Workshop on Strengthening Capacities to Use Spectral Signatures of Remote Sensing Applied in Environmental Control Processes for the Identification of Environmental Impacts in the Mining Sector

APEC Digital Economy Steering Group

December 2024

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Economic Cooperation

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Contents

EXECUTIVE SUMMARY

The workshop on "Strengthening Capacities for the Use of Spectral Signatures in Remote Sensing Applied to Environmental Control Processes for Identifying Environmental Impacts in the Mining Sector" took place in Lima on 16-17 August 2024, bringing together 111 participants from various economies. The attendance included 35 women and 76 men, and featured twelve expert presentations that provided valuable insights from diverse international contexts.

The workshop aimed to enhance the capacity of APEC economies in remote environmental monitoring and enforcement methodologies in the mining sector, utilizing spectral signatures for the automation of spatial analysis and the identification of environmental impacts related to mining activities.

After two days of presentations and technical exchanges, the following highlights emerged:

- **Importance of Remote Sensing in Environmental Monitoring:** Remote sensing technologies are essential for monitoring and managing the environmental impacts of mining activities. These tools allow for detailed assessments of issues such as Acid Mine Drainage (AMD), oil spills, and changes in land cover.

- **Detection and Management of Environmental Impacts:** Remote sensing is effective for identifying environmental problems, including the detection of toxic substances and evaluating their spread. These technologies are also valuable for monitoring deforestation, pollution, and changes in vegetation, facilitating environmental impact assessments and policy development.

- **Integration of Advanced Technologies:** The combination of remote sensing with artificial intelligence (AI) and advanced data analysis platforms, such as ARCGIS, enhances the precision and efficiency of environmental monitoring. This allows for more informed decision-making through access to comprehensive data and predictive capabilities.

- **Effective Environmental Management:** The application of remote sensing technologies is crucial for identifying and managing environmental impacts, particularly from mining activities. These technologies support the detection of significant environmental issues and facilitate the implementation of timely and precise environmental management strategies.

- **Need for Qualified Personnel:** The successful implementation of remote sensing technologies requires trained personnel. Education and capacity building are fundamental to maximizing the benefits of these technologies and ensuring accurate data analysis.

- **Challenges and Limitations:** Despite technological advancements, challenges remain regarding data accuracy, resolution, and interpretation. Addressing these limitations requires ongoing research, technological development, and adaptive strategies.

- **Policy and Implementation:** Integrating insights gained from remote sensing into policy development and implementation can strengthen environmental regulations and practices. Effectively utilizing remote sensing data promotes more robust environmental policies and their proper enforcement.

The workshop has been successful in enhancing the understanding and application of remote sensing technologies in the mining sector, paving the way for more effective environmental management and sustainable development. It has also highlighted existing barriers related to regulation, resources, and capacity building for professionals across APEC economies.

I) INTRODUCTION

The workshop on "Strengthening Capacities for the Use of Spectral Signatures in Remote Sensing Applied to Environmental Control Processes for Identifying Environmental Impacts in the Mining Sector" was organized to enhance the technical skills and knowledge of government officials from APEC economies, specifically from agencies focused on environmental quality monitoring. This workshop considered the current context of increasing importance of sustainable mining practices, where remote sensing technologies have become essential tools for identifying and assessing environmental impacts caused by mining activities.

Held in Lima, Peru, this two-day workshop brought together participants from APEC economies, including representatives from government institutions, the private sector and academia. The primary goal was to strengthen and develop capacities in remote environmental control methodologies in the mining sector through the use of remote sensors, providing valuable information to environmental enforcement institutions across APEC economies.

During the workshop, experts in remote sensing and environmental sciences, with a focus on the mining sector, shared insights on the latest advancements in the field, including the use of satellite imagery, hyperspectral sensors, and data analysis techniques, along with their practical applications in environmental enforcement tasks. Participants engaged in hands-on sessions, gaining direct experience with these technologies in real-world scenarios. The workshop served as a platform for knowledge exchange, fostering collaboration among professionals from various sectors involved in environmental management and mining.

This summary report highlights key discussions, findings, and recommendations that emerged from the workshop, aiming to advance the application of remote sensing in environmental control processes within the mining sector.

1.1 Background and Objectives

The environmental impact of mining activities has come under increasing scrutiny as concerns over sustainable resource extraction and environmental preservation continue to grow. In this context, remote sensing technologies, particularly the use of spectral signatures, have emerged as critical tools for monitoring and controlling environmental degradation. These technologies enable precise identification of changes in land use, alterations in water and air quality, among other environmental parameters, which are essential for assessing the impacts of mining operations.

The primary objective of this workshop was to strengthen the technical capacities of environmental professionals, policymakers, and stakeholders in utilizing spectral signatures from remote sensing data for effective environmental monitoring in the mining sector. By enhancing the ability to detect and analyze environmental impacts through advanced remote sensing techniques, the

workshop aimed to improve the overall effectiveness of environmental control processes.

1.2 Scope and Relevance of the Project

This project was implemented through a two-day workshop in Lima, Peru, bringing together representatives from various APEC economies. The workshop focused on sharing concrete experiences and best practices regarding the application of remote sensing technologies, specifically emphasizing the use of spectral signatures for monitoring and managing environmental impacts related to mining activities. Given the widespread and often severe environmental consequences of mining—such as deforestation, soil erosion, water pollution, and biodiversity loss—there is an urgent need for effective monitoring tools that can provide timely and accurate data to inform decision-making processes.

Scope

- **Geographical Focus:** The project was designed to be applicable in various mining regions, particularly those with significant environmental vulnerabilities. It included both large-scale industrial mining operations and smaller artisanal mining activities.

- **Technological Focus:** The core of the project was the dissemination of experiences in using spectral signatures in remote sensing to identify changes in environmental quality. This involved the use of satellite and aerial sensors, hyperspectral imaging, and advanced data processing techniques, as well as integrating these technologies into existing environmental monitoring systems.

- **Training and Capacity Building:** A key component of the project was training environmental professionals, policymakers, and other stakeholders. The workshop provided practical knowledge on how to interpret spectral data, apply it in environmental assessments, and use it for effective monitoring and mitigation of environmental impacts.

- **Stakeholder Engagement:** The project aimed to involve a wide range of stakeholders, primarily government agencies. This was crucial to ensure that the insights gained from remote sensing data could be effectively integrated into policy formulation and environmental management practices.

Relevance

- **Environmental Sustainability**: The project's relevance lies in its potential to enhance the sustainability of mining practices by providing accurate and timely data on environmental impacts. This enables more informed decisions that can reduce environmental damage and promote the rehabilitation of areas affected by mining.

- **Regulatory Compliance**: The remote sensing technologies applied in this project are valuable for ensuring adherence to environmental regulations. By improving the capacity to monitor and report on environmental conditions, the project supports efforts to enforce environmental standards in the mining sector.

- **Global and Local Impact:** While the project is globally relevant due to the widespread nature of mining activities, it also addresses local and regional socio-environmental issues. By empowering local stakeholders with tools to monitor their environments, the project contributes to community-level environmental protection and sustainable development.

- **Advancement in Technological Integration**: The project is significant for advancing the integration of cutting-edge remote sensing technologies in environmental management. As these technologies continue to evolve, their application in the mining sector becomes increasingly important for achieving sustainable development goals.

Overall, the project is relevant for enhancing stakeholders' capacity to manage the environmental impacts of mining activities, thereby contributing to more sustainable mining practices and improved environmental outcomes.

1.3 Target Audience and Stakeholders

The workshop was designed to be collaborative, welcoming participants from a wide range of sectors and backgrounds. The target audience included representatives from various government institutions across APEC economies. By engaging stakeholders from diverse fields, the workshop aimed to facilitate a comprehensive and multidisciplinary approach. Government officials gained insights into effective policy formulation, explored innovative technological solutions, and contributed research-based knowledge and practical field perspectives. This approach ensured that the knowledge and best practices shared during the workshop were relevant, practical, and applicable to all participants involved in building climate resilience.

II) PRE-WORKSHOP RESEARCH REPORT

Prior to the workshop, a thorough research phase was conducted to identify key challenges and opportunities. This research involved 13 participants from 9 economies.

The survey results indicate that 37.8% of respondents believe the use of remote sensing technology within APEC economies is still limited. While the small sample size makes the data referential, it provides a snapshot of the current adoption levels of such technologies by environmental institutions in the region. A key concern for all respondents (100%) is water resource contamination, which they see as a critical need for environmental control. Remote sensing is most commonly applied in water quality monitoring (61.5%), followed by deforestation monitoring (53.8%). The most popular spatial remote sensing methods used

include drones and satellite images, along with sensors such as multispectral, thermal, and radar.

The benefits of using remote sensing and spectral signatures in the mining sector were also highlighted, including early detection of issues, more accurate environmental assessments, better decision-making, and cost savings compared to traditional methods. However, challenges remain, particularly regarding investment, training, regulatory hurdles, and the transparency and valuation of information. The survey emphasizes the need for greater collaboration among APEC economies to share knowledge and technologies, which could accelerate the adoption and optimization of these tools.

This research served as a foundation for workshop discussions and helped tailor the agenda to address the specific needs and priorities of participants. For more information, please refer to Annex 1.

III) WORKSHOP

3.1 Agenda

The workshop agenda included a combination of keynote speeches, discussion panels, group sessions, and networking opportunities. Success indicators included active participation from attendees, knowledge sharing, and the development of concrete recommendations. The methodology combined presentations, interactive discussions, and networking spaces to ensure a dynamic and participatory environment.

The detailed Workshop Agenda is attached as Annex 2. The topics covered over the two days of the agenda are as follows:

Day 1 – 16 August 2024

- Technological Advances in Remote Sensing

Day 2 – 17 August 2024

- Remote Monitoring of Water Quality
- Remote Monitoring of Soil Quality
- Remote Monitoring of Soil and Forests

3.2 Speakers

The workshop featured prominent speakers from various sectors, including government, academia, and industry. Their expertise and perspectives were essential in guiding discussions and providing valuable insights. For more information, see Annex 3.

3.3 Summary of Keynote Speeches

The inaugural session was presided over by Engineer Juan Narciso, President of the Board of the Environmental Evaluation and Oversight Agency of Peru, who welcomed participants, encouraged active engagement in the sessions, and expressed gratitude to special guests and representatives from APEC economies. He then introduced the general moderator of the event, Magister José Pasapera, Director of Spatial Applications and Geomatics at the National Commission for Aerospace Research and Development (CONIDA), who moderated all sessions throughout the event.

Day 1

Petri Nygrien - SMAPS Oy Spectral Mapping Services – Finland

Topic: Responsible Mining through Airborne Hyperspectral Imaging

- Petri Nygrien's presentation highlighted the role of remote sensing technologies in environmental monitoring, particularly for detecting and managing the impacts of mining activities. His contributions emphasized the importance of these tools in formulating effective public policies and preventing long-term environmental damage.

- Nygrien provided an overview of various remote sensing methods, focusing on their application in environmental monitoring. He stressed the importance of understanding how these technologies can be used to detect and manage environmental impacts, especially in the mining sector.

- A central point of his presentation was the detection of acid mine drainage (AMD), which Nygrien identified as a critical environmental issue. He explained that while AMD can occur naturally, the majority is caused by human activities in mining. Remote sensing technologies, particularly hyperspectral imaging, can be used to detect AMD and assess its impacts.

- Nygrien illustrated his points with examples, such as the alumina spill in Ajka, Hungary, in 2010, where toxic waste caused severe environmental damage, resulting in loss of life and widespread ecological destruction. He emphasized that such incidents, which have occurred thousands of times worldwide, must be prevented. In this case, hyperspectral imaging was used to accurately determine the extent of the affected area.

- Another example included the detection of oil spills using hyperspectral analysis. Nygrien explained that different materials reflect varying amounts of electromagnetic energy, enabling the detection of hydrocarbons across different spectral ranges. This technology is particularly useful for identifying oil spills and assessing their environmental impacts.

- Nygrien discussed several environmental applications of remote sensing, including:

    - Detection of toxic drainage from tailings.
    - Estimation of spill extents.
    - Direct or indirect detection of spilled hydrocarbons through stress analysis in vegetation.
    - Water quality monitoring.
    - Assessment of damage to vegetation and dust retention.
    - Mapping of cultural assets and creation of environmental baselines for Environmental Impact Assessments (EIAs).

- He emphasized the importance of establishing an environmental baseline to understand the differences between initial and current conditions, which is crucial from both ecological and legal perspectives.

- Nygrien highlighted the long-term impact of environmental damage, noting that recovery can take generations. He called for prevention, advocating for the use of remote sensing technologies to alert stakeholders to impacts before they occur.

- The effectiveness of airborne hyperspectral imaging was underscored, pointing out that only a small portion of data is needed to provide comprehensive information to policymakers. This technology is invaluable for detecting AMD, oil spills, and the environmental stress they cause.

- However, he cautioned against unrealistic expectations, emphasizing that while remote sensing is a powerful tool, it is not infallible. The success of these technologies depends on their proper application and the expertise of operators. Choosing the right technology and having trained personnel to interpret the data are key to achieving accurate and actionable results.

Laercio Namikawa - National Institute for Space Research (INPE) – Brazil

Topic: Remote Sensing and Monitoring Tools for Environmental Management in Brazil

- Laercio Namikawa's presentation highlighted the fundamental role of remote sensing in environmental management in Brazil. By showcasing various applications, including deforestation monitoring, disaster response, and wildfire management, he illustrated how INPE's work is essential for preserving Brazil's natural resources and mitigating environmental risks. The presentation also emphasized the importance of continuous innovation and the adoption of advanced technologies to enhance environmental monitoring efforts.

- Remote sensing and satellite monitoring have been crucial tools for environmental management in Brazil. Namikawa emphasized that these technologies have played a significant role in responding to various environmental disasters over the years.

- He explained that INPE is at the forefront of space research in Brazil, responsible for using satellite imagery to monitor environmental changes, including deforestation, climate change, and vegetation cover.

- A primary focus of the presentation was the use of satellite technology to monitor deforestation in Brazil. Namikawa demonstrated how satellite images have been used to assess the extent and severity of deforestation, providing critical data to determine deforestation rates over time.

- He showcased statistical graphs illustrating deforestation trends, highlighting that while deforestation rates had decreased, there has been a slight upward trend in certain states in recent years. This data is publicly available through dashboards on INPE's website, ensuring transparency and accessibility.

- Namikawa discussed how INPE also uses degradation maps as a preventive tool against deforestation. The institute has developed an alert system that identifies at-risk areas, shown as polygons, which has been instrumental in detecting illegal mining activities in the Amazon. However, he noted that the effectiveness of detection depends on the resolution of the satellite images used.

- As part of his presentation, Namikawa shared satellite images of Peru, particularly in the Río Colorado area, comparing data from 2021 and 2024. These images demonstrated vegetation recovery in certain areas, highlighting the positive impact of restoration efforts.

- He also presented images of the Las Bambas copper mine, emphasizing how remote sensing has been used to identify areas where environmental risks have increased. Comparing satellite data with information provided by mining companies allows for cross-verification and more accurate environmental assessments.

- Namikawa concluded his presentation by focusing on wildfire monitoring. He presented maps showing the spread of wildfires and the affected areas, known as hotspots. Satellite data enables the calculation of impacted areas, providing valuable information for managing and mitigating the impacts of wildfires.

- He also mentioned that INPE is working on automating the analysis of historical data to maintain consistency with previous records, which were traditionally stored on paper or in other formats. This includes transitioning to data cubes and incorporating big data analysis, artificial intelligence, and machine learning to enhance the institute's analytical capabilities.

- Namikawa emphasized that INPE is evolving its methods by integrating advanced technologies such as artificial intelligence (AI) and machine learning to manage and analyze large datasets. This progression towards big data analysis will enable more sophisticated environmental monitoring and more informed decision-making processes.

Miguel Quintana - Environmental Systems Research Institute (ESRI / TELEMATICA) – Peru

Topic: Use of Artificial Intelligence in Geospatial Technology for the Analysis of Environmental Impacts in the Mining Sector

- Miguel Quintana's presentation highlighted the role of advanced remote sensing technologies and artificial intelligence (AI) in environmental management. By using tools such as hyperspectral imaging and the ARCGIS platform, mining companies can achieve more effective monitoring, analysis, and decision-making, supporting more sustainable and responsible mining practices.

- Quintana began by emphasizing the importance of Environmental, Social, and Governance (ESG) criteria for mining companies. Given the risks associated with mining activities, adhering to ESG standards is crucial for sustainable and responsible operations.

- He highlighted the involvement of leading companies in the field, including ESRI, NV5, Planet, and Capella Space. These companies are at the forefront of providing advanced remote sensing and analytical tools for environmental monitoring.

- Quintana discussed the variety of resources and tools available for hyperspectral analysis, incorporating AI. He demonstrated how ESRI's ARCGIS platform facilitates these analyses, offering a significant advantage due to its agnostic nature, meaning it can work with any type of sensor.

- A key feature of the presentation was a web application developed to consolidate various types of information, including satellite images and catalogs. This application provides easy access to a wide range of data, enhancing the capability for comprehensive analysis.

- Quintana showcased the application of hyperspectral imaging in a mining context, illustrating how different bands and indices (for example, for water bodies) are used to analyze recent and historical images. The ability to view images over time and at different resolutions is crucial for understanding changes and impacts.

- The presentation emphasized the role of AI in processing large volumes of data, which would be nearly impossible to manage manually. AI in ARCGIS allows for image extraction, trend prediction, anomaly detection, and identification of damaged structures, such as broken roads or construction issues.

- Quintana highlighted the use of data series for change detection, allowing for comparisons over time from different perspectives, including 3D views. This

provides a more comprehensive context for analyzing environmental changes and impacts.

- He noted the advantage of pre-trained algorithms available on the platform, which eliminates the need to manually train models. This efficiency accelerates the analysis process and ensures more consistent and reliable data.

- An example was provided in which AI algorithms were used to identify paths and routes within a mining concession area. The AI was trained to recognize newly constructed roads, abandoned routes, and potential paths for illicit activities. This demonstrates the platform's adaptability to various monitoring needs.

- Quintana concluded by emphasizing the benefits of using AI in environmental management, including faster processing times, improved data consistency, and enhanced decision-making capabilities. The integration of AI and advanced remote sensing technologies provides a powerful toolkit for managing and mitigating environmental impacts in the mining sector.

Lorenz Wendt (Virtual) - University of Salzburg – Austria

Topic: Applications of Remote Sensing in Environmental Protection and Humanitarian Action - Christian Doppler (CD) Laboratory GEOHUM

- Lorenz Wendt's presentation highlighted the diverse and significant applications of remote sensing in humanitarian efforts and environmental management. By demonstrating how technology can enhance the efficiency and effectiveness of data collection and analysis, Wendt underscored the value of remote sensing in addressing complex global challenges.

- Wendt began his presentation by emphasizing the wide range of applications for remote sensing technology. He highlighted the importance of addressing specific questions and needs to effectively utilize remote sensing data.

- He discussed the role of remote sensing in humanitarian efforts, particularly in response to natural disasters, conflicts, and displacement crises. He noted that these events require coordinated responses from local and international organizations to provide assistance and support to affected populations.

- The work at the University of Salzburg focuses on generating solutions for humanitarian actions by processing various types of datasets. This involves integrating remote sensing information with spatial analysis to conduct specific assessments, such as evaluating the impacts of climate change on health and diseases.

- Remote sensing enables rapid and large-scale observations, covering areas that would otherwise be inaccessible. Wendt provided examples of how satellite imagery can be used to estimate population sizes in refugee camps

or newly established settlements, which is crucial for planning and delivering aid.

- Traditional data collection methods for humanitarian responses often require numerous samples, but technology allows for a reduction in the number of necessary samples. Wendt explained how segmentation and classification of information facilitate analysis, making the process more efficient.

- He emphasized the importance of including environmental variables in remote sensing analyses, such as bodies of water, groundwater, and land cover. These variables are essential for assessing various factors, including vegetation health and food security.

- Wendt presented examples from Africa to illustrate how remote sensing can track changes in land cover and environmental conditions. These examples demonstrate the practical applications of remote sensing in monitoring and managing environmental and humanitarian issues.

- He underscored the need to understand specific requirements when selecting remote sensing products. With a wide range of tools and data available, it is crucial to identify and choose products that best fit the needs of the analysis or project.

- The presentation concluded with an emphasis on the importance of effectively using remote sensing technology to tackle humanitarian and environmental challenges. By leveraging advanced techniques and selecting appropriate tools, organizations can enhance their response capabilities and outcomes in various contexts.

Marcelo Scabuzzo - National Commission on Space Activities (CONAE) – Argentina

Topic: Remote Sensing of Environmental Quality Indicators Focused on Air Quality and SAR-SAOCOM Applications

- Marcelo Scabuzzo's presentation emphasized the diverse applications of remote sensing for assessing environmental impacts, focusing on monitoring land, water, and soil. Through examples of gas absorption, urban pollution, methane detection, and snow quality, he demonstrated how satellite technology and modeling are used to address environmental challenges and support sustainable practices.

- Scabuzzo introduced CONAE, highlighting that the institute employs around 100 scientists, including PhD and master's students, as well as technicians and scientists from the space agency.

- He outlined three main areas of impact for remote sensing in environmental monitoring: land, water, and soil. These focal areas are central to understanding and managing the environmental impacts of mining activities.

- He explained the concept of absorption windows for different gases as measured by satellites. This involves physical and technological principles that allow the measurement of energy absorbed by gases, which is crucial for monitoring atmospheric conditions and pollutants.

- Scabuzzo presented examples from the pandemic year, showing how satellite images revealed reduced pollution levels in urban areas due to lockdowns and isolation measures. This case highlighted the utility of remote sensing for observing changes in environmental impacts during significant global events.

- Another example involved the detection of methane emissions at landfill sites. Although CONAE's satellites are not hyperspectral, they use specific absorption bands to identify gas emissions, which is essential for monitoring and managing pollution at waste sites.

- He discussed the difference between satellite measurements and projections through modeling. He showcased modeling applications related to air quality, illustrating how remote sensing data can be integrated with models to predict and assess environmental conditions.

- The presentation also highlighted the importance of snow as an indicator of pollution. Scabuzzo emphasized the relevance of studying snow contamination, noting that remote sensing can estimate various parameters related to snow quality and contamination levels.

- He introduced the SOCOM satellite, an active radar satellite developed in Argentina. The SOCOM satellite is designed for radar imaging, providing valuable data for environmental monitoring and other applications.

- Scabuzzo concluded by reinforcing the importance of remote sensing in monitoring and managing environmental impacts, particularly in the context of mining. By leveraging satellite technology and advanced modeling, CONAE contributes to a better understanding of environmental changes and supports effective management strategies.

Juan Casas - Geological, Mining and Metallurgical Institute (INGEMMET) – Peru

Topic: Applications of Remote Sensing in Areas with Mining Environmental Impact

- Juan Casas Malpartida's presentation highlighted the use of remote sensing and spectroscopy for mineral identification and monitoring mining impacts. By employing advanced technologies and analyzing spectral signatures, INGEMMET contributes to a better understanding and management of the environmental impacts of mining activities in Peru.

- Casas Malpartida focused on using remote sensing to identify minerals through their spectral characteristics. He explained that by studying the spectral signatures associated with various minerals, indirect indicators can be used to detect the presence of valuable resources like gold and copper.

- Spectroscopy plays a crucial role in identifying the spectral characteristics of minerals. Casas Malpartida described how each mineral has a unique spectral signature, and a wide range of technologies—including spectroradiometers, satellites, aircraft, and drones—are employed to analyze these signatures.

- The presentation included an overview of how mining activities have evolved over time in specific areas. Casas Malpartida provided an example from the Ananea region (located in Puno, Peru), where approximate areas of mining impact have been estimated based on pixel resolution. This historical analysis helps understand spatial and temporal changes in mining activities.

- Another significant application discussed was the analysis of acid mine drainage (AMD) in the Cordillera Blanca. INGEMMET has developed a database of spectral signatures to identify minerals present in acid drainage from rocks. This helps assess the environmental impact of mining and manage AMD more effectively.

- Casas Malpartida also shared examples from other regions, including Madre de Dios and Puno. In these areas, remote sensing data is used to classify images and analyze various aspects of mining activity. These case studies illustrate the practical applications of remote sensing in different mining contexts.

Day 2

Gilles Wending (VIRTUAL) - Environmental Law Alliance Worldwide – USA

Topic: Impacts of Mining in Hydrological Systems and Needs for Monitoring

- Wending's presentation underscored the importance of continuous and long-term monitoring of mining impacts. Remote sensing technologies play a vital role in providing detailed and transparent information, enabling better management of environmental impacts and ensuring that mining activities are effectively monitored over time.

- He emphasized the critical need for monitoring mining impacts, highlighting that timely coverage is essential. Mining activities often have significant and lasting environmental effects that require ongoing observation.

- Wending discussed the large volumes of waste generated by mining operations, detailing the composition of metals and their associated toxicity. The presence of multiple toxic elements in mining waste presents complex

challenges, as addressing one metal often involves managing other hazardous substances.

- He explained how mining operations, including tailings storage facilities (TSF), pose a risk of contaminating groundwater. Even inactive mines can have ongoing environmental impacts, particularly on groundwater, due to the persistence of toxic substances. He highlighted the importance of long-term monitoring and trend analysis to address persistent environmental issues.

- Wending presented applications and benefits of remote sensing in environmental monitoring, such as its significance in understanding and tracking mining's environmental impacts across various aspects, including historical data and access to remote areas. It provides valuable information for assessing ongoing impacts and designing effective monitoring controls.

- Another key benefit of remote sensing discussed was transparency. Remote sensing tools facilitate access to information about mining impacts, supporting greater transparency and accountability in environmental management.

Dana Chadwick (VIRTUAL) - National Aeronautics and Space Administration, NASA – USA

Topic: Identification of Acid Mine Drainage Indicator Minerals and Precursors by EMIT Hyperspectral Sensor on Board the International Space Station

- Chadwick's presentation highlighted advanced imaging spectroscopy capabilities from space, particularly through the International Space Station (ISS). By providing high-resolution data and detailed maps, these technologies contribute to a better understanding of environmental issues such as acid mine drainage and the impacts of mining activities, even in remote and abandoned sites.

- She discussed the valuable data available from the ISS, explaining how imaging spectroscopy provides comprehensive and high-resolution information about the Earth's surface.

- Chadwick highlighted the "Golden Age of Imaging Spectroscopy," noting its capacity to detect very high-quality data. The volume and density of the data are so extensive that computing power sometimes struggles to process it effectively.

- She introduced the EARTH mission, focusing specifically on the Earth Surface Mineral Dust Source Investigation (EMIT). She showcased the regions where this mission is actively collecting data, emphasizing that the information is accessible for various applications and contexts.

- A significant finding from the mission relates to the identification of acid mine drainage (AMD). Chadwick presented a case study in collaboration with the

U.S. Geological Survey (USGS) for Leadville, Colorado, which allowed for the identification of different minerals associated with mining activities in the Amazon and other regions, linked to the presence of acid sulfates, illustrating how remote sensing can accurately and quickly track AMD and its impacts.

- She also discussed the environmental impact of abandoned mines, emphasizing that these sites can continue to have significant adverse effects on the environment.

Francisco Zuñiga - Procuraduría Federal de Protección al Ambiente de México (PROFEPA) – Mexico

Topic: Use of Remotely Piloted Aircraft System (RPAS) for Environmental Inspection of Soil in the Mining Industry

- Zuñiga's presentation emphasized the critical role of RPAS (drones) in environmental monitoring and regulation. By using drones for various applications, including waste management, incident documentation, and site inspections, PROFEPA enhances its ability to enforce regulations, assess environmental impacts, and ensure compliance with environmental standards.

- He provided a brief overview of PROFEPA, outlining its role and functions in environmental protection and regulation in Mexico.

- Zuñiga explained the types of RPAS currently utilized by PROFEPA, highlighting their differences in coverage and application. Drones have simplified field visits and are complemented by additional tools and technologies.

- He stressed the importance of accurately interpreting drone data and using appropriate software for processing. Effective data interpretation and software tools are crucial for analyzing and making informed decisions based on the data collected by drones.

- A case study presented involved a tailings dam in Chihuahua, Mexico, where drones are used to monitor and reduce the moisture levels of mining waste. This case illustrates how technology is applied to address specific environmental challenges and improve waste management.

- Zuñiga discussed how drones have been employed to gather evidence after mining accidents. This evidence is used to impose appropriate penalties and assess environmental damage. Aerial photographs from drones help accurately identify and document the extent of damage, ensuring that penalties and corrective measures are effectively applied.

- He provided examples of how drones have addressed challenges related to accessing remote or hazardous areas. Drones have proven valuable for

inspecting complex sites with extensive facilities, where traditional methods might be difficult or unsafe. They have also helped identify unauthorized constructions outside approved limits in Environmental Impact Assessments (EIA).

David Williams (VIRTUAL) - Environmental Protection Agency (EPA) – USA

Topic: Machine Learning Approach for Mapping Hotspots of Soil Contamination Using Imaging Spectroscopy at Historical Mine Sites

- Williams's presentation focused on advancements and challenges in soil analysis using modern technologies like imaging spectroscopy and machine learning. By leveraging these technologies and spectral libraries, the EPA aims to improve the precision of soil analysis and environmental monitoring.

- He discussed the challenges of soil analysis compared to mineral analysis. While mineral analysis is relatively straightforward, soil analysis is more complex due to the heterogeneous nature of soils. The EPA has been addressing this issue for over 30 years.

- Williams highlighted the use of machine learning in soil analysis, which requires processing a large number of images to be effective. Machine learning algorithms can analyze complex datasets and enhance the accuracy of soil analysis.

- He introduced imaging spectroscopy technology, which captures images across up to 300 spectral bands, compared to the three standard colors (red, green, blue) in conventional imaging. This technology improves the ability to identify various materials, including components of vegetation and soil.

- The presentation covered the use of spectral libraries, which contain extensive data on the spectral signatures of minerals and soils. These data assist in identifying and categorizing different soil components. Williams emphasized that spectral libraries from different entities contribute valuable information for analysis.

- Soil analysis involves collecting samples from specific locations using spectrometers, which are then sent to laboratories for detailed analysis. The laboratory conducts reflectance spectroscopy to measure the spectral properties of soil samples.

- Williams presented various applications of machine learning in soil analysis, demonstrating its potential to enhance soil monitoring and environmental assessment. He concluded that machine learning methods are diverse and require large amounts of data for training and analysis.

Raul Rivas - Instituto de Hidrología de Llanuras (IHLLA) – Argentina

Topic: Remote Sensing Data: Application in Assessment of Soil Characteristics

- Rivas's presentation emphasized the importance of understanding soil characteristics and processes for effective analysis using remote sensing technologies. While advanced technologies like hyperspectral imaging offer significant benefits, proper use of available tools and methods can also yield valuable insights for soil management and environmental protection.

- He focused on the importance of understanding soil profiles, particularly in the context of soil erosion. Rivas highlighted that soil is a valuable natural resource, formed over thousands of years through geological and climatic processes, but it can be quickly destroyed, underscoring the need for effective management and protection.

- Rivas explained that soil consists of several layers, known as soil horizons, each with distinct properties. These layers are crucial for analyzing soil using satellite data. He emphasized that before selecting tools for soil analysis, it's essential to comprehend soil processes and characteristics, such as texture, particle size, organic matter content, and water content. These factors influence the soil's reflectivity and spectral response.

- The presentation addressed how different aspects of soil contribute to its spectral response, which can be analyzed using satellite data. Rivas pointed out that while hyperspectral imaging provides detailed information, satisfactory results can also be achieved with less advanced or costly technologies. He suggested that using appropriate combinations of bands in remote sensing can provide valuable insights without the need for the latest equipment.

- Rivas recommended several methods for soil analysis, including spectroscopy, multispectral imaging, and microwave detection. He emphasized that understanding the soil's spectral response and selecting the appropriate methodology is crucial for accurate analysis and informed decision-making.

Govinda Terra - Instituto Brasileño de Medio Ambiente y Recursos Naturales Renovables (IBAMA) – Brazil

Topic: The Use of Remote Sensing Products in Activities to Combat Illegal Mining

- Govinda Terra's presentation illustrated IBAMA's efforts in utilizing remote sensing technologies for environmental protection, particularly in combating deforestation and illegal mining. By leveraging satellite data and inter-ministerial collaboration, Brazil has enhanced its enforcement capabilities,

protected Indigenous lands, and worked towards long-term environmental sustainability.

- Terra began by expressing gratitude for the opportunity to share Brazil's experience with remote sensing technologies in environmental protection. He focused on the critical issue of deforestation in the Amazon, primarily driven by illegal mining. His presentation built on earlier discussions by Laercio Namikawa (INPE) regarding the production of remote sensing products, now highlighting their practical applications in environmental management.

- He described IBAMA as Brazil's main environmental executive agency, responsible for project licensing and enforcing laws against illegal activities in remote regions. The agency has the authority to impose administrative penalties and coordinate with state and municipal levels within a robust legal framework to safeguard the environment for current and future generations.

- Brazil has implemented a satellite-based monitoring and control system using tools like Prodes and Deter. This system enhances the efficiency of deforestation detection by prioritizing critical areas and minimizing repeated detections. The remote application, combining technology with data analysis, has improved productivity while reducing risks and costs associated with field operations.

- The presentation highlighted the successful protection of Indigenous lands, such as the Yanomami territory. This case demonstrated the effectiveness of inter-ministerial operations aimed at dismantling the logistics supporting illegal activities. The strategy resulted in a significant reduction in illegal mining and restored governance in the region, effectively mitigating environmental impacts and protecting vulnerable communities.

- Terra concluded by emphasizing the importance of high-quality information and the capacity to use it effectively to guide enforcement strategies. He underscored that environmental enforcement is a powerful tool for changing the behavior of offenders but must be complemented with additional measures to sustain reductions in violations over time.

The last participation of the second day was by Engineer Alex Uriarte, Director of Environmental Supervision in Energy and Mining at OEFA and Project Overseer, who highlighted the collaborative learning and opportunities generated by the workshop and among the economies, thanking all participants for their active engagement and the numerous insights gained.

3.4 Highlights and Key Messages

The workshop on "Strengthening Capacities for the Use of Remote Sensing Spectral Signatures Applied in Environmental Control Processes for Identifying Environmental Impacts in the Mining Sector" brought together experts,

professionals, and stakeholders to explore the critical role of remote sensing technologies in environmental monitoring.

It featured twelve (12) speakers presenting perspectives from different economies and attracted over 100 participants from 11 economies, including Chile; Indonesia; Malaysia; Mexico; Papua New Guinea; Peru; The Republic of the Philippines; Chinese Taipei; Thailand, United States; Viet Nam.

The following highlights and key messages emerged from the discussions and activities:

1. **Importance of Remote Sensing in Environmental Monitoring**
    - Remote sensing technologies, including hyperspectral imaging and satellite observations, support faster or real-time monitoring of the current state of the environment, particularly in hard-to-access areas. They also enable the development of temporal assessments of environmental quality.

2. **Detection and Management of Environmental Impacts**
    - Remote sensing tools can effectively detect environmental issues such as Acid Mine Drainage (AMD), which is a significant concern in mining operations. Hyperspectral imaging is particularly valuable for identifying toxic substances and assessing their spread. These technologies are also useful for monitoring deforestation, pollution, and changes in vegetation, which are essential for environmental impact assessments and government policy development.

3. **Integration of Advanced Technologies**
    - The integration of artificial intelligence (AI) with remote sensing enhances the analysis of large datasets, improves the precision of environmental monitoring, and supports better decision-making.

4. **Role of Remote Sensing in Environmental Management**
    - Remote sensing helps track and manage various environmental issues, from soil and water contamination to soil erosion and forest fire monitoring. It provides critical data for developing effective environmental management strategies. Satellite technology and advanced modeling are used to monitor and predict environmental changes, providing valuable information to address challenges such as illegal mining and deforestation.

5. **Case Studies and Practical Applications**
    - Examples from different regions, including mining sites and areas affected by natural disasters, demonstrate how remote sensing technologies have been used to tackle specific environmental problems. These case studies highlight the practical applications and benefits of these technologies in real-world scenarios.

6. **Challenges and Limitations**
    - While remote sensing technologies are powerful tools, they are not without limitations. Accurate application and interpretation require trained personnel and an understanding of the capabilities and limitations of the technologies. The success of these technologies depends on selecting appropriate tools, managing data effectively, and addressing potential challenges in data accuracy and resolution.

7. **Long-Term Monitoring and Prevention**
    - Continuous monitoring using remote sensing is essential for understanding long-term environmental impacts (through temporal assessment) to prevent future damage. This approach supports the development of proactive strategies to mitigate environmental risks associated with mining activities.

8. **Collaboration and Innovation**
    - Collaborative efforts and the adoption of innovative technologies are vital for enhancing environmental monitoring and management. Interdisciplinary approaches and international cooperation can lead to more effective solutions and better outcomes for environmental protection.

These highlights and key messages reflect the success of the workshop in enhancing understanding and application of remote sensing technologies in the mining sector, paving the way for more effective environmental management aligned with sustainable development.

3.5 Networking Session Outcomes

The networking sessions generated several recommendations, including:

- **Access to Products:** Ensuring easy access to remote sensing products is crucial for their effective use.
- **Collaborations:** Strengthening partnerships between researchers and regulatory agencies is essential for achieving better outcomes.
- **Training Needs:** Extensive training and capacity building in various technical fields are required to effectively utilize these tools.
- **Implementation Challenges:** Having the tools available is one thing, but integrating them into institutions presents complexities that must be addressed.
- **Technical Support for Application:** Technical fundamentals are important for effective environmental application.

- **Budget and Safety:** Utilizing these technologies can save budget and time while enhancing personnel safety.
- **Need for Alliances:** Forming strategic alliances is necessary for effective implementation and support.
- **Availability of Spatial Information:** The availability and application of spatial information can provide greater support for environmental applications.
- **Continuous Learning:** Ongoing learning and adaptation are necessary to maximize the benefits of these technologies.

3.6 Pre- and Post-Workshop Evaluations

Two pre- and post-workshop evaluations were conducted for each day. The average number of participants for the pre- and post-tests was 53.25 per test.

Questions were included based on suggestions from the speakers, aligning with the topics they presented and the overall content of the workshop. Below is the general statistics of the participants and the results obtained by day:

Evaluation	Description	August 16	August 17
Pre-Test	Number of Participants	61	56
	Results (% Correct Answers)	69%	60%
Post-Test	Number of Participants	52	44
	Results (% Correct Answers)	87%	71%

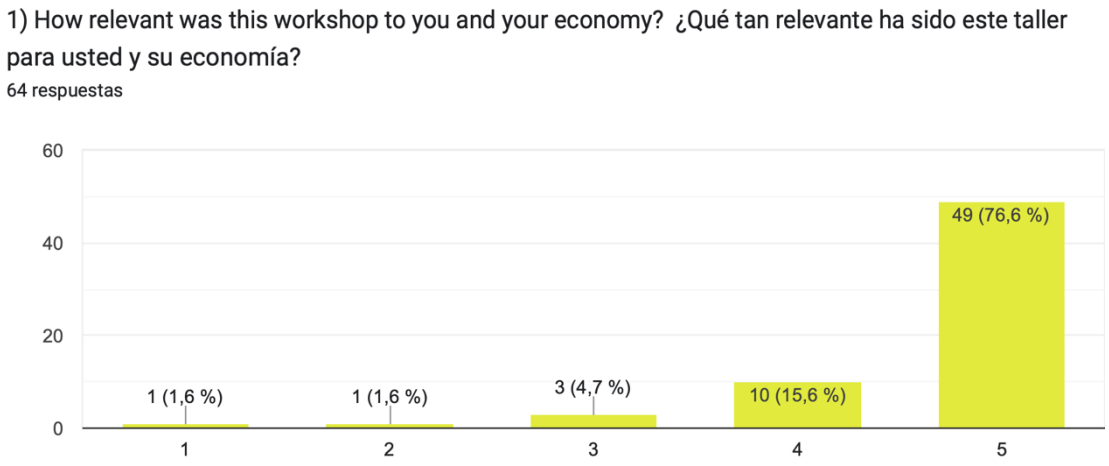
The calculations indicate that the event had a positive impact on the participants. Notably, the improvement was greater on 16 August (26% increase) compared to 17 August (18% increase). It's also noteworthy that in both days, the baseline results exceeded 50%, suggesting a strong level of knowledge about spectral signatures among the participants.

Based on this, it can be concluded that the results from the pre- and post-evaluations demonstrate a significant increase in success indicators. This suggests that the event met its objectives, as reflected in the improved knowledge of the participants by the end of the workshop.

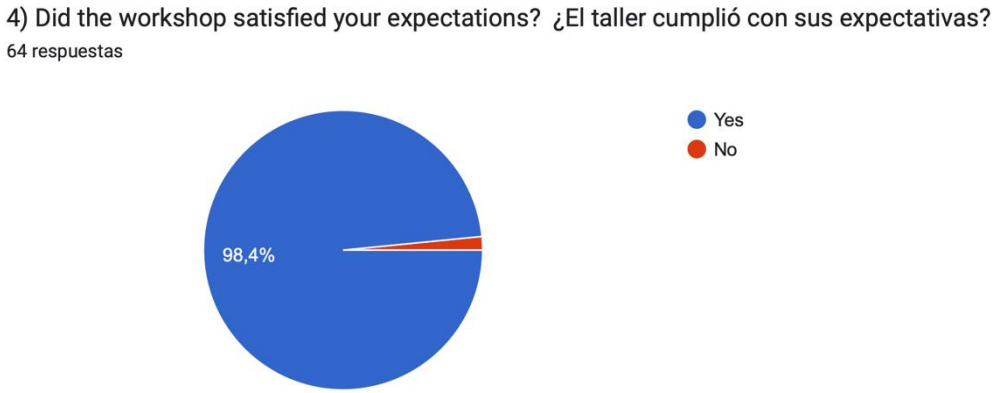
3.7. Project Survey

At the end of the workshop, a virtual survey was sent to all participants to gather feedback and general impressions. A total of 64 responses were received from seven (7) APEC economies.

Regarding the question: "How relevant was this workshop to you and your economy?" the majority of participants (76.6%) indicated that they found it very relevant, as illustrated in the graph below:



In summary, the data suggests that the workshop was perceived as highly valuable by the vast majority of participants. This aligns with the question regarding whether the workshop met participants' expectations, with 98.4% indicating that it did.



On the other hand, participants were asked how they would apply the content of the workshop and the knowledge acquired in their workplaces. Based on the responses, the following recommendations are proposed to strengthen environmental enforcement through remote sensing:

- **Invest in Training:** Offer ongoing training programs so that officials can effectively use remote sensing tools.

- **Develop Technological Infrastructure:** Create platforms and technological tools that facilitate access to and use of remote sensing data.
- **Encourage Collaboration:** Establish networks of collaboration among institutions and economies to share knowledge and resources.
- **Integrate Remote Sensing into Processes:** Systematically incorporate remote sensing into the planning, execution, and evaluation processes of environmental enforcement.
- **Update Regulations:** Adapt existing regulations to ensure the effective use of remote sensing in enforcement.
- **Promote Research and Development:** Encourage research into new applications of remote sensing and the development of performance indicators.

Finally, the main suggestions for improving the event focus on:

- **Content and Depth:** It is suggested to delve deeper into practical topics, include more case studies, especially from the region, and broaden coverage of issues such as sustainability and civil society participation.
- **Format and Duration:** It is proposed to increase the event's duration, offer more practical workshops, and allocate more time for networking and group discussions.
- **Participation and Diversity:** It is suggested to increase participation from different stakeholders (academia, industry, civil society), promote gender diversity among speakers, and facilitate interaction among participants through working groups and virtual platforms.
- **Materials and Resources:** It is proposed to share presentations in advance, provide access to satellite image databases, and create a virtual platform to facilitate information exchange.

IV) Conclusions

- **Success of the Workshop:** The workshop was successfully conducted, with participation from 111 people from various economies; 35 women (32%) and 76 men (68%) participated. The knowledge level of participants increased by an average of 22%.

- **Enhanced Monitoring Capabilities:** Remote sensing technologies, particularly hyperspectral imaging, significantly improve the capacity to monitor and assess environmental impacts related to mining activities. These tools provide detailed information on environmental changes and pollution levels, which is crucial for effective management and mitigation.

- **Integration of Advanced Technologies:** The integration of remote sensing with artificial intelligence (AI) and advanced data analysis platforms, such as ARCGIS, improves the precision and efficiency of environmental monitoring. These technologies enable better decision-making by providing comprehensive data and predictive capabilities.

- **Effective Environmental Management:** The application of remote sensing in environmental control processes is essential for identifying and managing the impacts of mining activities. These technologies support the detection of issues such as Acid Mine Drainage (AMD), pollution, and habitat changes, leading to more informed and proactive environmental management strategies.

- **Need for Qualified Personnel:** The successful implementation of remote sensing technologies requires trained personnel who are competent in using and interpreting these tools. Training and capacity building are critical to maximizing the benefits of remote sensing and ensuring accurate data analysis.

- **Continuous Monitoring and Prevention:** Long-term monitoring using remote sensing is vital for understanding and addressing the cumulative and ongoing environmental impacts of mining activities. Continuous data collection and analysis help prevent future environmental damage and support sustainable practices.

- **Collaboration and Knowledge Sharing:** Effective environmental management and monitoring are strengthened through collaboration and knowledge sharing among stakeholders, including governments, researchers, and industry professionals. Collaborative efforts lead to innovative solutions and better environmental outcomes.

- **Challenges and Limitations:** Despite advancements in remote sensing technologies, there are challenges related to data accuracy, resolution, and interpretation. Addressing these limitations requires ongoing research, technological development, and adaptive strategies.

- **Policy and Implementation:** Insights gained from remote sensing should be integrated into policy development and implementation to support more robust environmental regulations and practices. The effective use of remote sensing data can drive better environmental policies and their enforcement.

APPENDIX 1

Preworkshop Report

Workshop on Strengthening Capacities to Use Spectral Signatures of Remote Sensing Applied in Environmental Control Processes for the Identification of Environmental Impacts in the Mining Sector

I. INTRODUCTION

Mining is a key economic pillar in many APEC economies, but it also poses environmental challenges. To address these, member economies are implementing innovative technologies such as remote sensing and spectral signatures. These tools optimize processes related to environmental monitoring and enforcement, contributing to reduced environmental impact and promoting more sustainable mining practices.

To assess the level of adoption and application of remote sensing and spectral signatures in activities related to environmental control in mining, a survey was conducted with experts from member economies. This will provide insights into the best techniques employed by governmental authorities in their environmental monitoring and enforcement roles, with a focus on the mining sector.

This document presents the results of the survey, which involved professionals from specialized technical organizations in nine (9) APEC economies. The responses offer insights into the use of remote sensing, its application in environmental control within the mining industry, and its benefits and limitations. These results also help identify areas for collaboration to further strengthen this important tool, which contributes to the timely detection of environmental impacts and risk prevention in the mining sector, challenges shared across different APEC economies.

II. EXECUTIVE SUMMARY

Mining is an important activity shared by many APEC economies; however, it also presents environmental challenges that have driven the search for solutions to enable effective state action in remote monitoring and inspections. In this context, remote sensing and spectral signatures have emerged as technologies with the potential to optimize enforcement and risk prevention processes, contributing to the adoption of early mitigation measures for reducing environmental impact.

This document presents the findings and implications of the survey conducted as part of the preparation for the workshop: "Workshop on Strengthening Capacities to Use Spectral Signatures of Remote Sensing Applied in Environmental Control Processes for the Identification of Environmental Impacts in the Mining Sector." The primary goal of the survey was to identify the current level of adoption of

remote sensing and spectral signatures in activities related to environmental control in mining.

The survey involved thirteen experts from nine (9) APEC economies, coming from specialized technical organizations. 85% of the participants were male.

Table 1. Organizations and Economies that Participated in the Survey

Economy	Abbreviation	Organization Name
Chile	SMA	Superintendencia de Medio Ambiente
Malaysia	JMG	Department of Mineral and Geoscience
Mexico	PROFEPA	Procuraduría Federal de Protección al Ambiente
Papua New Guinea	NRI	National Research Institute
Peru	OEFA	Organismo de Evaluación y Fiscalización Ambiental
Chinese Taipei	CHA	Chemicals Administration, Ministry of Environment
Thailand	GISTDA	Geo-Informatics and Space Technology Development Agency
United States	EPA	Environmental Protection Agency
Viet Nam	MOIT	Ministry of Industry and Trade

The survey results indicate that 37.8% of respondents consider the use of remote sensing technology within APEC economies to still be limited. While this assessment provides valuable insights, it is important to note that these findings are only referential estimates due to the small sample size. Nevertheless, the data offers a general overview of the current adoption levels of such technologies by environmental institutions in APEC economies.

The primary conclusions indicate concerns about various environmental aspects resulting from mining activities, with a notable emphasis on the risk of contamination of water resources. Public organizations predominantly use remote sensing tools and spectral signatures for environmental supervision and control, with drones and satellite imagery being the most commonly used methods. Despite the availability of open-source software, the majority still rely on commercial software.

The results demonstrate that remote sensing has provided numerous benefits for economies that use it for environmental protection in the mining sector, such as early problem detection, which allows for risk prevention through more accurate environmental impact assessments and more informed decision-making. Another notable benefit is cost and time savings compared to traditional supervision and monitoring methods.

However, there are still opportunities to strengthen and expand the use of remote sensing. Survey results show that regulatory aspects are a significant barrier to overcome, and the costs associated with remote sensing and spectral signature tools are a major limitation for economies. In all cases, economies agree on the importance of enhancing capabilities and the high technical rigor required for effective remote sensing applications.

In summary, remote sensing and the use of spectral signatures emerge as strategic tools for environmental control in mining, offering tangible benefits for APEC economies. However, effective implementation requires addressing common challenges that necessitate greater collaboration among regional economies. Through cooperation, APEC economies can share solutions and specific methods that can scale to contribute to better environmental management.

III. PRELIMINARY ANALYSIS

The Asia-Pacific Economic Cooperation (APEC) forum plays a crucial role in the economic development of its member economies, many of which engage in mining activities. The Attractiveness Index is a measure used in the annual survey of mining companies conducted by the Fraser Institute (Mejía & Aliakbari, 2024). This index evaluates investors' perceptions of the attractiveness of mining jurisdictions based on factors such as geological potential and government policies.

In the most recent survey edition, it was observed that 57% of APEC economies are included in this index, reflecting their competitiveness and attractiveness in the global mining sector. Moreover, the top three positions belong to APEC economies: Canada; United States, and Australia.

While mining is a key sector for the economic development of APEC economies, it also presents significant environmental challenges that must be addressed sustainably. International best practices in this sector emphasize the importance of cooperation between the state, companies, and the public to inform and prepare the community to understand and propose measures to manage socio-environmental risks and socio-economic benefits associated with mining (World Bank, 2021).

Remote sensing is the science of detecting, measuring, and analyzing a substance or object from a distance (Australian Geological Survey Organization, 1999). It studies spectral, spatial, and temporal variations in electromagnetic waves, identifying surface materials and phenomena through their spectral signature (Sacristán, 2006). This technology allows for data capture that can be processed and analyzed to extract useful information, such as detecting environmental impacts, providing greater precision in detection, and saving resources for government entities.

APEC economies are implementing these technologies through their specialized agencies:

- **Australia**: Geoscience Australia is a reliable source of information on geological sciences, conducting systematic land mapping to maximize the benefits of mineral and energy resources sustainably (Australian Government. Geoscience Australia, 2019).
- **Canada**: The Canadian Centre for Mapping and Earth Observation (CCMEO) is involved in all aspects of geospatial data development and distribution. Its areas of expertise include research and development, digital transformation, geospatial data infrastructure, and governance (Government of Canada, 2024).
- **Peru**: Applies remote sensing technologies to improve land planning and reduce social conflicts related to mining in sensitive areas. The National Institute of Geology and Mining of Peru (INGEMMET) uses high-resolution images to delineate mining interest areas, promoting development through information management for sustainable mining activities across its territory.

The adoption of remote sensing and spectral signature technologies in the sustainable mining practices of APEC economies can lead to the timely detection of environmental impacts, reducing pollution, and enhancing operational efficiency of government agencies responsible for inspections. This strengthens environmental protection and promotes responsible economic activity contributing to sustainable development.

IV. SURVEY RESULTS

In preparation for the project DESG_204_2023A "Workshop on Strengthening Capacities to Use Spectral Signatures of Remote Sensing Applied in Environmental Control Processes for the Identification of Environmental Impacts in the Mining Sector," a survey was conducted with the main purpose of identifying the current level of adoption of remote sensing and spectral signatures in activities related to environmental control in mining.

Thirteen (13) responses were obtained from experts in nine (9) APEC economies: Chile; Malaysia; Mexico; Papua New Guinea; Peru; Chinese Taipei; Thailand; United States; Viet Nam.

The survey participants were highly qualified professionals specializing in various areas related to environmental management, geospatial technology, and scientific research. Among them were experts in geographic information systems, environmental specialists, geo-informatics scientists, and development and innovation officials, who contributed their experience in applying advanced technologies and innovative methods for environmental supervision and protection.

High-level public officials also participated, including directors, coordinators, and federal inspectors responsible for formulating and implementing public policies and overseeing compliance. Notably, of the thirteen (13) responses, only two (2) were from women, reflecting a predominantly male participation rate of 85%.

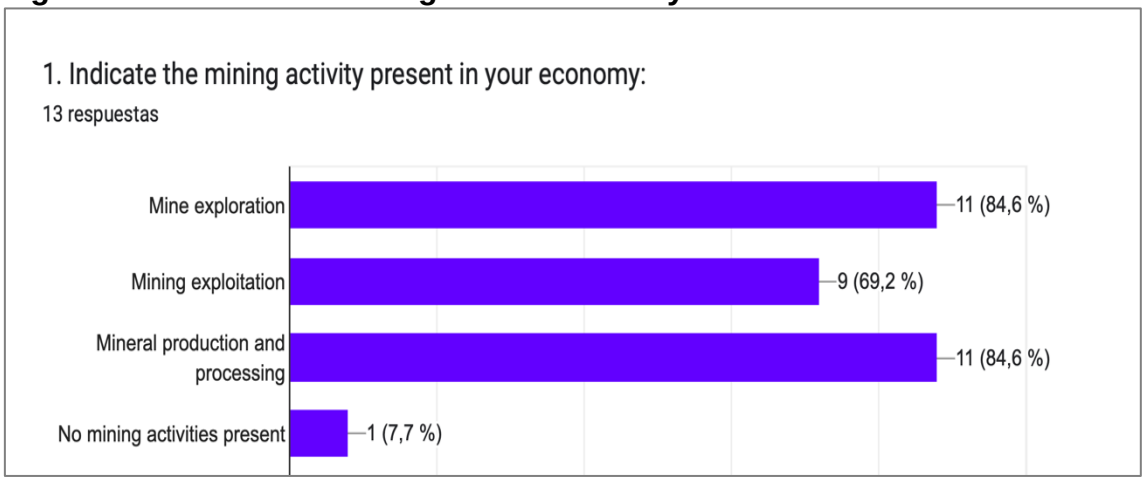
This group of professionals contributes their technical and scientific knowledge to the sustainable management of natural resources, some specifically in the mining sector. This diverse group of experts ensures a comprehensive and multidisciplinary perspective in analyzing and evaluating the issues addressed in the survey.

4.1. Mining Industry

The first question aimed to determine whether mining was part of their economy, and 93% of respondents answered affirmatively, giving particular significance to the survey responses.

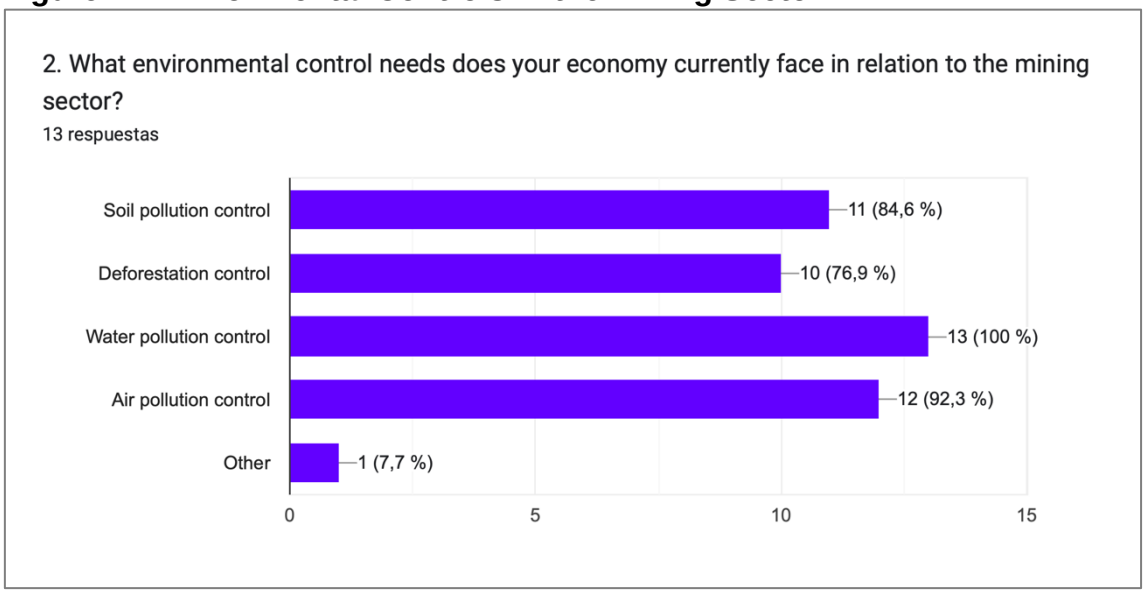
Regarding this, the most common activities reported are mineral exploration and production and processing, both with 84.6% affirmative responses. Mining exploitation is also significant, with 69.2%. For more details, see the following chart:

Figure 1. Presence of Mining in the Economy



Similarly, it was important to identify the environmental control needs faced by the economy in relation to mining activities:

Figure 2. Environmental Controls in the Mining Sector



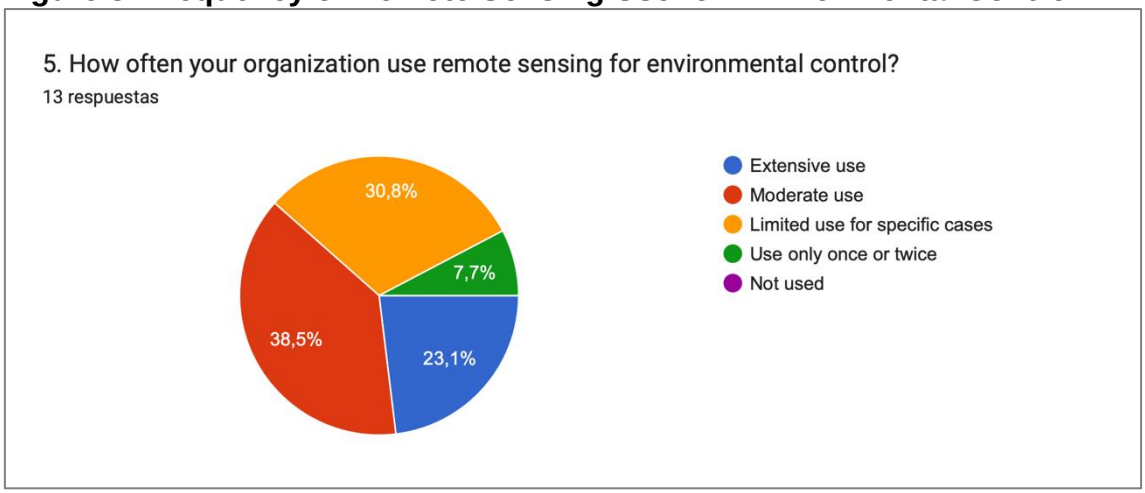
In this regard, it is observed that 100% of the respondents are concerned about water resource contamination, identifying it as a critical environmental control need for government agencies. Air, soil contamination, and deforestation are also of particular concern.

Additionally, there is a specified need to address water extraction and its impacts on both subterranean and surface water resources, as well as wetlands.

4.2. Remote Sensing

Specific survey questions regarding remote sensing aimed to determine the frequency with which organizations use it for environmental control.

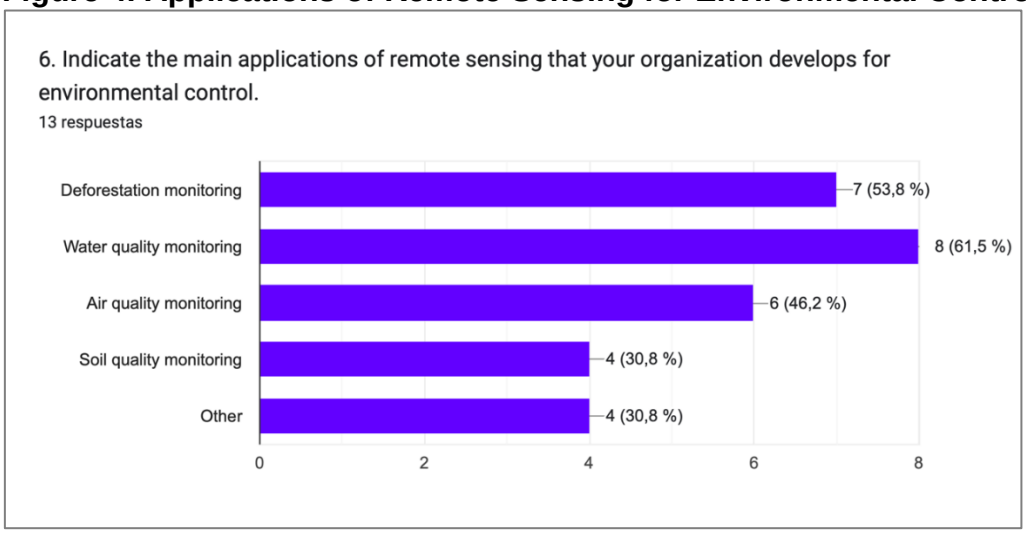
Figure 3. Frequency of Remote Sensing Use for Environmental Control



The main findings indicate that moderate use predominates at 38.5%, with a smaller percentage (7.7%) indicating that remote sensing has been used only once or twice for environmental management.

A subsequent question was posed to identify the primary applications of remote sensing for environmental control:

Figure 4. Applications of Remote Sensing for Environmental Control

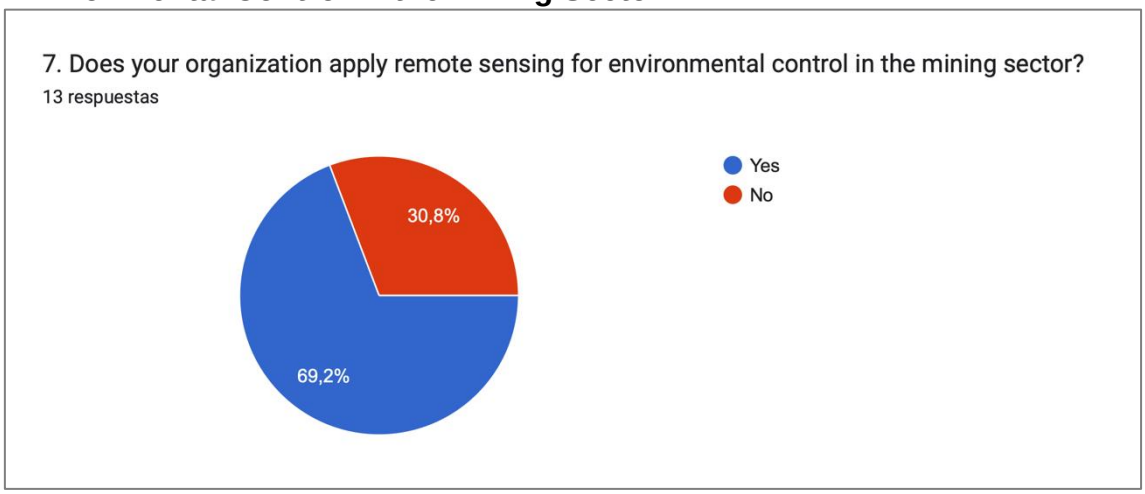


The responses indicate that the most common application of remote sensing is water quality monitoring, with a 61.5% incidence, followed by deforestation monitoring at 53.8%. These findings provide insights into how remote sensing supports and benefits the control of potential impacts on natural resources, primarily water and deforestation.

Specific uses also include identifying illegal mining activities, monitoring vegetation changes and glacier coverage, and estimating river volumes and surface areas.

Additionally, a specific question was asked about whether the organization represented applies remote sensing for environmental control in the mining sector:

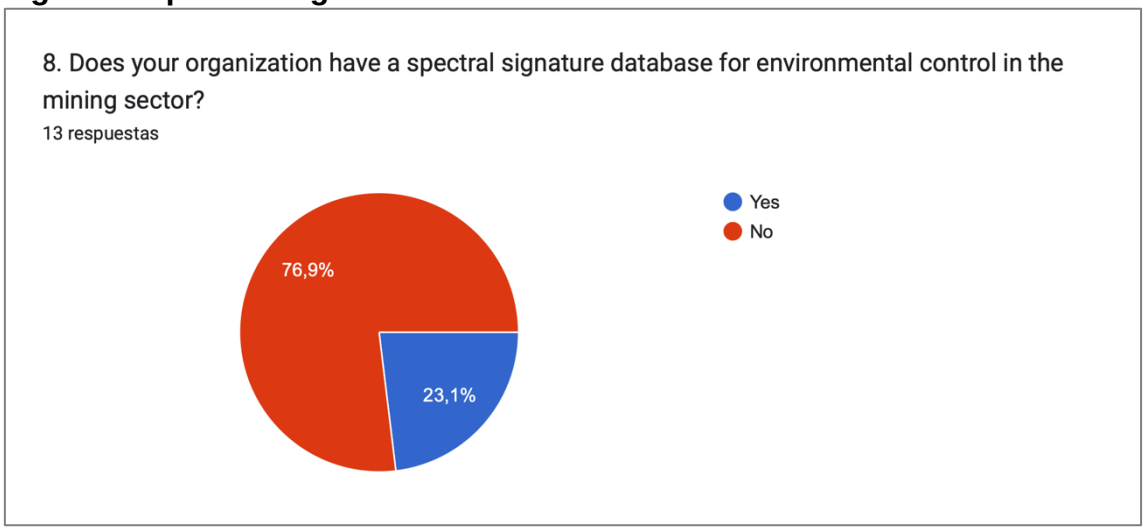
Figure 5. Specific Application of Remote Sensing in Your Organization for Environmental Control in the Mining Sector



A large majority of the surveyed organizations, nearly 70%, indicated that they use remote sensing tools for environmental control of their mining activities. In contrast, a smaller proportion (30.8%) stated that they do not use these tools. This includes organizations from Papua New Guinea; Chinese Taipei; and Thailand.

The next question aimed to determine whether their organizations have a database of spectral signatures for environmental control in the mining sector:

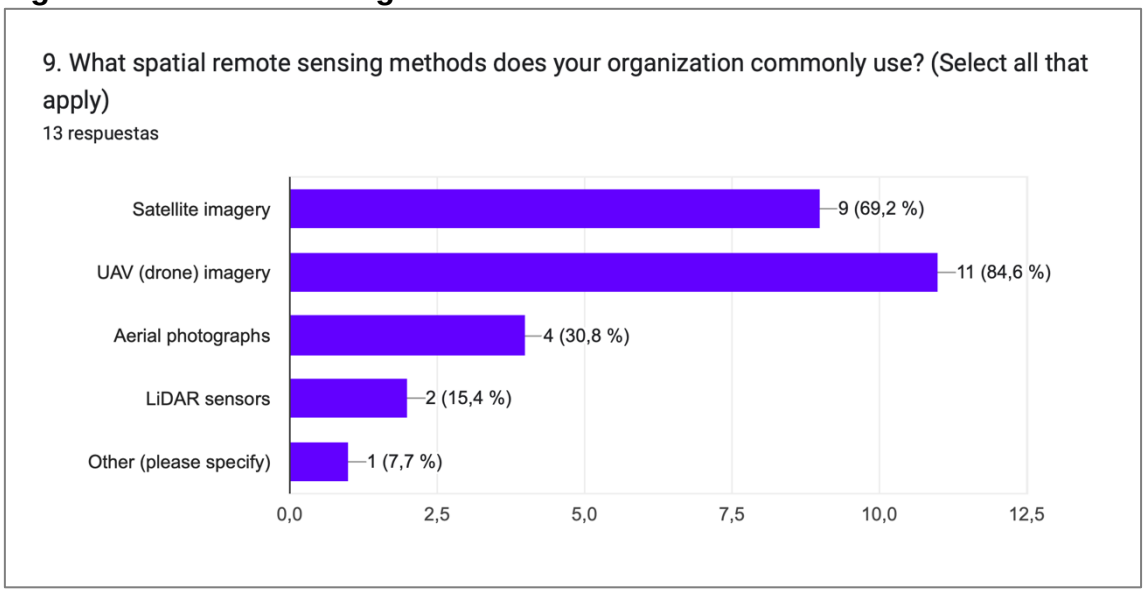
Figure 6. Spectral Signatures Database



As shown in the previous chart, the vast majority of respondents, 76.9%, reported not having a spectral signatures database.

On the other hand, it was important to understand which remote sensing methods are commonly used in the organizations.

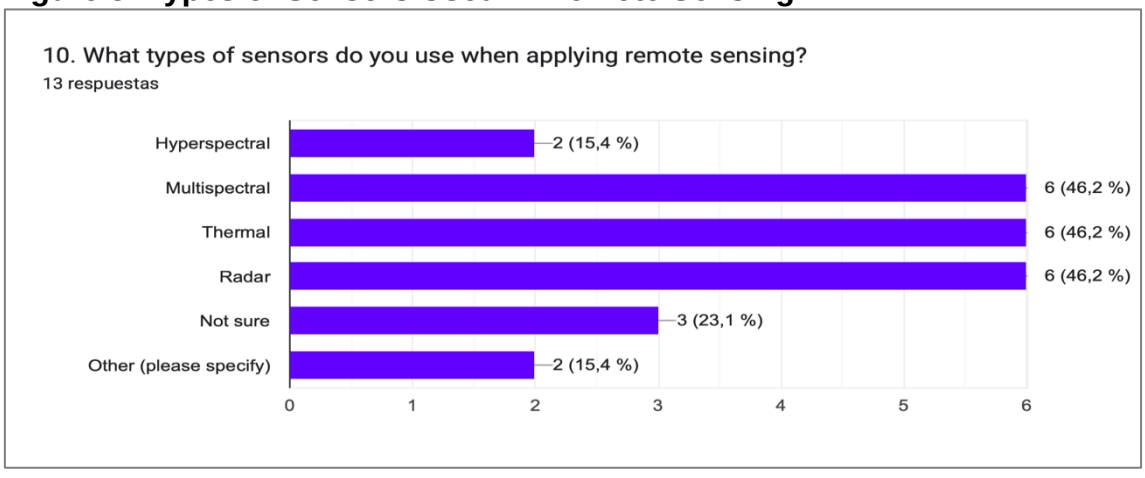
Figure 7. Remote Sensing Methods Used



The most commonly used method, with 84.6% of responses, is drones, establishing them as an essential tool in remote sensing. The use of satellite imagery, with 69.2% of responses, also indicates its significance for environmental control in mining. To a lesser extent, aerial photographs and LiDAR sensors are used, with 30.8% and 15.4% of responses, respectively. Overall, the chart reveals that the surveyed organizations utilize a variety of remote sensing methods, with drones and satellite images being the most popular.

It is also important to understand which types of sensors are most frequently used in remote sensing:

Figure 8. Types of Sensors Used in Remote Sensing

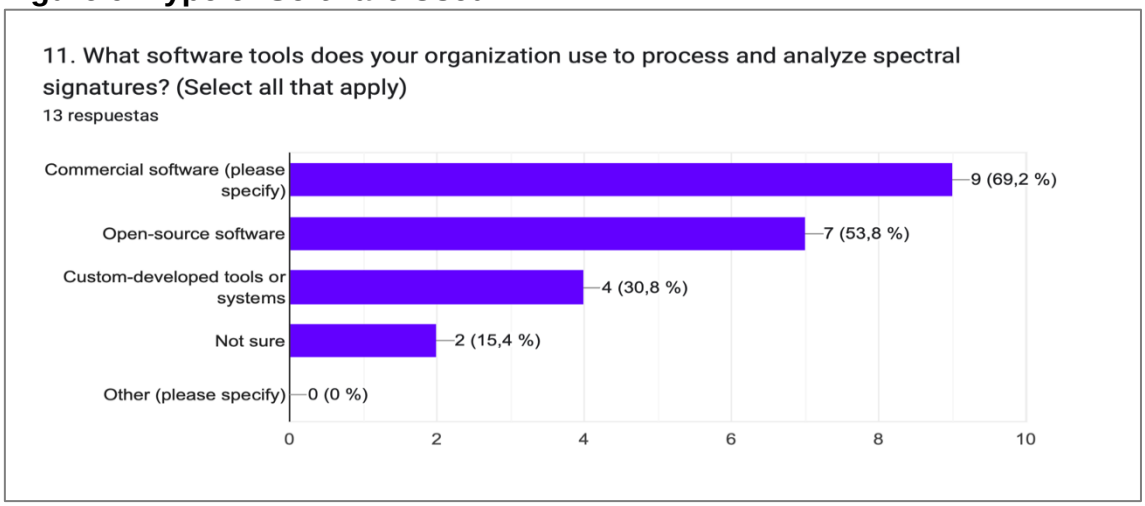


The previous chart reveals a diverse sensor usage among organizations. Multispectral, thermal, and radar sensors were the most commonly reported, each employed by 46.2% of respondents. This suggests a broad application of remote sensing technologies. While 23.1% of organizations expressed

unfamiliarity with sensor types, others specified the use of standard drone imagery.

Additionally, a question was asked about the types of software tools used for processing and analyzing spectral signatures:

Figure 9. Type of Software Used



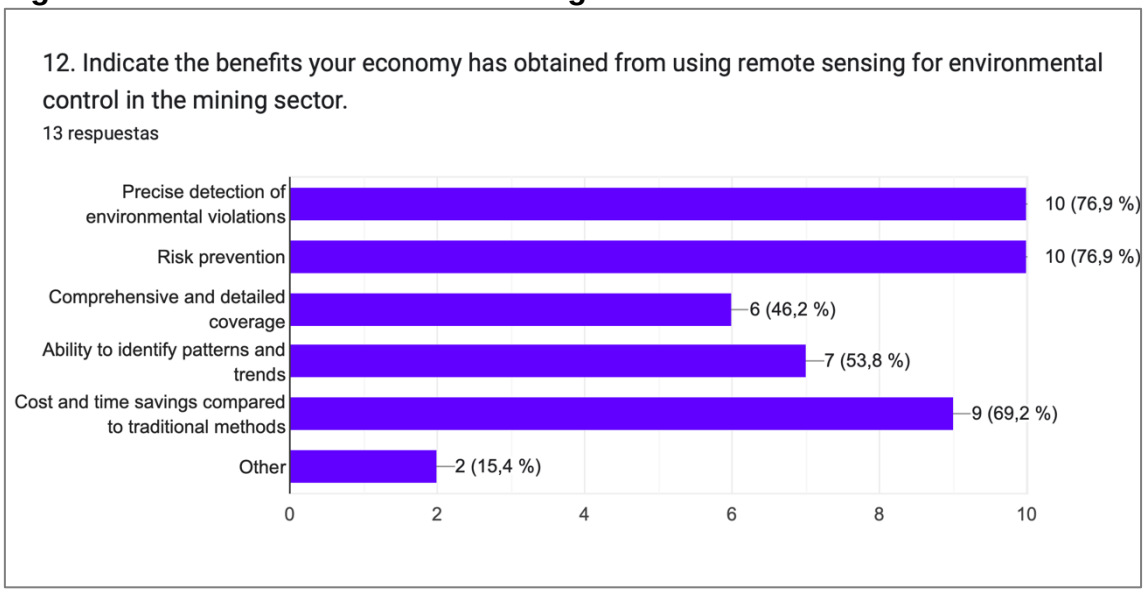
69.2% of respondents indicate that they process and analyze spectral signatures using commercial software, such as ESRI, ArcGIS, QGIS, and Agisoft, suggesting that commercial solutions are widely adopted.

53.8% report using open-source software, indicating that there is an active community of users who develop and share free tools for spectral data processing. The results demonstrate a diversity of approaches and flexibility.

4.3. Benefits and Limitations

As the final section of the survey, it was deemed relevant to understand the benefits and limitations of using remote sensing and spectral signatures for environmental control in mining.

Figure 10. Benefits of Remote Sensing

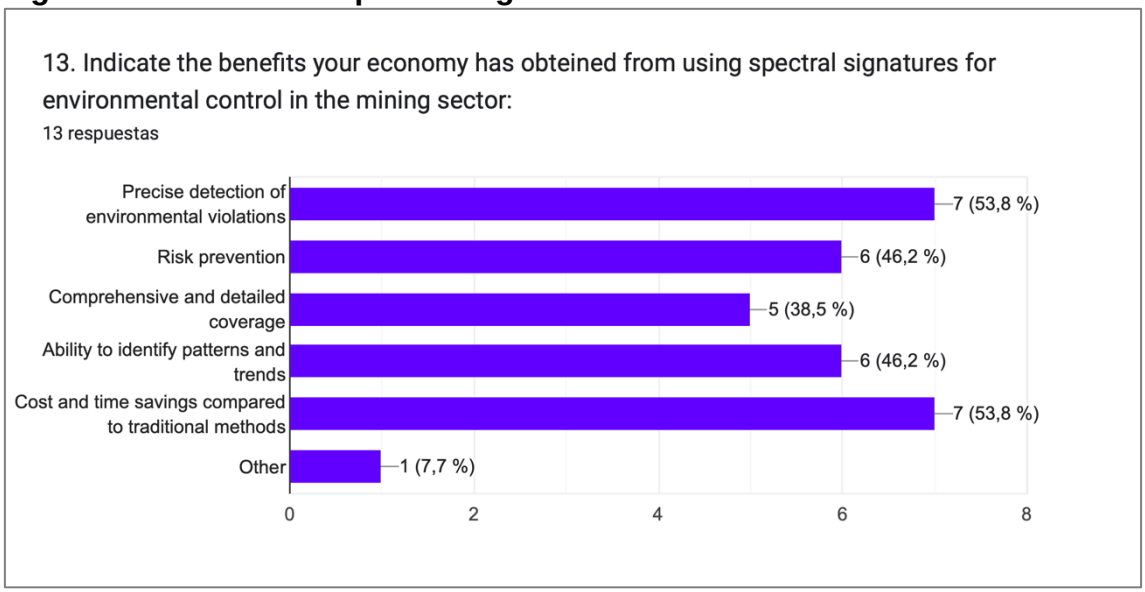


76.9% of respondents indicate that remote sensing enables precise identification of environmental violations in mining operations, which could facilitate the implementation of corrective measures and regulatory compliance. Similarly, the same percentage highlights the benefits of risk prevention, as continuous monitoring of mining areas helps identify potential environmental risks before major incidents occur, allowing for preventive actions and minimizing negative impacts.

The chart clearly shows that remote sensing has provided numerous benefits for economies using it in the mining sector. By enabling early problem detection, more accurate assessment of environmental impacts, and more informed decision-making, remote sensing contributes to more effective and sustainable environmental management in the mining industry.

Next, the survey inquired about the specific benefits of using spectral signatures:

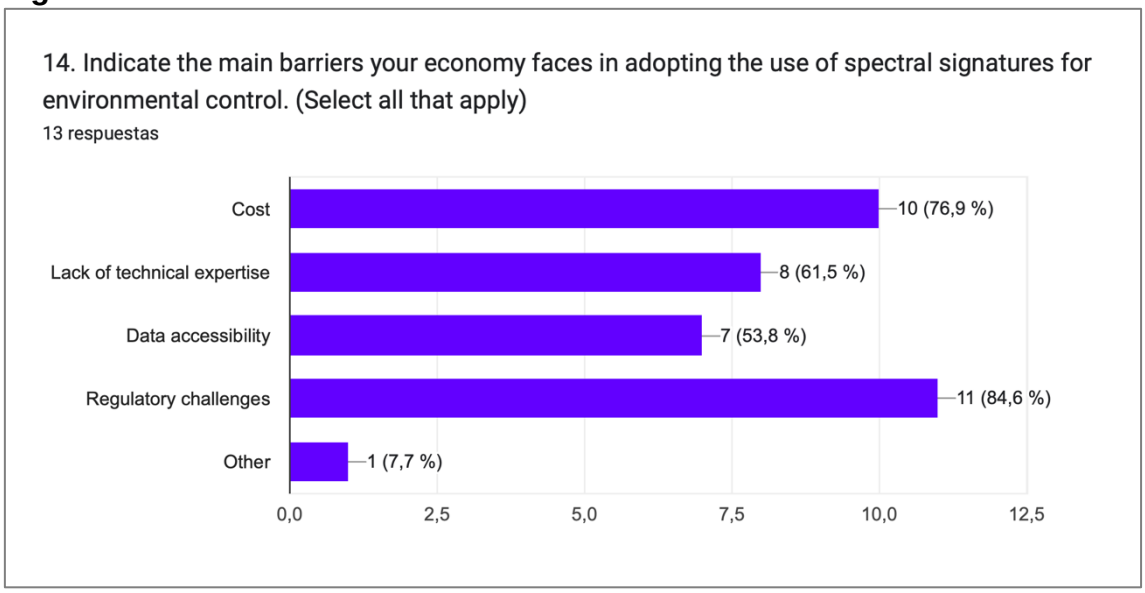
Figure 11. Benefits of spectral signatures



As can be seen, most of the surveyed economies highlighted that this technology allows for quick and accurate identification of any environmental regulation violations in mining operations. Additionally, compared to traditional monitoring methods, the use of spectral signatures is more efficient and cost-effective, as 53.8% also noted cost savings as a significant benefit.

Despite these advantages, it is important to understand the limitations associated with using spectral signatures for environmental control.

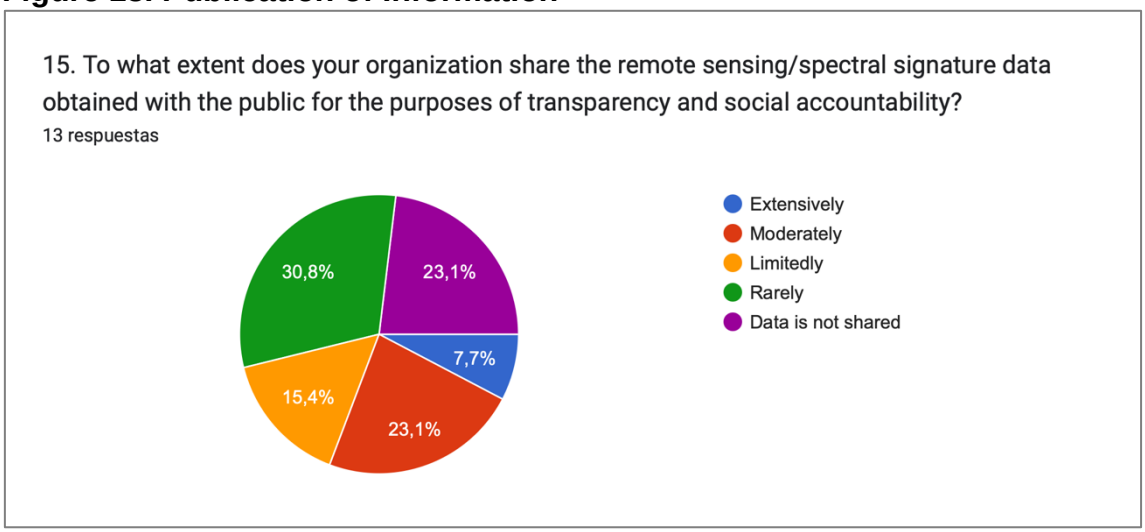
Figure 12. Barriers Encountered



The chart shows that the primary obstacles are associated with the regulatory framework (84.6%), highlighting the importance of investigating these regulatory challenges to prevent them from being limiting factors. Other significant factors include the costs and investments required (76.9%) and the lack of technical knowledge (61.5%).

Additionally, it was important to understand the frequency with which data obtained through remote sensors (or spectral signatures) is shared with the general public.

Figure 13. Publication of Information

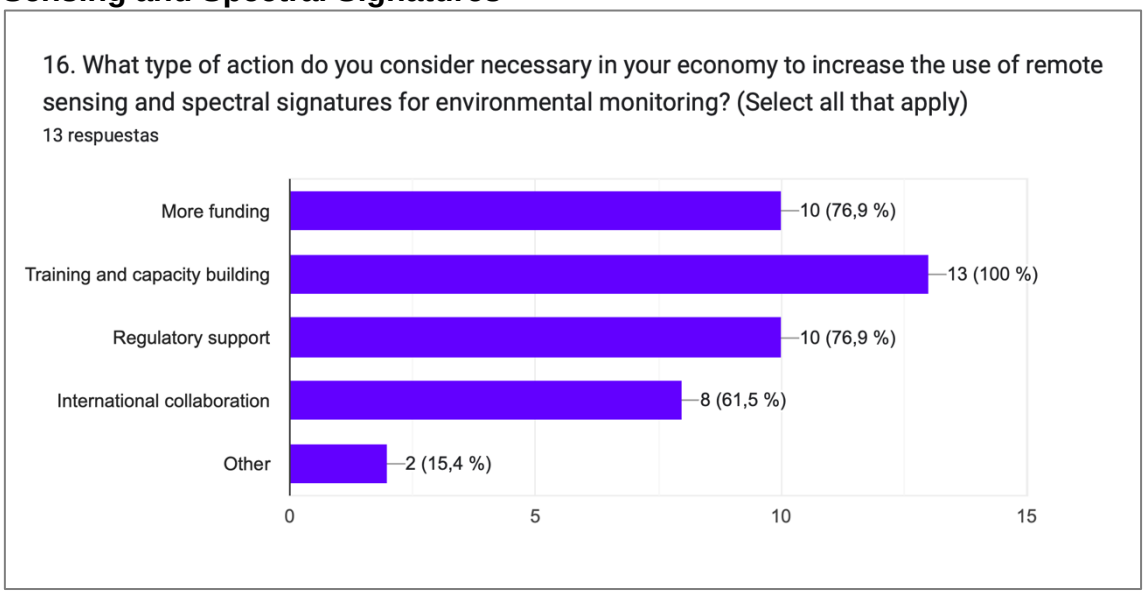


The survey reveals significant variability in how organizations share remote sensor data with the public. It is noted that 30.8% of organizations share data extensively, indicating that these organizations make substantial efforts to make the data they collect available to the public, thus promoting transparency and citizen engagement. Meanwhile, 46.2% share data moderately or limitedly,

indicating opportunities for improvement in enhancing the transparency and frequency of data sharing.

Finally, the survey asked what actions are considered necessary to increase the use of remote sensors and spectral signatures in environmental monitoring.

Figure 14. Actions to Consider for Strengthening the Use of Remote Sensing and Spectral Signatures



The chart shows that while the potential of remote sensors for environmental monitoring is enormous, their large-scale adoption is limited by several factors.

All surveyed economies (100%) agree that investing in training technical staff to effectively use and analyze data obtained from remote sensors is necessary. Additionally, 76.9% believe that having an appropriate regulatory framework that promotes the use of this technology and establishes standards for data collection and usage, as well as securing funding for its development and application, is crucial.

V. CONCLUSIONS

Remote sensing and spectral signatures have become essential tools for promoting more sustainable mining practices in APEC economies. To assess the current level of adoption of these tools in environmental control related to mining, a survey was conducted.

Thirteen (13) responses were received from experts across nine (9) APEC economies: Chile; Malaysia; Mexico; Papua New Guinea; Peru; Chinese Taipei; Thailand, United States; Viet Nam. It is notable that of the thirteen (13) responses, only two (2) were from women, reflecting a predominantly male participation rate of 85%.

The survey results indicate that 37.8% of respondents consider the use of remote sensing technology within APEC economies to still be limited. While this

assessment provides valuable insights, it is important to note that these findings are only referential estimates due to the small sample size. Nevertheless, the data offers a general overview of the current adoption levels of such technologies by environmental institutions in APEC economies.

The primary concern for 100% of respondents is the contamination of water resources, identifying it as a critical environmental control need for government agencies. The most common application of remote sensing reported is water quality monitoring (61.5%), followed by deforestation monitoring (53.8%).

Surveyed organizations use a variety of spatial remote sensing methods, with drones and satellite images being the most popular. Additionally, organizations reported using a range of sensors, with multispectral, thermal, and radar sensors being the most common.

The results show that remote sensing and spectral signatures have provided numerous benefits for economies using these tools in the mining sector. These include early problem detection, more accurate environmental impact assessment, and more informed decision-making. Cost savings compared to traditional monitoring and environmental oversight methods are also highlighted.

Despite advancements, limitations persist, such as required investments, training and specialization of personnel, regulatory challenges, and transparency and valuation of information.

Collaboration among APEC economies is essential to share knowledge, experiences, and technologies, thereby accelerating the adoption of these tools.

VI. RECOMMENDATIONS

- **Capacity Building:** Promote training programs to strengthen technical skills in remote sensing technology and data analysis.
- **Encouragement of Collaboration:** Foster collaboration among APEC economies through research networks, sharing best practices, and developing joint projects.
- **Integration into Public Policies:** Incorporate remote sensing into environmental and mining policies in each economy, establishing regulatory frameworks that encourage its use and identifying current regulatory limitations.
- **Promotion of Transparency:** Enhance transparency in the use of remote sensing data by facilitating public access to this information and encouraging citizen participation.

VII. REFERENCES

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APPENDIX 2

WORKSHOP AGENDA

Workshop on Strengthening capacities to use spectral signatures of remote sensing applied in environmental control processes for the identification of environmental impacts in the mining sector

16 Aug 2024, 08:30 am – 16:30 (GMT-5)

Lima Convention Center (**Pucllana Room, 6th floor**), Lima, Peru

Technological advances in remote sensing for environmental control		
Peru Time (GMT-5)	**Details**	**Keynote Speaker**
08:30 – 09:00	Registration process and ex-ante evaluation	-
09:00 – 09:05	Welcome remarks	Juan Narciso **Peruvian Agency for Environmental Assessment and Enforcement (OEFA) – Peru**
09:05 – 09:10	Opening of workshop	Juan Castro **Ministry of Environment (MINAM) – Peru**
09:10 – 09:15	Introduction to the Sessions	José Pasapera **National Aerospace Research and Development Commission (CONIDA) - Peru**
Session 1: Technological Advances in Remote Sensing - I		
09:15 – 09:45	Responsible mining through airborne hyperspectral imaging	Petri Nygrien **Spectral Mapping Services SMAPS Oy – Finland**
09:45 – 10:15	Remote Sensing and Monitoring Tools for Environmental Management in Brazil	Laercio Namikawa **National Institute of Special Research (INPE) – Brazil**
10:15 - 11:45	*Panel discussion (Q&A) and exchange of experiences*	
11: 45 - 11:30	*Coffee and break (and Family Photo)*	
Session 2: Technological Advances in Remote Sensing - II		
11:30 – 12:00	Use of Artificial Intelligence in Geospatial Technology for the analysis of environmental impacts in the mining sector	Miguel Quintana **Environmental Systems Research Institute (ESRI / TELEMATICA) – Peru**
12:00 – 12:30	Applications of Remote Sensing in Environmental Protection and Humanitarian Action - Christian Doppler (CD) Laboratory GEOHUM	Lorenz Wendt, (VIRTUAL) **University of Salzburg – Austria**
12:30 – 13:00	*Panel discussion (Q&A) and exchange of experiences*	
13:00 - 14:00	***Lunch***	
Session 3: Technological Advances in Remote Sensing - III		
14:00 – 14:30	Remote sensing of environmental quality indicators focused on air quality and SAR-SAOCOM applications	Marcelo Scabuzzo **National Commission for Space Activities (CONAE) – Argentina**
14:30 – 15:00	Applications of remote sensing in areas with mining environmental impact	Juan Casas **Geological, Mining and Metallurgical Institute (INGEMMET) – Peru**
15:00 – 15:30	*Panel discussion (Q&A) and exchange of experiences*	
15:30 – 16:30	**Networking Session** *Exchange of Contacts, establishment of alliances and cooperation among APEC economies*	

WORKSHOP AGENDA

Workshop on Strengthening capacities to use spectral signatures of remote sensing applied in environmental control processes for the identification of environmental impacts in the mining sector

17 Aug 2024, 08:30 – 16:30 (GMT-5)

Lima Convention Center (**Cajamarquilla Room, 4th floor**), Lima, Peru

Remote Control and Assessment of Water Quality, Soil Quality, and Deforestation		
Peru Time (GMT-5)	**Details**	**Keynote Speaker**
08:30 – 09:00	Registration process and ex-ante evaluation	-
09:00 – 09:05	Welcome remarks	Richard Tipula **Peruvian Agency for Environmental Assessment and Enforcement (OEFA) – Peru**
09:05 – 09:15	Introduction to the Sessions	José Pasapera **National Aerospace Research and Development Commission (CONIDA) - Peru**
Session 1: Water Quality Remote Control		
09:15 – 09:45	Impacts of mining in hydrological systems and needs for monitoring	Gilles Wending (VIRTUAL) **Environmental Law Alliance Worldwide (ELAW) – USA**
09:45 – 10:15	Identification of acid mine drainage indicator minerals and precursors by EMIT- hyperspectral sensor on board the International Space Station	Dana Chadwick (VIRTUAL) **National Aeronautics and Space Administration (NASA) – USA**
10:15 – 11:00	*Panel discussion (Q&A) and exchange of experiences*	
11:00 – 11:30	*Coffee and break*	
Session 2: Soil Quality Remote Monitoring		
11:30 – 12:00	Use of Remotely Piloted Aircraft System - RPAS for Environmental Inspection of Soil in the Mining Industry	Francisco Zuñiga **Federal Attorney of Environmental Protection (PROFEPA) – Mexico**
12:00 – 12:30	Machine learning approach for mapping hotspots of soil contamination using imaging spectroscopy at historical mine sites	David Williams (VIRTUAL) **Environmental Protection Agency (EPA) – USA**
12:30 - 13:00	*Panel discussion (Q&A) and exchange of experiences*	
13:00 - 14:00	***Lunch***	
Session 3: Soil and Forest Remote Monitoring		
14:00 – 14:30	Remote sensing data: application in assessment of soil characteristics	Raul Rivas **Plain Hydrology Institute (IHLLA) – Argentina**
14:30 – 15:00	The use of remote sensing products in activities to combat illegal mining	Govinda Terra **Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) – Brazil**
15:00 – 15:30	*Panel discussion (Q&A) and exchange of experiences*	
15:30 - 16:15	**Networking Session** *Exchange of Contacts, establishment of alliances and cooperation among APEC economies.*	
16:15 - 16:30	Closure remarks	Alex Uriarte (PO) **Peruvian Agency for Environmental Assessment and Enforcement (OEFA) – Peru**

APPENDIX 3

Summary of Speaker Profiles

1) Petri Nygrien, **Spectral Mapping Services SMAPS Oy, Finland**

Mr. Petri Nygrén is a cosmopolite, experienced professional, generalist and hands-on practicioner from aerial surveying industry, with a soft spot for animals and nature. He has been applying laser scanners, mapping- and hyperspectral cameras to a remote sensing project for worldwide customers since 1985. During his carreer he has been conducting aerial survey flying operations in 80 different economies as operations manager, instructor and navigator. Today he is a private consult providing training, processing and project services internationally

2) Laercio Namikawa, National Institute of Special Research INPE, Brazil

Ph.D in Geography at State University of New York at Buffalo in 2006, Ms.C in Applied Computing at INPE in 1994. Senior Technologist at Earth Observation and Geoinformatics Division at INPE, where started career in 1983.

Research topics include Environmental Modeling and Remote Sensing Image Processing: Spatial Dynamic Models, Digital Elevation Models, Hydrological Modeling, Disaster Management, Image Classification, Color Manipulation and Image Fusion

3) Miguel Quintana, Environmental Systems Research Institute - ESRI / TELEMATICA, Peru

Engineer specialized in Geomatics and Earth Observation, with over 10 years of experience in geospatial projects in various fields, such as disaster risk management, natural resource estimation, and urban studies, among others.

Currently, he works as a Remote Sensing & GIS Specialist at Telematica (official ESRI distributor), where he is responsible for creating solutions that combine the use of GIS with imagery from various platforms, such as drones and satellites (both optical and radar), to help users make informed decisions and obtain accurate and up-to-date information on the ground.

Previously, he has worked at the Peruvian Space Agency on important projects, such as the Estimation of Flooded Areas during El Niño (2017), Generation of Baseline Satellite Information in Metropolitan Lima for Disaster Response and Recovery (2018-2019), and Mapping of Areas Affected by Oil Spills in La Pampilla (2022). He is also a member of the College of Engineers of Peru

4) Lorenz Wendt, **University of Salzburg, Austria**

Dr. Lorenz Wendt, Diplom-Geologist, MSc, studied geology at the universities of Hamburg and Tübingen in Germany. After a few years in the construction

industry, he completed a Master's program in photogrammetry and geoinformatics. This combination paved his way to obtaining a PhD at Freie Universität Berlin, in which he analyzed hyperspectral data of planet Mars, where sulfates and phyllosilicates are indicative of liquid water in the planet's past. Since 2013 Dr. Wendt is a researcher at the Department of Geoinformatics at the Paris Lodron University of Salzburg, where he develops Earth-observation based services and information products for humanitarian organizations, in particular in the Christian-Doppler-Laboratory GEOHUM. He also teaches remote sensing and GIS both in the regular study program and in the distance learning offering UNIGIS.

5) Marcelo Scabuzzo, **National Commission for Space Activities - CONAE, Argentina**

PhD in Physics with a postdoctoral fellowship in Paris, France. Researcher at CONAE since 1997. Full professor at the University of Cordoba since 1990. Supervised over 30 postgraduate theses and has published more than 110 indexed articles on remote sensing applications. Former director of the Mario Gulich Institute of Advanced Space Studies, where he founded and led the Master's program in Spatial Information Applications and the PhD program in Geomatics and Space Systems.

6) Juan Casas, Geological, Mining and Metallurgical Institute, INGEMMET, Peru

Specialist in satellite image processing at the Remote Sensing Laboratory of INGEMMET, with expertise in reflectance spectroscopy and GIS modeling for processing, analyzing, and interpreting satellite images applied to geology and mining. A physicist by profession, he graduated from the Faculty of Physical Sciences at the National University of San Marcos. He has a specialization in Geological Applications of Remote Sensing and GIS from the Korea Institute of Geoscience and Mineral Resources (KIGAM) and has completed master's studies in Geographic Information Technologies.

7) Gilles Wending, Environmental Law Alliance Worldwide, USA

Dr. Gilles Wendling is a French geotechnical engineer with a master's degree in geotechnics from Grenoble University and a doctorate in hydrogeology from the École Polytechnique, University of Montreal, Canada.

Dr. Wendling is a member of the Association of Professional Engineers of British Columbia, Canada, and a former Executive Director of the Groundwater Association of British Columbia, as well as a former Technical Director of the Groundwater Association of Canada. With over 35 years of experience as a consultant and hydrogeologist, he has studied and characterized more than 1,000 contaminated sites impacted by mining and oil/gas projects. He has extensive experience assessing the environmental impacts of mining in Canada and provides expert opinions on multiple international cases. Gilles is very

interested in public awareness and education on water stewardship. He is a co-author of the book Canada's Groundwater Resources, Rivera et al., 2013.

Currently, Dr. Wendling resides in BC, Canada, and serves as a Staff Scientist for the Secretariat of the Environmental Law Alliance Worldwide (ELAW), a non-profit organization based in Eugene, Oregon, USA. ELAW is a global network of public interest environmental lawyers and scientists with members in over 60 economies.

8) Dana Chadwick, National Aeronautics and Space Administration, NASA, USA

Dana Chadwick is an Earth system scientist researching the interconnections among ecosystems, critical zone processes, and the evolution of landscapes. She utilizes imaging spectroscopy, extensive field sampling campaigns, and laboratory analyses in combination to uncover spatial distributions of ecosystem characteristics and link these patterns to underlying processes. She is currently the terrestrial vegetation algorithm lead for the Surface Biology and Geology Mission's VSWIR instrument and the Mission Applications Lead for the EMIT mission.

9) Francisco Zuñiga, **Federal Attorney of Environmental Protection of Mexico- PROPEFA, Mexico**

Biologist, graduated at Universidad Autónoma Metropolitana (Xochimilco campus), he was distinguished academically by earning bronze and silver medals in the XXII and XXI Domestic Biology Olympiads, respectively.

In his professional career, he has served as a government employee at Procuraduría Federal de Protección al Ambiente (PROFEPA) for the last five years, he worked at the Programa Nacional de Auditoría Ambiental and later joined the Subprocuraduría de Inspección Industrial as federal inspector.

Currently he has focused on integrating technology into inspection visits, utilizing tools such as: RPAs Remote Pilolted Aircraft Systems, Geographic Information System (GIS), Ground-penetrating radar, Gas analyzer, Specialized cameras, RTK systems (Real Time Kinematic) and Information processing software.

10) David Williams, Environmental Protection Agency - EPA, USA

David Williams has degrees from North Caroline State University in Soil Science, and The Ohio State University in Environmental Science. He has worked at EPA for 32 years, specializing in remote sensing application development including multi-sensor fusion (SAR, thermal hyperspectral), use of thermal sensors for toxic chemical gas detection and characterization, imaging spectroscopy of contaminated soils and vegetation and global change monitoring and assessment using long term satellite observations.

11) Raul Rivas, Plain Hydrology Institute, IHLLA, Argentina

He is the Principal Investigator at the Scientific Research Commission of the province of Buenos Aires. As a Geologist specializing in hydrology and remote sensing, and a Ph.D. in Physics, he has extensive experience in estimating local energy balances using monitoring stations and satellite imagery. With over 260 publications, he has a proven track record in human resources development, project management, and R&D&i transfer to companies. Notably, he led the formation of a Public-Private Partnership Consortium for the installation of environmental monitoring stations, a project awarded the Diploma of Honor in the category of Initiatives with application to the production of goods and/or services in the XVI edition of the Dr. José A. Balseiro Awards for Technological Linkage Initiatives in the period 2020-2021. He has directed, co-directed, and participated in R&D&i projects, and has been awarded fellowships by the governments of France and Spain, as well as a high-level fellowship from the European Union.

12) Govinda Terra, **Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) Brazil**

Govinda Terra currently holds the position of Chief of Staff to the President of Ibama. He earned both a Bachelor's and Licentiate's degree in Geography from the University of São Paulo. Additionally, he is a specialist in Expertise, Auditing, and Environmental Management, and holds a Master's degree in Protected Area Management in the Amazon.

Govinda has extensive experience in environmental enforcement operations, particularly in combating illegal deforestation in the Amazon. His expertise also includes geoprocessing and his role as an Environmental Analyst at the Brazilian Institute of Environment and Renewable Natural Resources (Ibama).

From 2016 to 2020, he served as the Inspection Control and Logistics Coordinator, where he was instrumental in planning and executing measures to standardize and train environmental inspectors. Moreover, Govinda plays an active role in the formulation, coordination, planning, and execution of international events in collaboration with the Latin American Network of Environmental Inspection and Compliance and other international partners.