

THE ROLE OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN MODERN MINING

Anastasia CHIS (URSOI)¹, Nicolae DIMA¹

¹ University of Petroșani, Petroșani, Romania

RESEARCH ARTICLE

Abstract

Geographic Information Systems (GIS) have become indispensable in the mining sector, facilitating exploration, mine planning, operations, environmental management, and post-closure monitoring. This paper reviews the state-of-the-art applications of GIS across the mining lifecycle, analyzes their benefits and limitations, and outlines future directions. By synthesizing findings from recent literature, we demonstrate how GIS improves the accuracy, efficiency, and safety of mining operations, while supporting sustainable development and regulatory compliance.

Keywords: *Geographical Informatic Systems, Spatial Information, Maps*

#Corresponding author: : anastasiachis12101997@gmail.com

INTRODUCTION

Geographic Information Systems (GIS) have become essential tools in the mining industry, transforming how companies explore, plan, operate, and rehabilitate mining sites. By integrating spatial data with analytical capabilities, GIS enhances decision-making throughout the entire mining lifecycle—from early exploration to post-closure monitoring. (Choi et.al, 2020)

Mining is inherently spatial: minerals are found in specific locations, geological processes vary over space, and environmental impacts must be monitored across landscapes. Traditionally, geologists relied on paper maps, manual calculations, and field notes. Today, GIS allows the integration of diverse datasets—geological, geophysical, geochemical, environmental, and socioeconomic—into a unified digital platform, enabling more accurate and efficient mining operations (Choi, Y., et al. ,2020).

MATERIAL AND METHOD

Mining is fundamentally a spatial enterprise: ore bodies, geological structures, and environmental constraints are geographically distributed, and spatial relationships govern

both opportunities and risks. Historically, geological mapping, resource estimation, and environmental monitoring relied on manual maps, field notes, and separate non-integrated datasets. The advent of Geographic Information Systems (GIS) allows for integration of varied spatial and attribute data — geological, geochemical, geophysical, topographic, environmental, infrastructure — into unified, interactive, and analyzable platforms. This transformation supports better decision-making throughout the mining lifecycle, from exploration to closure and remediation. (Szafarczyk, Siwek, 2025)

This paper reviews contemporary research on GIS applications in mining, examining how GIS has been applied, what benefits it delivers, and what challenges remain.

Applications of GIS in the Mining Lifecycle

1 Mineral Exploration

GIS supports exploration by helping geologists analyze complex datasets to identify areas with high mineral potential. Key uses include(Szafarczyk, Siwek ,2025):

- **Geological mapping:** Integrating rock types, structures, faults, and mineral occurrences.

- **Remote sensing analysis:** Using satellite data (e.g., Landsat, Sentinel) to detect alteration zones.
- **Spatial modeling:** Weight-of-evidence and machine-learning models for mineral prospectivity mapping.

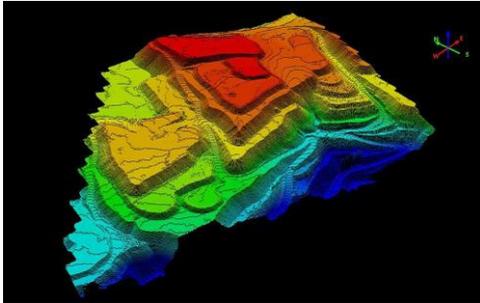


Figure. 1. GIS of a mine

These tools reduce exploration risk and direct fieldwork to the most promising sites.

One of the earliest and still most significant uses of GIS in mining is in mineral exploration. By integrating geological, geochemical, geophysical, and remote-sensing data layers, GIS enables the generation of prospectivity maps that highlight areas with high potential for mineralization. For instance, the study Geological mapping and mineral prospectivity using remote sensing and GIS in parts of Hamissana, Northeast Sudan used GIS together with remote sensing data to map geological features and identify prospective gold zones over a region of $\sim 1,379 \text{ km}^2$. [SpringerLink](#) Also, by combining structural geology (faults, lithologies), alteration zones, and topography, GIS helps define promising drill targets, reducing risk and focusing exploration resources. As noted in the broader review, GIS simplifies the traditional labor-intensive task of manually overlaying and interpreting multiple data sets — thereby speeding up early-stage exploration and improving the accuracy of target selection.

2. Resource Assessment and Reserve Estimation

GIS helps connect geological models with spatial datasets such as: (Xu et al., 2017).

- Drillhole sampling data
- Ore grade distribution
- 3D block models

By visualizing and interpolating data, GIS enables more accurate estimation of ore quantity and quality, improving economic feasibility assessments.

Beyond simply mapping where minerals *might be*, GIS is used to more precisely estimate resources and even to automate resource accounting. The recent preprint The Use of GIS Tools in Mining: Process Automation of Calculating the Volume of Mineral Extracted from a Deposit demonstrates how GIS can be used to automate volume calculations for open-pit mines — from field measurement data through calculation, visualization and interpretation — improving accuracy, reducing human error, and speeding up the process. Such GIS-based resource accounting supports compliance with legal/regulatory requirements (e.g., reporting extracted volumes), better mine planning, and transparent resource management. (Xu et al., 2017)



Figure. 2. Quarries

3. Mine Planning and Design

Modern mine planning relies heavily on GIS for (Xu et al., 2017):

- **Optimized pit design** considering terrain, geology, and environmental constraints.
- **Infrastructure planning** (roads, processing facilities, waste dumps).
- **Slope stability and geohazard assessment** using terrain analysis and digital elevation models (DEMs).

GIS tools make it easier to simulate operational scenarios and reduce engineering risks.

GIS also plays a key role in mine design, infrastructure planning, and operational optimization. According to the review in Applied Sciences, GIS-based methods have been applied for: ore reserve estimation; optimizing open-pit boundaries; designing mine infrastructure (roads, processing plants, waste dumps); and evaluating potential conflict or constraint zones (e.g., environmental or social issues) (Vangu et al., 2023).

In underground coal mines — where safety is paramount — advanced 3D and spatio-temporal GIS models are being developed to assess accident risk, plan ventilation networks, drainage systems, and emergency rescue routes. For example, the recent paper *A Review on the 3D Cartographic and Spatiotemporal GIS Models for Safety of Accidents in Deep Underground Coal Mines* outlines how spatial-temporal GIS analyses (e.g., hotspot, space–time cube, kernel density) are used to model accident occurrences and dynamics over time and space. Furthermore, GIS enables integration of terrain data (Digital Elevation Models — DEMs), geological structure, and surface constraints to design safer and more efficient mining infrastructure.

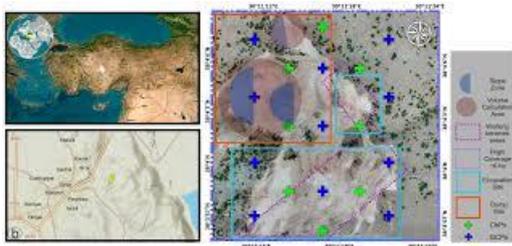


Figure.3. Mining plan design

4. Environmental Management and Hazard Assessment

Mining has significant environmental impacts, and GIS provides robust ways to monitor and mitigate them (G. M. Vangu et al., 2023):

- **Land use/land cover change detection** using satellite imagery.
- **Water quality monitoring** through watershed mapping and hydrological modeling.
- **Air quality and dust dispersion models.**
- **Habitat and biodiversity assessment** for compliance with environmental regulations.

GIS enables environmental teams to track impacts in near real time.

Mining has significant environmental and social impacts — land degradation, water/soil contamination, deforestation, subsidence, air and dust pollution. GIS, often in combination with remote sensing, is widely used to model, monitor and mitigate these impacts.

An Overview of GIS-Based Modeling and Assessment of Mining-Induced Hazards: Soil, Water, and Forest

(<https://www.mdpi.com/1660-4601/14/12/1463>) shows how GIS helps assess hazards like soil contamination, water pollution,

deforestation, erosion, and land-use change, enabling spatially explicit risk analyses. Moreover, at a broader scale, spatial analyses using GIS and remote sensing supports cumulative and strategic impact assessments — useful for regulators, communities, and companies to understand not just site-level but regional or global effects of mining. The work *Assessing impacts of mining: Recent contributions from GIS and remote sensing reviews* how GIS helps map land-use change, water and soil impacts, social and economic effects, and supports conflict resolution and disaster mitigation.

Finally, integrated GIS databases help track mining concessions, permit boundaries, infrastructure, and environmental constraints — supporting sustainable resource management and regulatory compliance. For instance, the recent article *Design of a GIS Database for Surface Mining* describes design and implementation of a GIS database for surface mining, aiming to manage permits, exploitation perimeters, and to support concession promotion. Paradigm.

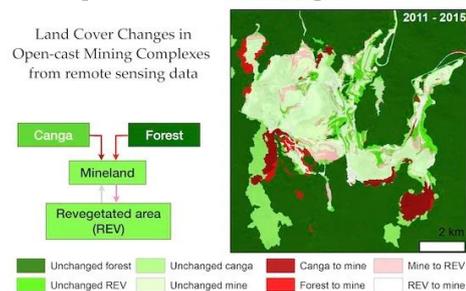


Figure. 4. Land cover changes

5. Health, Safety, and Risk Management

GIS enhances mine safety by:

- Mapping accident hotspots
- Identifying unstable terrain
- Visualizing underground workings to prevent collapses
- Supporting emergency planning and evacuation routes

Spatial analysis helps companies reduce risks to workers and communities.

6. Operational Monitoring and Asset Management

Mining operations involve fleets, machinery, and infrastructure spread over large areas. GIS supports (G. M. Vangu et al., 2023):

- **Real-time equipment tracking**
- **Monitoring haul roads conditions**
- **Managing utilities and pipelines**

- **Visualizing production data spatially**
Integration with IoT and GPS improves productivity and reduces downtime.

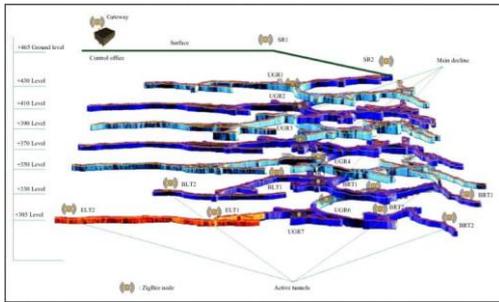


Figure 5. GIS of an underground mine

7. Mine Closure and Rehabilitation

GIS plays a crucial role in post-mining activities (Werner et al 2019):

- Designing **rehabilitation plans** based on topography and soil conditions
- Monitoring **vegetation recovery** using remote sensing
- Assessing long-term environmental stability

These tools ensure compliance with closure regulations and promote sustainable land use after mining.

The review builds upon existing systematic reviews (e.g., Review of GIS-Based Applications for Mining: Planning, Operation, and Environmental Management) and recent research articles. We surveyed peer-reviewed papers published in the last decade (2015–2025), focusing on studies that apply GIS to mineral exploration, mine planning, operational management, environmental impact assessment, hazard modeling, and resource accounting. Key databases (Google Scholar, PubMed, MDPI, Sciendo) were searched with keywords like “GIS mining,” “mine planning,” “remote sensing mining,” “mineral prospectivity,” “mine environmental GIS,” and “mine safety GIS.”

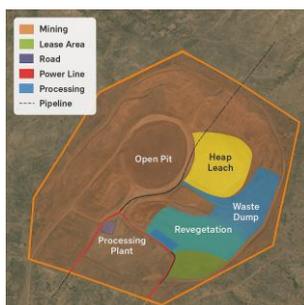


Figure 6. Mine closure and rehabilitation

RESULTS AND DISCUSSION

Key GIS Technologies Used in Mining

- **Remote sensing platforms:** Landsat, Sentinel, drones (UAVs)
- **Digital Elevation Models (DEMs):** LiDAR, SRTM
- **3D GIS and modeling software:** ArcGIS, QGIS, Leapfrog, Surpac
- **Machine learning integration** for mineral prospectivity mapping
- **Web-GIS platforms** for real-time data sharing across teams

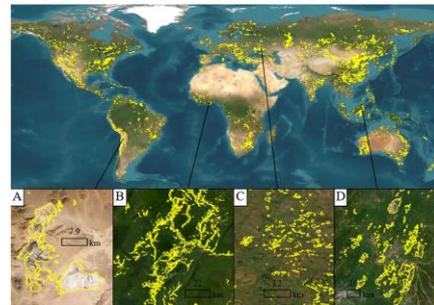


Figure 7. Images of mining activities

Benefits of GIS in Mining (Werner, T. et al 2019)

- Improved accuracy of exploration and planning
- Reduced operational costs
- Better environmental compliance
- Enhanced safety and risk management
- Stronger communication among stakeholders
- Faster, data-driven decision-making

Challenges and Future Trends

Challenges (Werner et al 2019)

- High cost of data acquisition
- Need for skilled GIS professionals
- Data integration across different formats and platforms.

Future Trends

- **AI-driven exploration modeling**
- **Integration with drones and autonomous vehicles**
- **Cloud-based geospatial platforms**

Real-time 4D GIS (space and time) for dynamic mine monitoring

Benefits of GIS in Mining

From the literature surveyed, the key benefits of this type of GIS include (Werner et al 2019):

- **Integrated spatial data management:** GIS allows storage and manipulation of georeferenced and attribute-rich data (drillholes, ore bodies, terrain, hydrology, infrastructure) in unified databases.
 - **Improved exploration efficiency and accuracy:** By layering geology, remote sensing, geochemistry, and geophysics — GIS facilitates target zone identification, maximizing the likelihood of successful drilling and minimizing wasted effort.
 - **Better mine planning and operational optimization:** Through spatial modeling and 3D/temporal GIS, companies can design pits, infrastructure, ventilation, and safety systems more optimally, reducing cost and risk.
 - **Accurate resource estimation and compliance:** Automation of volume calculations reduces human error, speeds up reporting, and ensures consistent resource accounting — important for regulation and transparency.
 - **Environmental and hazard risk management:** GIS supports environmental monitoring, hazard modeling, land-use change detection, contamination assessment, and long-term rehabilitation planning.
 - **Facilitating sustainable development and regulatory compliance:** By integrating concession data, infrastructure, environmental constraints, and social data, GIS can help companies and regulators manage mining more responsibly.
- environmental, and infrastructural datasets often come in different formats, scales, and accuracies. Integrating them into a coherent GIS database requires substantial effort.
- **Need for skilled personnel:** Effective GIS application demands expertise in geology, mining engineering, GIS, remote sensing, and data management — a multidisciplinary skill set that may not always be available.
 - **Computational and resource constraints:** High-resolution spatial data (e.g., DEMs, remote sensing imagery, 3D models) and temporal analyses (for hazards or environmental monitoring) can be computationally intensive, especially for large mining areas or deep underground mines.
 - **Uncertainties in modeling:** Spatial models — whether for mineral prospectivity, hazard prediction, or resource estimation — inherently involve assumptions and uncertainties. Over-reliance on model outputs without validation (e.g., through drilling, on-site sampling) can lead to misleading conclusions. The authors of the comprehensive review note that despite widespread use, robust evaluations of many GIS-based methods remain limited.
 - **Regulatory and data-sharing limitations:** In many regions, geological data, mining permits, and environmental data are sensitive or proprietary, which limits data sharing, transparency, and broader-scale spatial analyses.

Challenges and Limitations

Despite its many advantages, the application of GIS in mining also faces several challenges:

- **Data quality, availability, and integration issues:** Geological, geochemical, geophysical,

Future Directions and Emerging Trends

The field of GIS in mining is dynamic and evolving. Several promising directions emerge from recent literature (Szafarczyk, et al, 2025):

- **3D and spatio-temporal GIS modeling:** As demonstrated in the recent review on underground coal mines, using GIS in 3D + temporal

framework helps assess accident risk, monitor environmental changes, and improve safety management. [SpringerLink+1](#).

- **Automation of resource and production accounting:** The recent preprint on automating volume calculations shows potential for greater efficiency, consistency, and regulatory compliance in resource management. [preprints.org+1](#)
- **Integration with remote sensing, UAVs, sensor networks and IoT:** Combining GIS with remote sensing (satellite imagery, UAV/drone data), real-time sensors (environmental, structural, operational), and IoT could enable near real-time mine monitoring, environmental surveillance, and dynamic risk management. The review on GIS-based applications anticipates such integration as part of future digital transformation.
- **Standardized GIS databases for mining sectors:** As seen in the study on designing a surface mining GIS database, there is growing interest in developing national or regional GIS-based systems for managing mining concessions, permits, environmental data, and mine perimeters — especially in jurisdictions seeking efficient resource governance.

Broader environmental and social impact assessment: Using GIS and remote sensing to model cumulative impacts, land-use changes, water/soil contamination, and social effects — not only at mine-site scale but regionally — to support sustainable mining policies and community engagement. (Szafarczyk, Siwek, 2025)

CONCLUSIONS

GIS has emerged as a foundational technology in modern mining. Through data integration, spatial modeling, visualization, and analysis, GIS supports mineral exploration, resource estimation, mine planning, operational management, environmental monitoring, hazard assessment, and regulatory compliance. The benefits — improved efficiency, accuracy,

safety, and sustainability — are well documented. (Kunytzka, 2024)

Nevertheless, challenges remain: data quality and integration need for multidisciplinary expertise, computational demands, and uncertainties in modeling. Looking ahead, the integration of GIS with remote sensing, sensor networks, 3D/temporal modeling, and standardized databases appears promising. With continued research and technological development, GIS is likely to become even more central to mining — not only for optimizing resource extraction, but also for ensuring environmental responsibility, safety, and sustainable development. (Maryna Kunytzka, 2024)

REFERENCES

- Choi, Y., Baek, J., & Park, S. (2020). *Review of GIS-Based Applications for Mining: Planning, Operation, and Environmental Management*. *Applied Sciences*, 10(7), 2266. [MDPI+2sejong.elsevierpure.com+2](#)
- Geological mapping and mineral prospectivity using remote sensing and GIS: the case of Hamissana, Northeast Sudan. (2021). *Journal of Petroleum Exploration and Production Technology*, 11, 1123–1138.
- Kunytzka, M. (2024). *Opportunities and advantages of GIS for building three-dimensional models in mining*. *Mining Journal of Kryvyi Rih National University*, 58(2), 10–20. [mining-journal.com.ua](#)
- Szafarczyk, A., & Siwek, M. (2025). *The Use of GIS Tools in Mining: Process Automation of Calculating the Volume of Mineral Extracted from a Deposit*. Preprint. [preprints.org+1](#)
- Vangu G. M. et al. (2023). *Design of a GIS Database for Surface Mining*. *Journal of Applied Engineering Sciences*, 13(2), 289–296. [Paradigm](#)
- Werner, T. T., Bebbington, A., & Gregory, G. (2019). *Assessing impacts of mining: Recent contributions from GIS and remote sensing*. *Extractive Industries and Society*, 6(3), 993–1012. [commons.clarku.edu+1](#)
- Xu et al. (2017). *An Overview of GIS-Based Modeling and Assessment of Mining-Induced Hazards: Soil, Water, and Forest*. *International Journal of Environmental Research and Public Health*, 14(12), 1463. [MDPI](#)