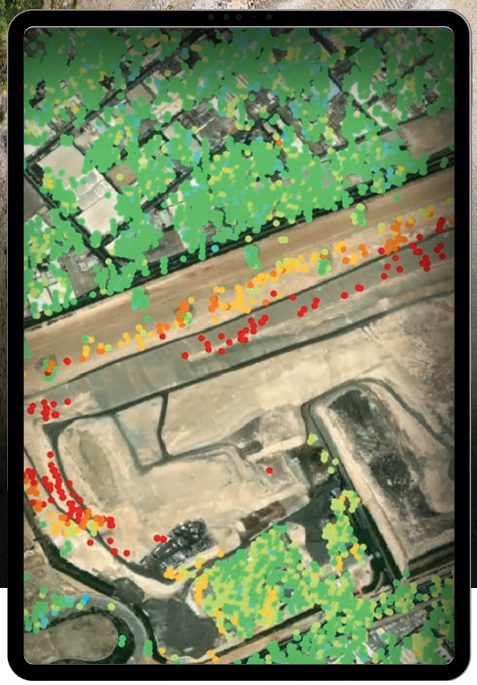
GEOFEM

Harnessing Satellite Intelligence for Tailings Dam Management



Satellite data with engineering insight.

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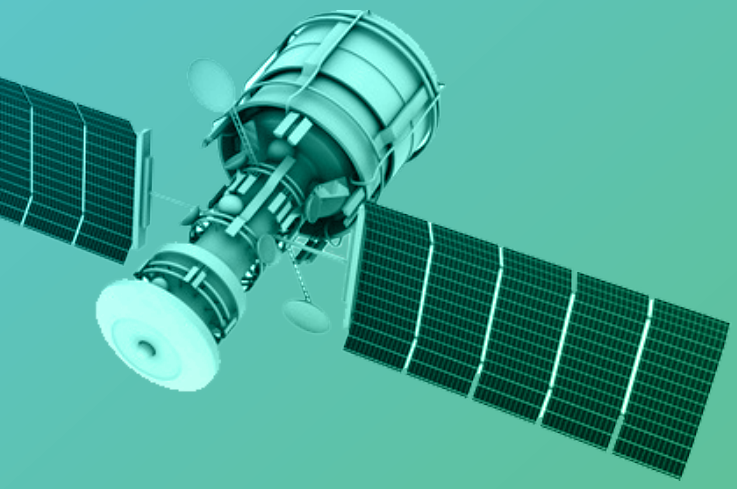


Introduction

With Radar Above, The Future is Within Reach

Tailings dams, crucial components of mining operations, store vast quantities of mining waste, presenting unique challenges in terms of safety, environmental stability, and asset management. However, with the implementation of satellite data analysis, we possess a powerful tool to enhance our understanding and safeguarding of these critical assets.

Defining the Landscape

Tailings dams are engineered structures designed to contain the byproducts of mining operations, known as tailings. These dams are often massive, with some reaching heights comparable to skyscrapers, and can hold billions of gallons of waste material. Despite their importance, these dams face significant risks: according to the International Commission for Large Dams, around 1,500 tailings dams are currently in operation worldwide, with roughly 10% being considered 'high-risk' structures.

The View from Above

Through technologies like Interferometric Synthetic Aperture Radar (InSAR), satellites can detect miniscule changes in ground movement, offering insights into everything from subsidence to structural deformation.

InSAR can detect ground movements as small as a few millimetres over areas spanning thousands of square kilometres. With the ability to capture data at regular intervals, this technology provides a dynamic, real-time view of ground behaviour around tailings dams.

Visualising Success

In this guidebook, we'll delve into the nuts and bolts of satellite radar data analysis, exploring its applications, methodologies, and best practices for tailings dam management. We'll showcase compelling case studies, illustrating how these technologies are already making a difference in our industry. From monitoring moisture content to assessing dam deformation, we'll uncover the myriad ways in which satellite radar data can revolutionise the management of tailings dams. Along the way, we'll arm you with the knowledge and tools needed to harness these capabilities effectively, ensuring that your assets remain secure and your operations sustainable in the face of ever-evolving challenges.

Get ready to elevate your approach to tailings dam management.

Let's delve deeper

Dr. Skevi Perdikou
CEO
Geofem Ltd

"Between 2000 and 2020, there were over 200 recorded tailings dam failures worldwide, many attributed to geohazards such as ground movement and landslides."

World Mine Tailings Failures.org

"The 2019 Brumadinho dam disaster in Brazil, caused by liquefaction and subsequent ground movement, resulted in economic losses exceeding $6 billion, including environmental damage, fines, and compensation costs."

Bloomberg, 2019

"Landslides triggered by heavy rainfall or seismic activity are a leading cause of tailings dam failures, responsible for approximately 25% of all incidents."

Geotechnical News, 2018

Chapter 1: The Tailings Dam Challenge

Unseen Forces, Unseen Dangers

Since tailings dams are such momentous structures, they may seem impervious to the naked eye. Yet, beneath the surface, ground movements imperceptible to even the most keen-eyed observer are steadily developing. According to research by the International Mining Journal, ground movements as small as a few millimetres around tailings dams can signal potential risks to their stability. These movements, though miniscule, can precipitate impending challenges, posing a constant threat to the integrity of the structure.

Drainage Dilemmas

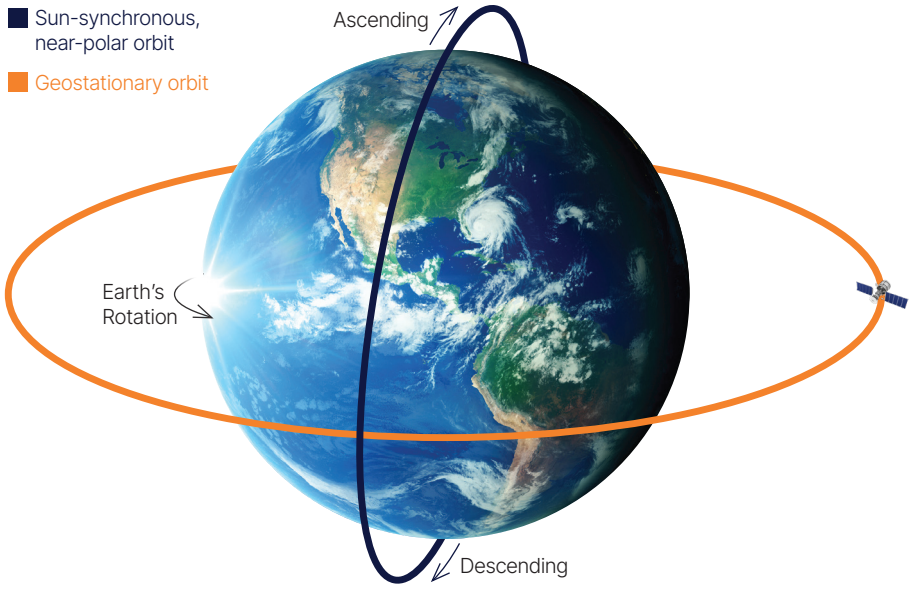
Poor drainage management is a perennial headache for managers of tailings dams, with consequences ranging from compromised structural stability to environmental contamination. In fact, a study published in the Journal of Environmental Quality found that inadequate drainage systems can exacerbate the risk of dam failure, amplifying the potential for catastrophic events. It's a delicate balancing act – one that requires meticulous attention to details and proactive intervention to mitigate the risks posed by water infiltration and saturation.

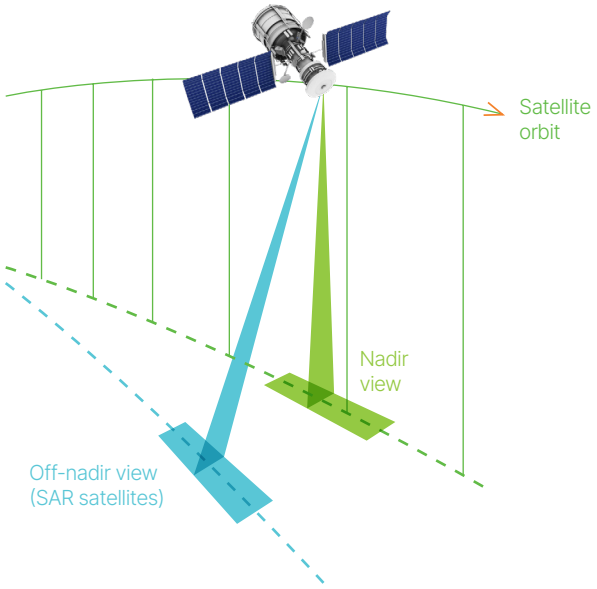
The Cost of Faults

Whether it's a minor crack or a major fracture, addressing faults is no small feat, both in terms of technical complexity and financial burden. Research by the International Journal of Mining Science and Technology suggests that repairing faults in tailings dams can cost millions of dollars, not to mention the reputational damage and regulatory scrutiny that accompany such incidents.

Chapter 2: The Basics of SAR (Synthetic Aperture Radar)

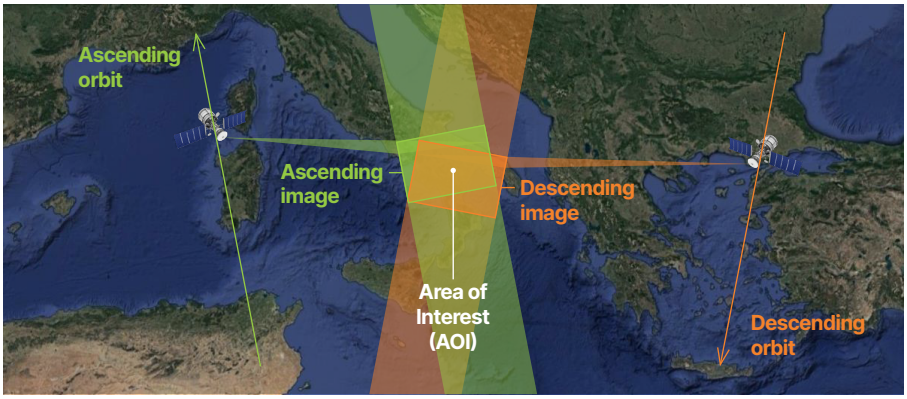
At its base, SAR is a remote sensing technology that allows analysts to observe the Earth's surface using radar pulses to create detailed images of terrain features and surface characteristics. Unlike optical imaging, which relies on visible light, SAR operates in the microwave portion of the electromagnetic spectrum, allowing it to penetrate clouds, vegetation, and the darkness of night.





The Marvel on Interferometry

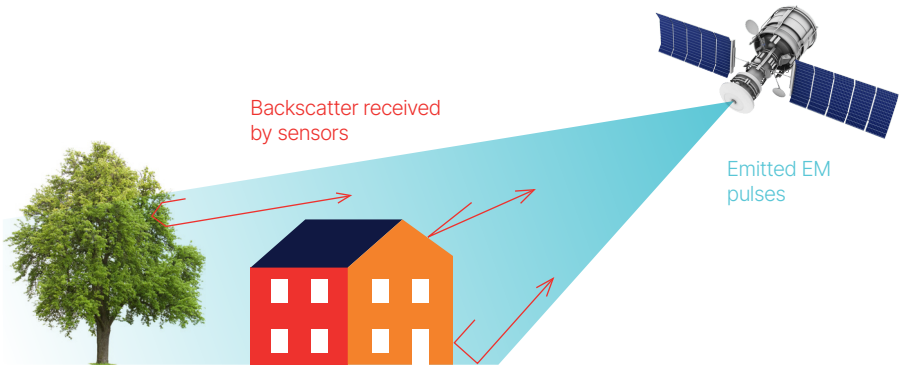
Let's dive deeper into one of SAR's most powerful techniques: Interferometric Synethetic Aperture Radar, or InSAR for short. Imagine two SAR images of the same area, captured on different days. By comparing these images and measuring the phase difference between the radar signals, we can create detailed maps of surface deformation with a high degree of precision. This process, known as interferometry, unlocks a wealth of information about ground movements, subsidence, and structural changes – key factors in assessing the health and stability of tailings dams.



Radar Waves

So, how does SAR actually work? Essentially, by emitting microwave pulses toward the Earth's surface and detecting the return of the reflected signals, or backscatter, to the sensor. By analysing the properties of the reflector radar waves, such as their amplitude and phase, SAR systems can extract a wealth of information about surface features, including topography, roughness, and moisture content.

From detecting ground movements to mapping surface moisture, SAR provides a window into the dynamic processes shaping our world – and, with it, the opportunity to safeguard our assets and secure our future in an ever-changing landscape.



Chapter 3: The SAR solution

> "Dam failures due to slope instability can lead to economic damage ranging from 10% to 30% of the total project costs."
>
> Geofem

Section A: Monitoring Ground Deformation / Identifying Subsidence

The Brilliance of Interferometry

At the heart of SAR's ground deformation monitoring capabilities lies the magic of interferometric analysis – an innovative technique that allows us to measure changes in terrain elevation with great accuracy. By comparing SAR images acquired at different times and analysing the phase differences between radar signals, we can create detailed maps of ground deformation, revealing patterns of subsidence and uplift that may go unnoticed by traditional monitoring techniques.

Unlocking Insights with InSAR

One of the most powerful tools in the SAR arsenal is Interferometric Synthetic Aperture Radar (InSAR). This technique leverages the principles of interferometry to generate precise measurements of ground displacement, enabling analysts to detect subsidence with high levels of sensitivity. This comprehensive view of ground deformation dynamics facilitates risk assessment and proactive measures to mitigate potential hazards.

Section B: Detection of Slope Stability

Unveiling Hidden Risks

The slopes of tailings dams are dynamic landscapes, constantly subjected to the forces of gravity, erosion, and environmental factors. Beneath their seemingly stable façade lies the potential for instability, with risks ranging from minor slippage to catastrophic landslides. Traditional monitoring methods often fall short in detecting these hidden risks, leaving assets vulnerable to the unpredictable whims of nature and complex mining operations. But, with SAR technology, stakeholders can better unveil the hidden dangers lurking on these slopes.

"The Cadia Valley Tailings Storage Facility failure of 2018 led to the closure of the mine for 6 months while cleanup and remediation measures were carried out. This downtime led to financial losses for stakeholders."

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Detecting Changes in Terrain

SAR provides a comprehensive view of slope morphology, allowing us to identify potential instability hotspots . One of SAR's most valuable capabilities is its ability to detect changes in terrain elevation over time – a telltale sign of slope instability. Through interferometric analysis, SAR imagery can reveal subtle shifts and movements occurring on the slope, signalling potential risks of instability long before they escalate into full-blown crises. By comparing SAR images acquired at different intervals, analysts can track the progression of slope deformation, identify areas of accelerated movement, and prioritise interventions accordingly.

Proactive Monitoring for Risk Mitigation

With SAR technology, we gain the ability to monitor slope instability in near real-time, allowing us to take proactive measures to mitigate risks and safeguard our assets. SAR can provide the insight needed to make informed decisions and protect against potential hazards such as reinforcing vulnerable slopes, implementing erosion control measures, and adjusting land use practices to minimise the likelihood of instability. By integrating SAR data into our monitoring protocols, we can ensure that tailings dams remain secure and resilient in the face of evolving environmental dynamics.

Section C: Integration with Geotechnical Models

By integrating SAR-derived insight into geotechnical models, we bridge the gap between observation and interpretation, harnessing the power of both disciplines to unravel the complexities of ground behaviour around tailings dams.

Enhancing Predictive Capabilities

Geotechnical models serve as virtual laboratories, allowing us to simulate the behaviour of complex geological systems under varying conditions. By incorporating SAR-derived data into these models, engineers enhance their predictive capabilities, enabling analysts to forecast potential outcomes with greater accuracy and confidence. Assessing the long-term stability of a tailings dam or predicting the effects of environmental factors on slope dynamics are just some of the ways that SAR-geotechnical model integration allows for insights to anticipate risks and plan interventions proactively.

Validating Assumptions and Hypotheses

In geotechnical engineering, assumptions and hypotheses abound, yet, without monitoring data to validate them, they will remain just that. SAR-derived insights provide a wealth of observational data, allowing testing and refinement of models with real-world measurements. Comparing model predictions with SAR-observed ground deformation patterns provides valuable feedback on the validity of assumptions, helping improve the accuracy and reliability of predictive models over time.

Empowering Informed Decision-Making

In the ever-evolving landscape of tailings dam management, informed decision-making is paramount. By integrating SAR-derived insights with geotechnical models, stakeholders are empowered with the knowledge and foresight needed to navigate complex risks with confidence and clarity.

Section D: The Opportunity for Early Warning Systems

In the high-stakes world of tailings dam management, timing is everything. With SAR technology, stakeholders gain the ability to anticipate risks before they manifest into full-blown crises, allowing pre-emptive action to be taken to mitigate their impact. By monitoring ground deformation and identifying subtle signs of instability, SAR-derived insights provide invaluable early warning signals that can alert stakeholders to potential hazards, giving them precious time to implement preventive measures and safeguard their assets.

Harnessing the Power of Consistent Monitoring

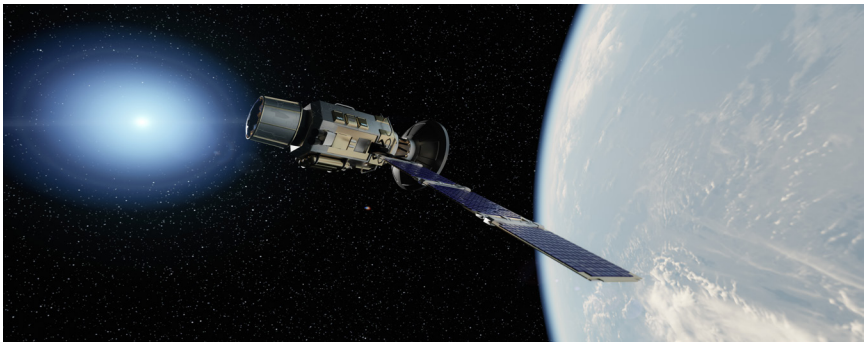
By continuously capturing SAR imagery and analysing it for signs of change, we create a dynamic monitoring framework that allows stakeholders to stay one step ahead of evolving risks. SAR-derived insights offer a window into the ever-changing dynamics of the Earth's surface, enabling swift and decisive responses to emerging threats such as gradual subsidence and sudden shifts in terrain elevation.

Equipping Stakeholders with Timely Information

The world of emergency response turns on timely information. SAR-derived insights equip stakeholders with the knowledge they need to make more informed decisions and take decisive action in the face of emerging threats. By providing timely updates on ground deformation, subsidence, and other indications of instability, SAR technology ensures that decision-makers have access to the most up-to-date information available.

"The 2015 Samarco dam failure in Brazil resulted in 60 million cubic metres of toxic sludge, affected 650 kilometers of river, and caused ecological damage"

BBC, 2015



"The breach of the Mount Polley tailings dam in British Columbia, Canada in 2014 released over 24 million cubic meters of water and 8 million cubic meters of tailings into nearby water bodies."

Mining Watch, Canada, 2017

Section E: Soil Moisture Detection

Soil moisture is a critical factor in the health and operation of tailings storage facilities (TSF). Too much moisture in tailings and too much seepage into tailings dams both adversely affect the stability and safety of these facilities, potentially leading to disaster. Moisture levels must therefore be monitored closely. With SAR technology, we gain a window on moisture levels across the entire surface of TSFs

Unveiling Moisture Patterns with SAR

SAR operates by emitting microwave pulses towards the Earth's surface and measuring the properties of the reflected radar waves. By analysing the interactions between these radar waves and the soil, SAR can provide valuable insights into soil moisture content and distribution. Whether it's mapping moisture patterns across vast landscapes or tracking changes in soil moisture over time, SAR offers a powerful tool for understanding the dynamic interplay between water, soil and tailings.

Backscatter

One of SAR's key capabilities lies in its ability to measure backscatter – the amount of radar energy reflected back to the sensor from the Earth's surface. The amount of backscatter detected by SAR is influenced by various factors, including moisture content, surface roughness, and vegetation cover. By analysing changes in backscatter over time, we can infer changes in soil moisture content, providing valuable insights into hydrological dynamics and environmental processes.

Quantifying Moisture with SAR

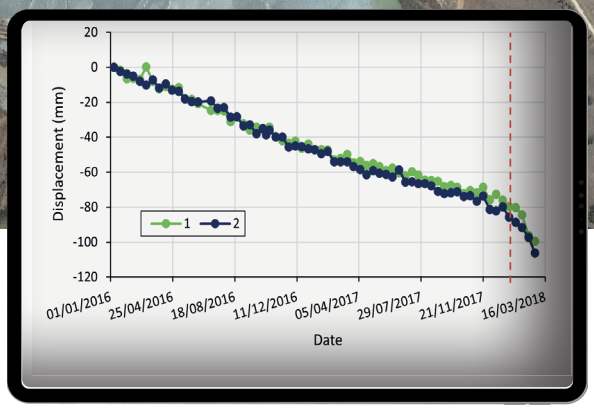
Through sophisticated algorithms and image processing techniques, SAR data can be transformed into quantitative measurements of soil moisture content. By calibrating SAR-derived backscatter measurements against ground-based moisture observations, we can improve the accuracy of the soil moisture algorithms even further to suit site-specific conditions.

Applications in Tailings Dam Management

In tailings dam management, monitoring soil moisture content is of paramount importance. Changes in soil moisture can influence the stability of slopes, affect drainage patterns, and impact the integrity of dam structures. Integrating SAR-derived soil-moisture data into monitoring protocols provides valuable insights into the hydrological dynamics surrounding tailings dams, enabling us to anticipate risks, optimise drainage management, and mitigate the potential for erosion and slope instability.

Case Study 01

Cadia Valley, NSW



The Cadia Valley Northern Tailings Storage Facility (NTSF) forms part of a gold and copper mining processing complex. A section of the tailings dam collapsed on 9th March 2018, releasing some tailings into the adjacent southern TSF.

The Challenge

Ascertaining whether these events can be predicted and prevented in the future.

The Solution

InSAR analysis combined with optical satellite imagery could assess historical movement trends in the area of interest.

The Benefits

Depending on what value of velocity or accleration were set as the alert level, operations of the NTSF may have been warned about a potential failure location one or two months prior to the collapse. This would have given the operators time to further investigate the issue in-situ and possibly resolve it by undertaking some tailings dam stabilisation measures or adjusting their operations.

"Geofem investigated how early the collapse of this tailings dam facility could have been predicted had the dam been monitored regularly using satellite SAR data. With sufficient warning time, the collapse may have been avoidable with proactive remedial methods."

SCAN THE QR CODE
to find out more about this project.

Chapter 4: The Benefits of Leveraging InSAR for Tailings Dam Maintenance and Management

"Satellites like Sentinel-1 provide InSAR data with revisit times of 6-12 days, allowing for near real-time monitoring and timely detection of potential issues."

European Space Agency

Risk Mitigation

One of the most compelling advantages of integrating InSAR into tailings dam maintenance and management is the ability to mitigate risks proactively. By providing constant monitoring of ground deformation, subsidence, and slope instability, these technologies offer early warning signs of potential hazards enabling stakeholders to take pre-emptive action to prevent accidents, minimise environmental impacts, and protect surrounding communities.

Cost Savings

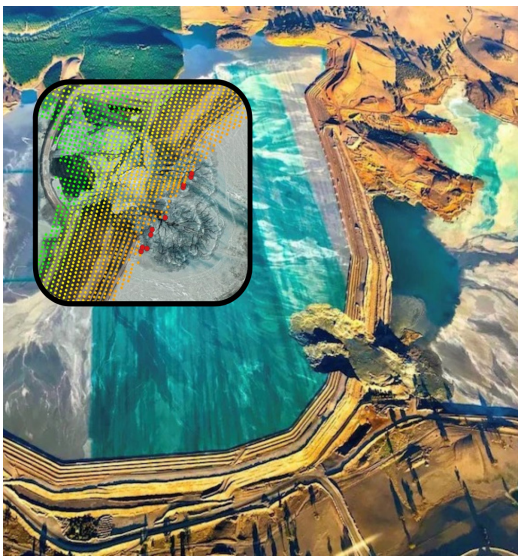
In addition to enhancing safety, InSAR and remote sensing techniques can lead to significant cost saving for tailings dam stakeholders. By detecting maintenance issues early, optimising resource allocation, and streamlining operational workflows, these technologies help minimise downtime, reduce repair costs, and maximise the lifespan of dam structures. Moreover, by identifying areas of potential risk before they escalate into emergencies, stakeholders can avoid costly cleanup efforts, legal liabilities, and regulatory fines associated with dam failure.

Regulatory Compliance

Regulatory compliance is a top priority for tailings dam stakeholders and InSAR can play a crucial role in meeting these requirements. By providing accurate, up-to-date data on dam conditions, environmental impacts, and operational performance, these technologies enable stakeholders to demonstrate compliance with safety, environmental, and social responsibility regulations. Moreover, by enhancing transparency and accountability, SAR and remote sensing data can facilitate communication and collaboration with regulatory agencies, fostering a culture of trust and partnership.

"InSAR monitoring of tailings dams has demonstrated the capability to detect deformation rates as low as 1-2mm per year, providing critical early warnings and helping to prevent failures."

Transactions on Geoscience and Remote Sensing, 2007



Improved Operational Efficiency

Efficiency is the cornerstone of successful tailings dam maintenance and management, and InSAR is instrumental in optimising operational workflows. By automating data collection, analysis, and repeating processes, these technologies streamline decision-making, reduce manual labour, and minimise human error. Moreover, by providing timely insights into dam conditions and performance, InSAR and remote sensing data empower stakeholders to make informed decisions quickly, ensuring that resources are allocated efficiently, and operational objections are achieved effectively.

Enhanced Environmental Stewardship

Environmental stewardship is a core value for tailings dam stakeholders, and SAR, InSAR, and remote sensing techniques enable them to fulfil this commitment with precision and integrity. By monitoring environmental indicators such as soil moisture, vegetation health, and water quality, these technologies help identify potential impacts of dam operations on surrounding ecosystems and enable stakeholders to implement proactive measures to mitigate these effects. Moreover, by providing accurate, reliable data on environmental performance, SAR and remote sensing data enhance transparency and accountability, fostering a culture of responsible resource management and sustainable development.

Insurance Premium Reduction

Insurance premiums for tailings dams can be significant, but SAR, InSAR, and remote sensing techniques offer a pathway to cost reduction. By providing insurers with accurate, reliable data on dam conditions, maintenance practices, and risk mitigation measures, these technologies demonstrate a commitment to safety, compliance, and responsible stewardship. As a result, insurers may offer lower premiums and more favourable terms to stakeholders who leverage SAR and remote sensing data to enhance risk management and ensure the long-term viability of their assets.

Quantifying Moisture with SAR

Through sophisticated algorithms and image processing techniques, SAR data can be transformed into quantitative measurements of soil moisture content. By calibrating SAR-derived backscatter measurements against ground-based moisture observations, we can improve the accuracy of the soil moisture algorithms even further to suit site-specific conditions.

Insurer Confidence

Finally, integrating SAR, InSAR, and remote sensing techniques into tailings dam maintenance and management instils confidence in insurers, investors, and other stakeholders. By providing objective, evidence-based insights into dam conditions, performance, and risk factors, these technologies enable stakeholders to demonstrate their commitment to safety, sustainability, and regulatory compliance. As a result, insurers are more likely to view tailings dams as low-risk investments and offer favourable coverage terms, which in turn enhances stakeholder confidence and support for ongoing operations and development initiatives.

Want to learn more about how to safeguard your infrastructure with satellite intelligence? Contact Geofem to start a conversation.

Case Study 02

East Rand, South Africa

A tailings dam in the East Rand region of South Africa suffered a failure at a one location in 2020. Unfortunately, this resulted in the contamination of a minor water course.

The Challenge

To establish whether this failure could have been foreseen by satellite InSAR analysis.

The Solution

In one of our pilot studies of tailings dam condtion surveys by InSAR there were clear signs of distress in the dam in the months leading up to the failure.

The Benefits

Displacement to the naked eye that would not have been identified by visual surveys alone were able to be noticed. Had regular but inexpensive and non-disruptive InSAR monitoring been undertaken, the location of instability would have been pinpointed and remedial measures undertaken to avoid the failure and pollution of the local watercourse.

"InSAR retrospectively monitored this tailings dam collapse and detected millimetric displacements that were invisible to the naked eye"

SCAN THE QR CODE
to find out more about this project.