Mapping Change – Integrating Remote Sensing into Botswana's Mining Cadastre for Sustainable Land Management and Climate Action.

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Key words: Mining cadastre, remote sensing, sustainable land management, climate action, Botswana.

SUMMARY

Effective governance of mineral resources is a cornerstone of sustainable development in resource-dependent economies. In Botswana, mining particularly diamond extraction—has been central to economic growth, poverty reduction and national development planning. However, expanding mining activities have intensified land disturbance, environmental degradation and climate-related risks, exposing limitations within existing regulatory and monitoring frameworks. The Mining Cadastre System (MCS), while critical for the administration of mineral rights, remains largely focused on legal and administrative functions, with limited integration of dynamic spatial and environmental intelligence. This paper examines the potential for integrating remote sensing technologies into Botswana's Mining Cadastre System to enhance sustainable land management and contribute to national and global climate action objectives. The analysis demonstrates that remote sensing integration can transform the mining cadastre from a static registry into a proactive decision-support system that strengthens transparency, environmental accountability and climate resilience.

Tshoboko

Tiriso e e siameng ya ditswammung ke karolo e e botlhokwa mo tsweletsong ya ditlhabololo mo mafatsheng a a ikaegileng ka meepo jaaka Botswana. Mo lefatsheng la Botswana, meepo bogolo jang ya teemane e nnile motheo wa kgolo ya itsholelo, go fokotsa lehuma le go tshegetsa mananeo a tlhabololo ya naga. Le fa go ntse jalo, koketsego ya ditiro tsa meepo e bakile mathata a go kgoberega ga lefatshe, tshenyo ya tikologo le dikotsi tse di amanang le phetogo ya loapi, se se bontshang diphoso mo ditsamaisong tsa go tlhokomela le go lekola tikologo. Pampiri eno e sekaseka bokgoni jwa go kopanya maranyane a remote sensing mo go tokafatsa tiriso e e tsweletseng ya lefatshe le go tshegetsa maikaelelo a naga le a lefatshe ka bophara a phetogo ya loapi. Diphetho di supa fa go kopanya remote sensing go ka fetola tirisano ya kwa meepong e e oketsang ponatshego, maikarabelo a tikologo le go nonotsha boikemelo kgatlhanong le phetogo ya loapi.

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ABSTRACT

Botswana's mining sector is a critical driver of national economic growth, yet expanding mining activities present significant environmental, land management, and climate-related challenges. The Mining Cadastre System (MCS), while effective in administering mineral rights, remains largely focused on legal and administrative processes, with limited integration of spatial intelligence for monitoring land-use change or environmental compliance. This paper explores the potential of integrating remote sensing technologies into Botswana's MCS to enhance sustainable land management and support climate action objectives. Using a qualitative and analytical approach, the study reviews existing cadastre practices, evaluates relevant remote sensing data sources, and develops a conceptual framework for integrating satellite-based monitoring with mineral tenure data. Case studies from large-scale and small-scale mining illustrate how multi-temporal imagery can detect land disturbances, monitor rehabilitation, and improve transparency. Comparative analysis with Ghana, Tanzania, and Australia demonstrates international best practices for spatially enabled mineral governance. The proposed workflow diagram shows how remote sensing can be operationalized for compliance assessment and decision-making. Findings indicate that integrating remote sensing transforms the cadastre into a dynamic decision-support platform, strengthens governance, and aligns mineral resource management with climate resilience and sustainability goals. This study provides a policy- and practice-oriented roadmap for advancing climate-responsive, spatially enabled mining cadastre systems in Botswana and similar resource-dependent economies.

1. INTRODUCTION

Mining has always been one of the most significant pillars of Botswana's economy, contributing substantially to gross domestic product (GDP), export earnings, employment creation and public revenue. Since the discovery of diamonds shortly after independence, Botswana has leveraged mineral wealth to invest in infrastructure, education, healthcare and social development, positioning itself as one of Africa's most stable and prosperous nations (Republic of Botswana, 2020). Despite these achievements, the environmental footprint of mining activities has become increasingly visible, particularly in the form of land degradation, habitat loss, water stress and long-term rehabilitation challenges.

Globally, there is growing recognition that mineral development must be balanced with environmental sustainability and climate action. Climate change intensifies existing environmental pressures by intensifying droughts, floods, heat strain and land degradation, all of which directly affect mining landscapes and surrounding communities (IPCC, 2022). In this context, effective land governance and spatial monitoring are essential for ensuring that mining activities align with sustainable development objectives.

Mining cadastre systems are internationally recognized as foundational instruments for transparent and accountable mineral rights administration. They provide legal certainty, reduce conflicts over mineral tenure and support orderly exploration and exploitation of mineral resources (Otto et al., 2017). In Botswana, the Mining Cadastre System has contributed to improved governance and investor confidence. However, its functionality remains largely transactional, focusing on licensing and tenure management rather than continuous monitoring of environmental and land-use impacts.

Remote sensing technologies offer extraordinary opportunities to observe, analyse and manage land-use change at multiple spatial and temporal scales. By integrating satellite-derived data into mining cadastre operations, governments can enhance oversight, improve compliance monitoring and support climate-informed decision-making. This paper explores how such integration can be achieved within Botswana's institutional and policy context, with the broader aim of strengthening sustainable land management and climate action.

2. BOTSWANA'S MINING CADASTRE SYSTEM IN CONTEXT

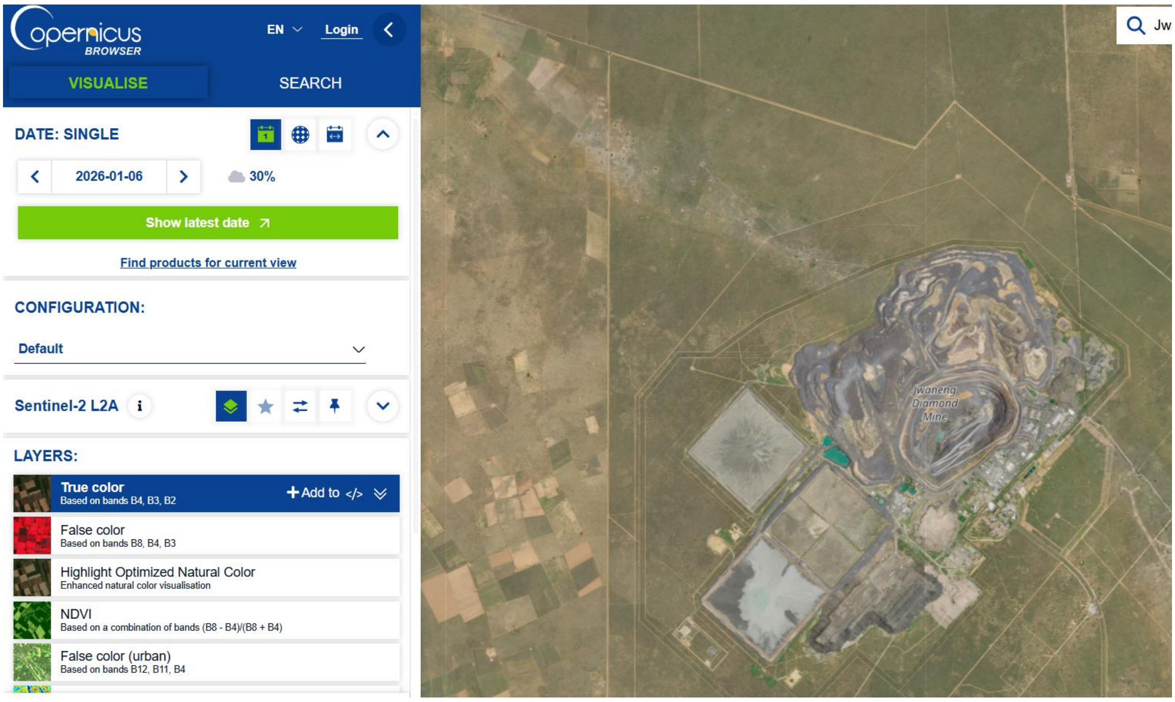
2.1 Overview of the Mining Cadastre System

A mining cadastre is an official register that records mineral rights, including exploration licenses, retention licenses, mining leases and their associated spatial extents. Its primary purpose is to ensure legal certainty, transparency, and efficiency in the allocation and management of mineral rights (Enemark et al., 2016). In Botswana, the Mining Cadastre System is administered by the Department of Mines under the Ministry of Minerals and Energy, in accordance with the Mines and Minerals Act (Republic of Botswana, 2019).

The Botswana Mining Cadastre System supports key administrative functions such as license application processing, renewal, transfer, and cancellation. It also maintains spatial records of licensed areas, helping to prevent overlaps and disputes between mineral rights holders. Over time, the system has improved regulatory oversight and contributed to Botswana's reputation as a mining-friendly jurisdiction.

Despite these strengths, the system's spatial component is largely static. Spatial data are typically submitted by applicants during the licensing process and are not systematically updated or validated against actual land-use conditions on the ground. As a result, the cadastre provides limited insight into how licensed areas evolve over time or how mining activities interact with environmental and climatic processes. Botswana's major mining operations are spatially distributed across the country, with significant concentrations at Jwaneng, Orapa, Letlhakane and Damtshaa.


Zim
20°S
Karowe Diamond MINE
Letlhakane Diamond Mine
20°E
25°E
Tropic of Capricorn
Khomecau Copper Mining
Redpath Botswana
Debswana Jwaneng Mine
25°S
Pretor
Johannesburg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SEARCH
DATE: SINGLE
2026-01-06
30%
Show latest date
Find products for current view
CONFIGURATION:
Default
Sentinel-2 L2A
LAYERS:
True color
Based on bands B4, B3, B2
Add to
False color
Based on bands B8, B4, B3
Highlight Optimized Natural Color
Enhanced natural color visualisation
NDVI
Based on a combination of bands (B8 - B4)/(B8 + B4)
False color (urban)
Based on bands B12, B11, B4
Jw

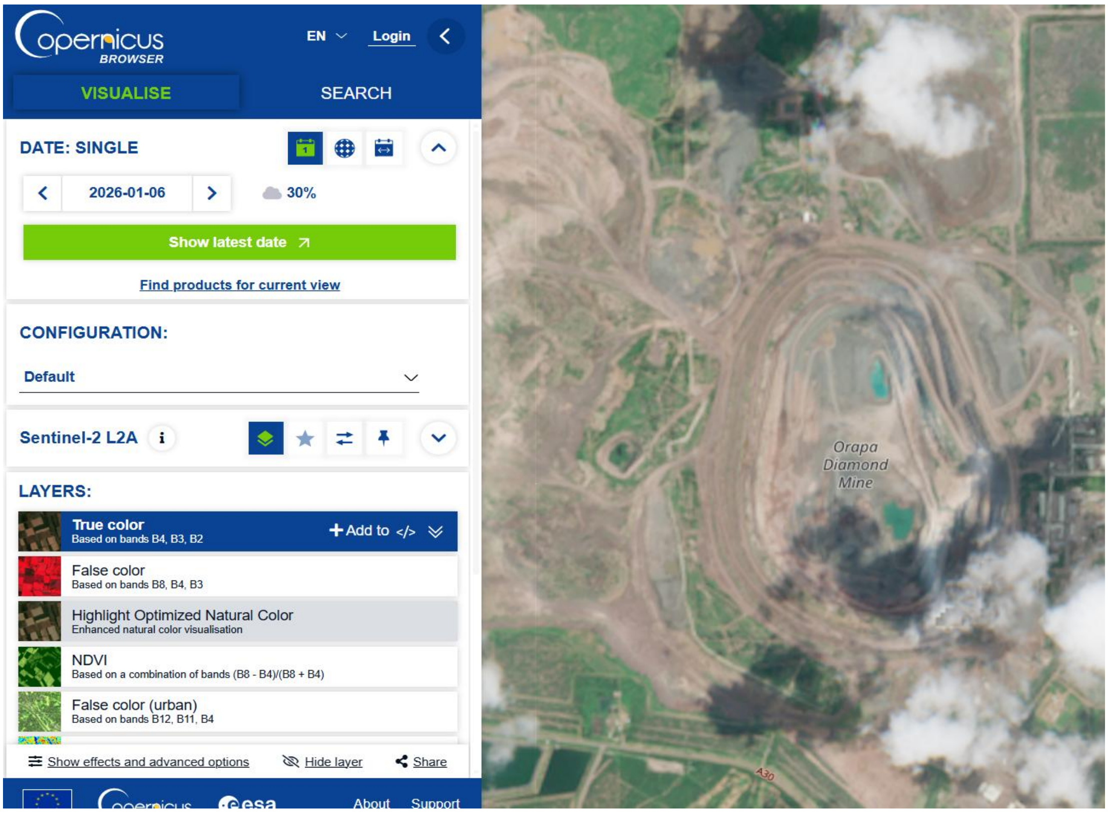


Figure 1: *Location of major mining areas in Botswana*
(Source: Copernicus Sentinel-2, European Union and Google Earth)

2.2 ENVIRONMENTAL AND CLIMATE MONITORING GAPS

Environmental management in Botswana's mining sector is primarily addressed through Environmental Impact Assessments (EIAs) and Environmental Management Plans (EMPs). While these instruments are essential for identifying potential impacts and mitigation measures, they are often conducted at discrete points in time and may not capture cumulative, indirect, or long-term environmental changes (Glasson et al., 2013).

Furthermore, climate change introduces dynamic risks that are difficult to address through periodic assessments alone. Increased variability in rainfall, prolonged droughts, and extreme weather events can alter land stability, water availability, and ecosystem resilience within mining areas. The absence of continuous, spatially explicit monitoring within the mining cadastre limits the government's ability to anticipate and respond to these challenges proactively.

3. REMOTE SENSING AND SUSTAINABLE LAND MANAGEMENT

3.1 Principles and Evolution of Remote Sensing

Remote sensing refers to the acquisition of information about the Earth's surface without direct physical contact, typically through satellite, aerial, or drone-based sensors. These technologies measure reflected or emitted electromagnetic radiation, enabling the extraction of information on land cover, vegetation health, soil conditions, and surface disturbances (Lillesand et al., 2015).

Advancements in sensor technology, spatial resolution, temporal frequency, and data accessibility have significantly expanded the applicability of remote sensing in land management. Freely available satellite missions such as Landsat and Sentinel provide continuous, long-term datasets that are particularly valuable for monitoring environmental change in developing country contexts.

3.2 Applications in Mining and Environmental Governance

Remote sensing has been widely applied in the mining sector to detect land disturbance, monitor mine expansion, assess rehabilitation success, and identify illegal or artisanal mining activities (Hassan et al., 2019; Sonter et al., 2017). Multi-temporal analysis enables the identification of trends and patterns that are not easily observable through ground-based inspections alone.

From a sustainable land management perspective, remote sensing supports evidence-based decision-making by providing objective, consistent, and scalable data. It complements traditional monitoring approaches and enhances the capacity of regulatory institutions to oversee large and often remote mining areas.

4. CONCEPTUAL FRAMEWORK FOR INTEGRATING REMOTE SENSING INTO THE MINING CADASTRE

4.1 Rationale for Integration

Integrating remote sensing into the mining cadastre represents a shift from a purely legal-administrative system to a spatially enabled governance platform. Such integration aligns with global trends toward digital land administration and fit-for-purpose approaches that emphasize flexibility, affordability, and sustainability (Enemark et al., 2016).

4.2 Proposed Integration Framework

The proposed framework comprises several interrelated components:

- **Spatial Linkage**: Integration of mineral license boundaries with up-to-date satellite imagery and derived land-use layers.
- **Temporal Monitoring**: Regular analysis of land-use and land-cover change within and around licensed areas.
- **Compliance Verification**: Automated or semi-automated detection of unauthorized land disturbance or deviation from approved mining plans.

- **Inter-Agency Data Sharing**: Collaboration between mining, environmental, land administration, and climate institutions.
- **Decision Support**: Visualization tools and dashboards to support regulatory decision-making and public transparency.

This framework emphasizes interoperability, scalability, and alignment with existing institutional mandates.

5. ENHANCING TRANSPARENCY, ACCOUNTABILITY AND GOVERNANCE

Transparency is a core principle of good mineral governance. By integrating remote sensing into the mining cadastre, regulators and stakeholders can independently verify whether mining activities are occurring within licensed boundaries and in compliance with environmental conditions. Public access to selected spatial information can reduce conflicts, build trust, and strengthen social license to operate (World Bank, 2020).

Enhanced transparency also supports anti-corruption efforts by reducing discretionary decision-making and increasing traceability within mineral rights administration.

6. CONTRIBUTION TO CLIMATE ACTION AND RESILIENCE

6.1 Monitoring Climate-Related Impacts

Remote sensing enables continuous monitoring of climate-related variables such as vegetation stress, surface water dynamics, and land degradation. Within mining areas, such information is critical for identifying climate vulnerabilities and informing adaptation measures.

6.2 Alignment with National and Global Commitments

Botswana’s commitments under the Paris Agreement and its Nationally Determined Contributions emphasize sustainable land management, ecosystem protection, and climate resilience (Republic of Botswana, 2021). An integrated mining cadastre provides the spatial evidence base needed to operationalize these commitments within the mineral sector.

7. METHODOLOGICAL APPROACH

This study adopts a qualitative and analytical research design, drawing on:

- A review of peer-reviewed literature on mining cadastre systems, remote sensing, and sustainable land management;
- Analysis of Botswana’s mining, environmental, and climate policy documents;

- Conceptual framework development informed by international best practices.

The methodology emphasizes contextual relevance and practical applicability within Botswana's institutional and technological environment.

8. DISCUSSION

The integration of remote sensing into Botswana's Mining Cadastre System presents both opportunities and challenges. While technical capacity, data management, and institutional coordination remain constraints, the increasing availability of free satellite data and cloud-based platforms significantly lowers barriers to implementation (Copernicus Programme, 2020). Capacity building, policy alignment, and sustained political commitment are critical for success.

9. CASE STUDIES FROM BOTSWANA

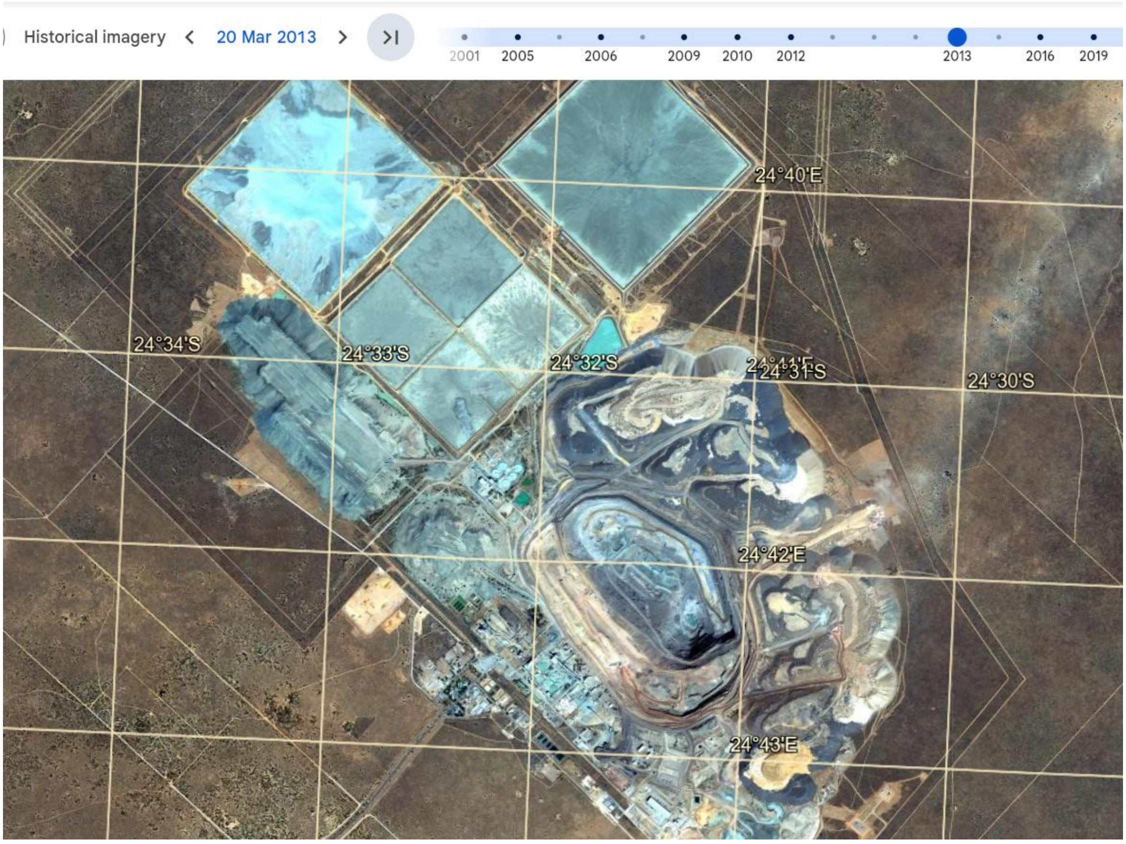
9.1 Large-Scale Mining: Debswana Diamond Operations

Debswana Diamond Company operates several major mines in Botswana, including Jwaneng, Orapa, Letlhakane, and Damtshaa. These operations occupy extensive land areas and have long operational histories, making them ideal candidates for demonstrating the value of integrating remote sensing into the mining cadastre.

Multi-temporal satellite imagery (e.g., Landsat and Sentinel-2) can be used to monitor:

- Expansion of open pits and waste rock dumps over time;
- Changes in vegetation cover surrounding mining areas;
- Effectiveness of progressive mine rehabilitation;
- Surface water changes related to dewatering and tailings storage facilities.

Integrating such observations into the mining cadastre would allow regulators to verify whether spatial expansion aligns with approved mining leases and environmental management plans, thereby strengthening compliance monitoring.


Historical imagery
20 Mar 2013
2001
2005
2006
2009
2010
2012
2013
2016
2019
24°40'E
24°34'S
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24°42'E
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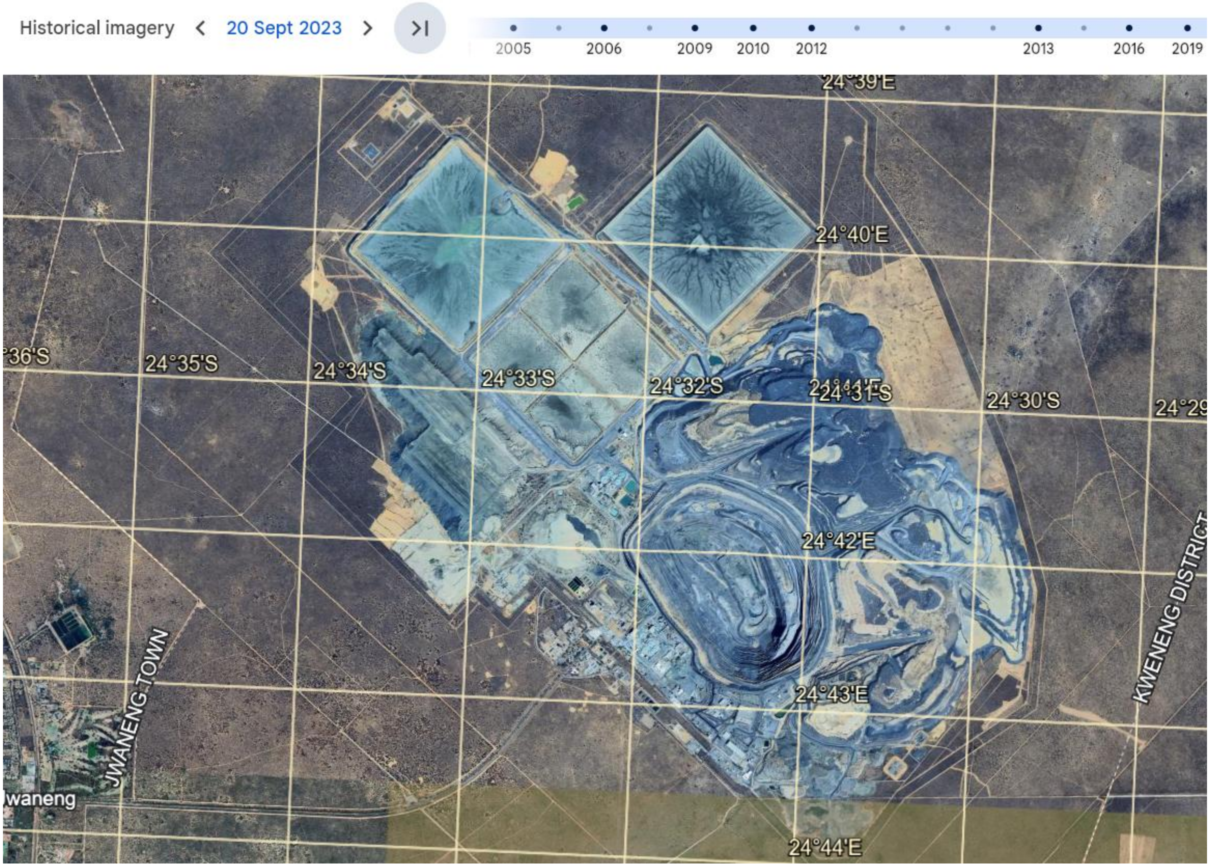

Figure 2: Temporal expansion of Jwaneng Diamond Mine
Source: Google Earth Timelapse, 2024

9.2 Small-Scale and Artisanal Mining Contexts

In addition to large-scale mining, Botswana hosts small-scale and artisanal mining activities, particularly for industrial minerals. These operations are often more difficult to monitor due to their dispersed nature and limited reporting capacity. Remote sensing provides a cost-effective means of detecting new disturbances, informal mining sites, and encroachment into restricted or environmentally sensitive areas.

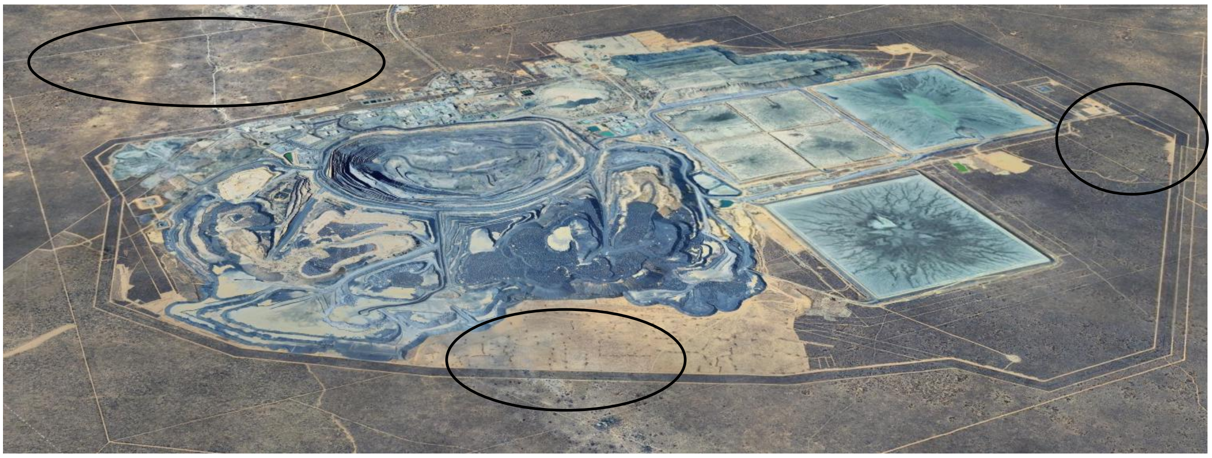

Figure 3: *Surface land disturbance detectable through satellite imagery along mining and exploration areas*
(Source: Google Earth, 2024)

10. WORKFLOW FOR AN INTEGRATED REMOTE SENSING–ENABLED MINING CADASTRE

10.1 Proposed Operational Workflow

The integration of remote sensing into the Mining Cadastre System requires a clear operational workflow linking data acquisition, analysis, and decision-making. The proposed workflow consists of the following stages:

1. **Data Acquisition** – Collection of satellite imagery from freely available sources (e.g., Sentinel-2, Landsat 8/9) at regular intervals.
2. **Pre-Processing** – Atmospheric correction, geometric alignment, and cloud masking.
3. **Change Detection Analysis** – Identification of land-use and land-cover changes within and around licensed mining areas.
4. **Cadastre Integration** – Overlay of detected changes with mineral license boundaries stored in the mining cadastre.

5. **Compliance Assessment** – Comparison of observed changes with approved mining and environmental plans.
6. **Decision Support and Reporting** – Generation of alerts, maps, and dashboards for regulators and policymakers.

Satellite Data (Sentinel / Landsat)

↓

Image Pre-processing

↓

Land Use Change Detection

↓

Overlay with Mining Cadastre Boundaries

↓

Compliance & Impact Assessment

↓

Regulatory Decision-Making

Figure 4: Workflow diagram illustrating the integration of remote sensing data into the Mining Cadastre System for monitoring and decision support.

10.2 Institutional Roles and Responsibilities

Successful implementation depends on clearly defined institutional roles. The Department of Mines would remain responsible for cadastre management, while environmental authorities and land administration agencies contribute thematic data and expertise. A shared geospatial platform would facilitate inter-agency collaboration and data exchange.

11. COMPARATIVE ANALYSIS: INTERNATIONAL EXPERIENCES

11.1 Ghana

Ghana has implemented reforms to strengthen its mining cadastre and has increasingly adopted geospatial technologies to address challenges related to illegal mining (galamsey). Satellite imagery has been used to identify unauthorized mining activities and support enforcement actions. Botswana can draw lessons from Ghana's experience in linking spatial monitoring with regulatory enforcement, particularly for small-scale mining contexts.

11.2 Tanzania

Tanzania's mining sector reforms include the use of digital cadastre systems and enhanced spatial oversight. While remote sensing integration remains limited, ongoing initiatives demonstrate the value of centralized digital platforms for improving transparency and reducing conflicts. Botswana's relatively advanced institutional capacity positions it well to move further toward full remote sensing integration.

11.3 Australia

Australia represents a mature example of integrating spatial data into mineral governance. Several states employ remote sensing and geospatial analytics to monitor mine compliance, rehabilitation progress, and environmental impacts. Although Botswana operates in a different socio-economic context, Australia's experience highlights the long-term governance benefits of spatially enabled mining cadastres.

Country	Cadastre Type	Remote Sensing Use	Key Lessons
Botswana	Digital	Limited	High integration potential
Ghana	Digital	Illegal mining detection	Enforcement support
Tanzania	Digital	Emerging	Transparency gains
Australia	Advanced	Full integration	Best practice

Table 1: Comparative overview of mining cadastre and remote sensing integration in selected countries (Botswana, Ghana, Tanzania, Australia).

12. DISCUSSION: IMPLICATIONS FOR POLICY AND PRACTICE

The inclusion of case studies, workflow design, and comparative analysis reinforces the practical feasibility of integrating remote sensing into Botswana's Mining Cadastre System. International experiences demonstrate that while technical solutions are readily available, institutional coordination, legal mandates, and sustained capacity development are decisive factors for success.

13. CONCLUSION AND RECOMMENDATIONS

This paper has demonstrated that integrating remote sensing into Botswana's Mining Cadastre System can significantly enhance sustainable land management and support climate action. By transforming the cadastre into a dynamic monitoring and decision-support platform, Botswana can strengthen environmental oversight, improve transparency, and align mineral development with long-term sustainability goals.

Key recommendations include:

1. Policy reform to mandate spatial and environmental monitoring within the mining cadastre;
2. Technical integration of remote sensing and GIS capabilities;
3. Capacity building for government institutions;
4. Strengthened inter-agency collaboration;
5. Phased implementation leveraging freely available satellite data.

This approach positions Botswana as a regional leader in climate-responsive mineral governance and supports the achievement of national development and climate commitments.and support climate action. By transforming the cadastre into a dynamic monitoring and decision-support platform, Botswana can strengthen environmental oversight, improve transparency, and align mineral development with long-term sustainability goals.

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BIOGRAPHICAL NOTES

Thulani Jonas is a MSc in Civil Engineering Candidate from Botswana with professional experience in mining and land administration. She has completed industrial training at Debswana Mine and the Palapye Sub Land Board. Her academic interests focus on mining cadastre systems, remote sensing applications and sustainable land and resource management.

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