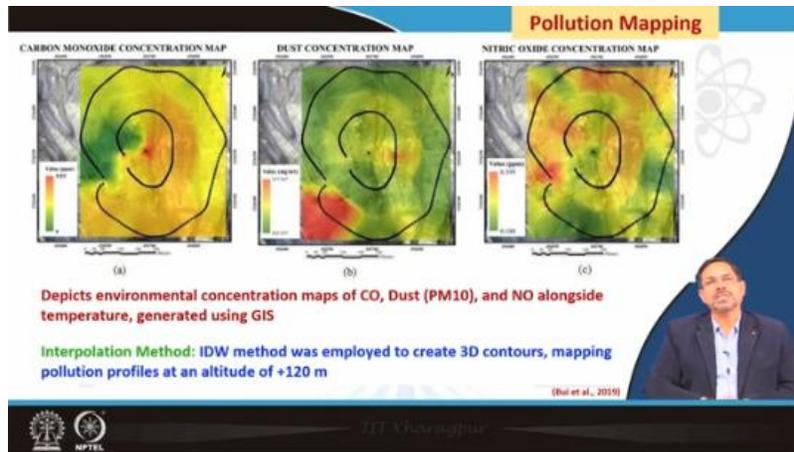
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graph LR
    A((Synchronizing with multiple machines using various spectral bands)) --> B((Use of specially designed multi-spectral films to capture dust emissions))
    B --> C((Spectral differentiation of pollutants based on physical properties))
  
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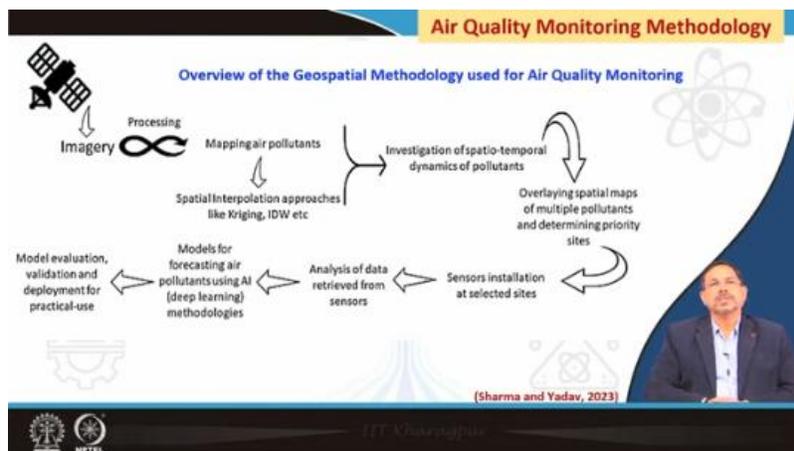
(Bj et al., 2015)

So, multispectral sensors capture images across multiple wavelength bands. That is how they highlight the pollutant type, nature, and what kind of pollutant it is. So, the process, as far as multispectral-based analysis for pollutant detection is concerned, can start with synchronized photographing. So, the photography or imaging has to be synchronized with multiple machines using various spectral bands. Then, the use of specially designed multispectral films to capture dust emissions, followed by the spectral differentiation of the pollutants based on physical properties. So, synchronization, followed by their designation as far as the capture of emission properties, and then you differentiate based on their physical behavior or physical properties.

So, based on that, we can differentiate and also spatially, in terms of a map, we can also map the means. So, in terms of the spatial distribution, you can see the carbon monoxide concentration. So, the scale is there from low to high concentration, and the quantity level is mentioned at different points. So, the first one, upper left, demonstrates the carbon monoxide concentration; the middle one is for the dust concentration, and the rightmost one is the nitric oxide concentration map. So, the different colors talk about the different quantities or concentrations of that particular gas.



So, here, the authors Bui et al. in 2019 have used different interpolation or weighted methods to create this kind of three-dimensional contour for mapping the pollution profiles at an altitude of 120 meters. So, as an overview, if we have the overview of geospatial methodology using air quality monitoring, as far as the different types of air pollutants are concerned. So, once the data or the imagery is received from the airborne platform—it could be a satellite, a UAV, an unmanned vehicle, or anything. So, once the imagery is received, the image goes for processing in terms of mapping the air pollutants. And we also do some kind of extrapolation and interpolation, as far as using kriging or other kinds of methods like IDW techniques.



Further, it goes in terms of the investigation of spatio-temporal dynamics of the pollutants. So, when you have more than one time-period image, then we have the option of going in terms of the temporal. So, T1 minus T2 kind of different time frame. And then we can see the variation in the form of a map at different places. So, we put it under spatio-temporal dynamism by overlaying the spatial maps of multiple pollutants and determining priority sites.

So, on that basis, we can narrow down the search in terms of installation of the sensors at various sites, and the data can be retrieved from the sensors. And then we can also use the data in terms of deep learning AI or artificial intelligence or other methods, and then we go for prediction using different modeling approaches. Part of the data we also use in terms of validation, and the information we finally get out of this, as far as the air quality helps, is in coming out with different mitigation measures. So, in continuation, we also have different advanced analytical techniques as far as geo-information is concerned. So, a few multispectral digital processing techniques convert spectral data into digital images. We also have matrix additive color synthesis, which combines the images from different spectral bands to enhance pollutant visualization or their display. We also have multi-dimensional level segmentation, which divides the data into layers for focused analysis. So, all these three fall under advanced analytical techniques as far as air pollution, what you say,

**Advanced Analytical Techniques in Remote Sensing**

**Multi-Spectral Digital Processing:** Converts spectral data into digital images  
**Matrix Additive Color Synthesis:** Combines images from different spectral bands to enhance pollutant visualization  
**Multi-Dimensional Level Segmentation:** Divides data into layers for focused analysis

**Quantitative and Semi-Quantitative Analysis**

- **Digital Image Analysis:** Converts spectral patterns into pollution concentration estimates.
- **Data Analysis Methods:**
  - Clustering Analysis:** Groups similar pollution patterns.
  - Piecewise Regression:** Models pollution data to detect trends.

mapping and monitoring are concerned. Let us have a look at different quantitative and semi-quantitative analyses. Yes, using digital analysis, we can convert the spectral pattern into pollution concentration estimates. We just saw it in the form of a map in the previous slide. And we also follow data analysis approaches such as clustering or piecewise regression, which groups similar pollution patterns or models the pollution data to detect any kind of trend or pattern as far as time or spatio-temporal displays are concerned.

Now, let us have a look at the other type of data collection and measurement. We put them under column concentration average-based measurement. So, column concentration measurement, particularly in mining areas, focuses on quantifying the gases, aerosols, or particulate matters that are distributed vertically in the atmosphere or accumulated over the surface. So, that is what we call the column concentration. So, a kind of 3-

dimensional pixel we call it a voxel. So, the principle is absorption and scattering, column integration, and differentiation analysis.

**Column Concentration Measurement**

Column concentration measurement in mining areas focuses on quantifying gases, aerosols, or particulate matter distributed in vertical columns of the atmosphere or accumulated on the surface.

**Principle**

- 1. Absorption and Scattering:**
  - ❖ Gases/particles absorb and scatter radiation (solar or emitted)
  - ❖ Instruments measure these interactions to estimate concentrations
- 2. Column Integration:**
  - ❖ Total substance concentration in a vertical atmospheric column is calculated by integrating values across altitude
- 3. Differential Analysis:**
  - ❖ Techniques like the Differential Column Method (DCM) isolate local emissions by removing background influences

**Applications**

- **Air Quality:** Monitor CO<sub>2</sub>, CH<sub>4</sub>, and SO<sub>2</sub> emissions
- **Emission Identification:** Pinpoint sources from industrial and mining areas
- **Climate Studies:** Understand contributions of GHGs to global warming

The slide features a speaker in the bottom right corner and logos for ANU and NPTEL at the bottom left.

So, in terms of absorption and scattering, different gases and particulate matter absorb and scatter radiation. So, based on the solar or emissivity. So, the instruments, in terms of absorption and scattering, measure these interactions to estimate the concentration of that particular gas of interest. Now, coming to the column integration, the total substance concentration in a vertical atmospheric column is calculated by integrating values across altitude. So, finally, across an altitude, whatever the total substance concentration is there in a vertical scale.

So, it is calculated by integrating the values across the altitude. So, we put it under column integration, OK? That is across the volume. So, finally, the differential analysis means the technique that is used in terms of the differential column method (DCM), which helps in isolating the emissions coming from local or regional sources by removing the background influences. If you have any other particulate matter or gases that can interfere with the signal as far as the column concentration is concerned. So, this differential analysis method is used to remove some of this background influence.

So, in a sense, it removes the noise; it filters the noise. So, we get the information about the particular gas of our interest. Now, coming to various applications, yes, we have been considering air quality monitoring as far as methane, carbon dioxide, or sulfur dioxide emissions are concerned. We also use this kind of column concentration measurement principle for identifying the emissions that help in pinpointing the sources from industrial or mining areas. And thereby, it helps in broader studies such as climate change or contributions to climate in a bigger context.

So, the techniques, as far as column concentration measurement is concerned, yes, remote sensing using spectroscopy, satellite instruments, and thermal infrared. The Fourier transform infrared spectroscopy, FTIR spectroscopy, uses solar light for gas absorption measurements such as greenhouse gas monitoring. So, the dedicated outdoor air systems are also useful in terms of measuring these gases by detecting specific wavelength absorption. So, this is based on the spectroscopy principle. And, satellites such as TROPOMI 5P, MODIS, OCO-2 monitor carbon dioxide. All these satellites, even GOSAT, monitor carbon dioxide, methane, and all these aerosols on a global scale.

**Column Concentration Measurement Techniques**

**A. Remote Sensing**

**Spectroscopy:**

- FTIR Spectroscopy: Uses solar light for gas absorption measurements (e.g., GHG monitoring in MUCNet)
- DOAS (Dedicated Outdoor Air System): Measures trace gases by detecting specific wavelength absorption

**Satellite Instruments:**

- Tools like TROPOMI, MODIS, OCO-2 monitor CO<sub>2</sub>, CH<sub>4</sub>, and aerosols globally
- Analyze radiance to calculate gas amounts

**Thermal Infrared:**

- Measures heat emitted by gases like CO<sub>2</sub> and CH<sub>4</sub>, effective for night-time or all-weather monitoring

**B. Modeling**

**DCM (Dynamic Casual):**

- Isolates emissions by comparing upwind/downwind measurements

**Atmospheric Transport Models:**

- WRF-STILT simulates pollutant dispersion and tracks emission sources

**Radiative Transfer Models:**

- Correct for atmospheric scattering to improve accuracy

And, allowing in terms of analyzing radiance to calculate the amount or the concentration of any particular gas or the gas of our interest. Coming to the thermal infrared, the thermal infrared remote sensing measures, as we already discussed, based on the heat emission by all these different gases, carbon dioxide or methane. So, this heat emission or the difference in heat emissivity property by different gases helps in measuring or monitoring their concentration. And, as we already discussed, thermal remote sensing or thermal infrared remote sensing is more effective or usually practiced during nighttime in contrast to daytime because it has the advantage of nullifying many other noises. But, it has all-weather monitoring capabilities.

Now, once we have the data in terms of geoinformation, we can take them into modeling such as dynamic causal models, which isolate the emission by comparing upwind and downwind measurements in terms of eddies or eddy covariance. So, it falls under the broader domain of the eddy covariance principle, which isolates the emission by comparing the upwind and downwind measurements. So, that the rest is your actual volume. And, then coming to the atmospheric transport models such as WRF-STILT, these models simulate pollutant dispersion and track the emission sources. And, finally,

the RTMs, radiative transfer models, correct for atmospheric scattering to improve the accuracy of the gas which is the measurement target.

Two satellites the first one in terms of the column concentration average measurement is SCIAMACHY. SCIAMACHY which stands for Scanning Imaging Absorption Spectrometer for Atmospheric Cartography. This SCIAMACHY satellite was an advanced imaging spectrometer. It was mounted on ENVISAT satellite mission and launched in 2002. It operated till 2012.

And, they provide lot of data as far as the global coverage is concerned the global spread is concerned. So, the primary objective is global as measurement and focused on various gases including trace gases in troposphere and stratosphere. So, the the altitude is defined. So, the column concentration has measured the gases including the trace gases at what is there available at the troposphere or and at the stratosphere level and thereby detects the as useful in detecting the atmospheric components measured aerosols cloud properties and surface reflectance And, these were key for understanding atmospheric composition and processes.

So, little bit of the science aspect of this. So, if the data coming from the SCIAMACHY over the mining areas have be are analyzed, then we can understand the gases which is emitting out of the mining areas because of different activities. So, thereby we can track the gases coming from mining such as coal mining like carbon dioxide and methane that means carbon dioxide and methane or sulfur dioxide from metal ore processing and that is how we can identify emission hotspots over the mining areas. And, this data coming from the SCIAMACHY sensor helps in detecting the aerosols from mining which is emerging from the mining areas as far as dust are concerned. And, also useful in tracking the pollutant transport and thereby measure the ozone layer impacts from mining related pollutants such as nitrogen dioxide.

So, SCIAMACHY data the data coming from the schema key sensor or a platform supports compliance verification and environmental standards and thereby provide baseline data for long term atmospheric health analysis or lot of or long-term health analysis over mining areas or mining industries. The other satellite which measures the greenhouse gases is GOSAT. So, it stands for greenhouse gases observing satellite this satellite was launched in 2009. And, it is the first spacecraft which was specifically designed to measure the column abundance of the greenhouse gases like carbon dioxide,

methane, ozone and many others. So, this was launched in 2009 now GOSAT 1 and we also have GOSAT 2 I think in orbit.

**Greenhouse Gases Observing Satellite (GOSAT)**

The Greenhouse Gases Observing Satellite (GOSAT), launched in 2009, is the first spacecraft specifically designed to measure the column abundances of greenhouse gases like CO<sub>2</sub> and CH<sub>4</sub> globally

- GOSAT uses the Thermal and Near-Infrared Sensor for Carbon Observation (TANSO-FTS) to retrieve gas concentrations using shortwave infrared spectra
- Provides comprehensive data on greenhouse gas concentrations with long-term observations starting from 2009
- Generates Level-2 products like XCH<sub>4</sub> (column-averaged dry-air mole fractions of CH<sub>4</sub>)
- Employs Geostatistical and Kriging methods for gap filling in datasets and Spatio-Temporal trend analysis

**Influence in Mining Industries**

- Emission Monitoring: Tracks CH<sub>4</sub> from coal mining and fossil fuel extraction
- Regulatory Support: Helps enforce emission compliance and reduction goals
- Impact Assessment: Evaluates environmental effects of mining operations
- Inventory Enhancement: Detects and improves data on unreported emissions

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So, this GOSAT sensor as the name indicates greenhouse gas observing satellite it uses thermal and NIR sensors the near infrared sensors for carbon observation using a what you say TANSO-FTS based principle to retrieve the gas concentration using shortwave infrared spectra. So, thereby the data or the images coming from the GOSAT provides comprehensive data on greenhouse gas concentration with long term observation because of its periodic repetition or the temporal resolution. So, the GOSAT data generates level 2 products like methane or we say methane concentration. So, column average dry air mole fraction of methane. So, so based on this we have the level 1, level 2, level 3 data these are the different processing steps are applied to that.

And employs also we can employ various geostatistics techniques such as Kriging's to fill the data gap. Unlike other satellites, this GOSAT do not have a continuous what you say global coverage. So, there could be there are a kind of gaps at equators or at various places between two passes. So, these gaps are filled using different geostatistical techniques such as Kriging so that the spatial temporal analysis or trend analysis can be can be projected. So, what are the influence of this GOSAT data the influence of GOSAT data in mining industries in terms of emission monitoring because they help in tracking the methane from coal mine and fossil fuel extraction helps in regulatory support and helps enforce the emission compliance and reduction goals.

So, they are useful in impact assessment as far as mining operations are concerned and detect and improve the data which is on which are unreported in terms of the emission of different greenhouse or the or the trace gases. So, SCIAMACHY and GOSAT they are very good data set as far as column concentration average is concerned for different

greenhouse gases and are very useful as far as the mining induced greenhouse gases or the gas emission is concerned. So, the other one is drone based monitoring yes if we can mount different sensors such as IRIS+ with OPC-N2 and we can monitor particulate matter 10. So, the principle in terms of underground mining or natural gas leak detection even if surface mining we use the drone. So, we mount different sensors and so that we can quickly get information about methane

**Drone-Based Monitoring Applications**

**Surface Mining:**

- Drones equipped with optical particle counters, such as the IRIS+ with OPC-N2, monitor PM10 emissions
- Challenges in air sampling were addressed by optimizing probe placement, resulting in accurate and reliable data

**Underground Coal Mines:**

- Methane emissions from ventilation shafts are measured using drones like the DJI Inspire 1 with CRDS analyzers
- These systems require multiple transects at varying altitudes for comprehensive data

**Natural Gas Leak Detection:**

- Drones with sDLAS analyzers effectively identify methane leaks from pipelines, though limitations in distinguishing concentration levels exist
- Innovative setups, such as fixed-wing drones with retro-reflector laser spectrometers and coordinated drone swarms, enhance efficiency



(Bobra et al., 2021)

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or methane leak from pipelines or there are because of different ventilation shafts. So, this kind of immediate requirement is fulfilled by capturing the data flying a drone. So, these are the challenges which in terms of air sampling which is address on real time basis using the sensors mounted on drone. Coming to a case study in terms of detection of methane, nitrogen oxide, carbon monoxide emission from coal mines using the sentinel 5P TROPOMI data. The overview this study was done over a site in Russia using 5P TROPOMI sensor.

**Case Study: Detection of CH<sub>4</sub>, NO<sub>2</sub> and CO Emissions from Coal Mines by Sentinel-5P**

**Overview**

The study explores Methane (CH<sub>4</sub>), Nitrogen Dioxide (NO<sub>2</sub>) and Carbon Monoxide (CO) emissions from Coal Mines in the Kuznetsk Basin, Russia, using Sentinel-5P satellite data from May 2018 to December 2022

**Methodology:**

- Satellite data from the TROPOMI sensor on Sentinel-5P were used
- The study applied a 3σ filter to detect emission exceeding background levels
- Background levels were calculated weekly, factoring in seasonal and regional variations

**Key Findings:**

- **Emission Events:** 339 high CH<sub>4</sub> emission events were identified, along with 861 NO<sub>2</sub> and 874 CO events. High CH<sub>4</sub> emissions were found to correlate with high NO<sub>2</sub> and CO emissions, both temporally and spatially, indicating common sources (coal mines).
- **Temporal Trends:** A clear annual increase in methane background concentrations was observed. Monthly variations in methane were significant, attributed to the presence of multiple super-emitters.
- **Spatial Trends:** Emission events clustered around coal mines. Winter months (November–January) lacked methane data due to dense cloud cover.

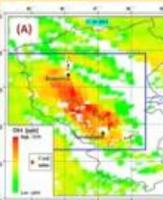
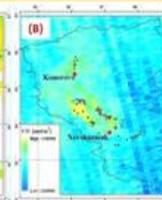
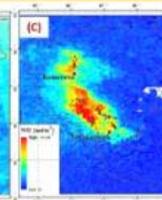




Figure: High Emissions around Coal Mines on 17-10-2021 (A) CH<sub>4</sub>, (B) NO<sub>2</sub>, (C) CO



(Trenchev et al., 2023)

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And methodology this study applied a 3sigma filter to detect the emission and based on the level or the threshold. And on the upper right hand side, we can see the high emission around the coal mines on a particular date 17th October 2021. The first one is in terms of methane. The second one is in terms of nitrogen dioxide and the third one is in terms of carbon monoxide. So, this emission over a coal mine site and their what you say immediate capture because TROPOMI Sentinel 5P has a daily coverage.

So, immediate capture and their spread and understanding in terms of the spatio-temporal pattern help in addressing different mitigation efforts. So, these are the references that have been used for the preparation of the slides. So, let us conclude with these four points. The geoinformation technologies enable efficient detection of pollutants such as methane and particulate matter, thereby offering high spatial resolution and safety provisions as far as mining operations are concerned. They are crucial for identifying pollution hotspots and thereby assessing the environmental impacts of mining activities on air quality or the surrounding ecosystems.

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## CONCLUSION

- Geo-Information technologies enable efficient detection of pollutants like Methane and particulate matter, offering high spatial resolution and safety for mining operations
- They are crucial for identifying pollution hotspots and assessing the environmental impact of mining activities on air quality and ecosystems
- Remote sensing supports regulatory compliance and aids in the development of effective mitigation strategies for reducing mining-related pollution
- By minimizing human exposure to hazardous environments and improving monitoring efficiency, RS provides a cost-effective and non-intrusive solution for sustainable mining

And, geoinformation including remote sensing supports a lot of regulatory compliance, compliance with respect to rules and guidelines, and thereby helps in the development of effective mitigation strategies by reducing pollution induced from mining-related activities. So, by minimizing human exposure to hazardous environments and improving monitoring efficiency, geoinformation along with remote sensing images helps in providing cost-effective and non-intrusive solutions for sustainable mining. The satellites based on optical, thermal, and also column concentration measurement or column concentration average measurement provide good data as far as various air pollutants, greenhouse gases, and particulate matter are concerned. We can also mount these sensors on platforms such as drones to immediately collect or capture data in terms of accidents or leaks over mining areas. So, if we use these datasets intelligently, applying different advanced data processing techniques, we can come out with a spatio-temporal analysis.

So, that we can imitate the pattern and come out with different prediction properties that help in sustainable mining practices. Thank you very much.