

Potential of Using Satellite Remote Sensing and GIS in Monitoring of Mine Disasters

DO Thi Phuong Thao^{1,2,*}, BUI Ngoc Quy^{2,3}, TRINH Le Hung⁴

¹ Hanoi University of Mining and Geology, Hanoi, Vietnam

² Research and Development of Geospatial Data Management and Analysis Techniques, Hanoi, Vietnam

³ Central Institute for Natural Resources and Environmental Studies, Vietnam National University, Hanoi, Vietnam

⁴ Le Quy Don Technical University, Hanoi, Vietnam

* Corresponding email: dothiphuongthao@hmg.edu.vn

Abstract: *In recent times, numerous methods have been developed to predict disasters in mining areas. Among these, the use of remote sensing and Geographic Information Systems (GIS) stands out due to its advanced nature. This technology has revolutionized the process of detecting potential risks in mining areas, significantly enhancing our ability to prevent disasters. The paper in question conducts a comprehensive review of the application of remote sensing and GIS in monitoring mine disasters. This review is based on an analysis of 44 publications from 2009 to May 2024. These publications provide insights into the practical application of these technologies in mining. The findings indicate that remote sensing and GIS are effective in identifying hazards in mining areas. The majority of studies (≈50%) focused on slope stability, followed by surface deformation monitoring (≈37.5%), while research on harmful gas detection remained limited (≈12.5%). Slope stability determination is crucial in open-pit mining where the stability of the pit walls is paramount. Harmful gas detection is vital in preventing health hazards to miners and mitigating the risk of explosions. The results of this study could provide guidance for creating specifications for the usage of remote sensing and GIS technology in analyzing mine disasters. These specifications would serve as a roadmap for the effective implementation of these technologies, enhancing the safety and efficiency of mining operations. The application of remote sensing and GIS in mining is a promising field with significant potential for further research and development. The findings underscore the importance of these technologies in advancing the field of mining safety and disaster prevention. The review emphasizes the potential of these technologies to revolutionize the mining industry by providing a more accurate, efficient, and safer way to monitor and predict mining disasters. This could lead to significant improvements in the safety standards of mining operations worldwide.*

Keywords: remote sensing and GIS, mine disasters, deformation monitoring, slope stability, harmful gas

1. Introduction

According to (Düzgün & Demirel, 2011), remote sensing plays an important role in mine management, helping to maintain safe, efficient operations while reducing the dangers involved. There are some publications reviewed on the application of remote sensing (RS) and Geographic Information Systems (GIS) in the mine industry. (Sikakwe & Environment, 2023) conducted a systematic review to analyze the utilization of satellite RS and GIS in mineral exploration. While (Werner, Bebbington, & Gregory, 2019) provided a summary of recent studies that assess different historical, present, and anticipated effects of mining using GIS and/or RS, (Loots, Grobbelaar, & Van der Lingen, 2022) presented a review of RS unmanned aerial vehicles application in the mining sector, (Omali, 2021) evaluated the potential of RS and GIS in mining and mineral sector. Advancements in the ecological environment monitoring of mining regions based on RM were mentioned in (Song, Song, Gu, Li, & Health, 2020). Also related to environmental management, (J. Li et al., 2020) provided a comprehensive overview of the RS models and techniques for different kinds of environmental monitoring in the mine area of China. In addition, (Chen, Li, He, & Wang, 2017) analyzed the most recent progress in the use of RS techniques for fine-scale land use and land cover classification in open-pit mine areas. It primarily focuses on the land cover thematic resolution that has been proposed, important aspects of mine area, and the features, feature selection techniques, and classification algorithms that have been used. Also, a comprehensive summary relating to publications on the topic of assessing reclamation status and assisting landscape planning procedures in mining areas using RS and GIS technology was presented in (Buczyńska, 2020). Similarly, the GIS-based techniques for reclamation planning and environmental management in mines are reviewed in (Choi, Baik,

& Park, 2020). The study discussed the benefits and drawbacks of utilizing GIS in mining and made recommendations for GIS's future development. (McKenna, Lechner, Phinn, & Erskine, 2020) performed an extensive investigation to evaluate the state of RS research on vegetation dynamics throughout the restoration of mine sites from 1970 to 2019. The available research indicates that RS is a valuable tool for quickly and thoroughly defining coal mine fires. (Biswal, Raval, & Gorai, 2019) offered a review on the use of different satellite data for fire detecting and mapping in the coal mining site. In addition to assessments of RS in the mining industry. While (Park & Choi, 2020) published an overview of unmanned aerial vehicle applications in mining from exploration to reclamation, (Ren, Zhao, Xiao, Hu, & Technology, 2019) summarised current circumstances and future outlooks of UAV monitoring in mine industry, (Minh & Dung, 2023) reviewed various potential applications for UAVs in the mining sector, (L. Q. Nguyen, Dang, Bui, Ngoc, & Tran, 2022) provided a brief description of current advancements in the mapping and surveying of surface, underground, and abandoned mines using unmanned aerial vehicles, (B. D. J. I. M. Nguyen, 2023) realized that UAVs have potential in mine waste dumps. Regarding the determination of mine surface deformation, (Owczarz, 2020) presented an overview of the techniques used in geodetic and RS research to identify surface displacements generated by mining.

The literature showed that RS and GIS technology are valuable tools for mine management and monitoring. Although there are many reviews on the application of RS and GIS in mining, there has not been any in-depth research on the application of this technology and GIS to assess possible risks when mining. Therefore, in this review, the authors attempted to give a general overview of the roles of RS and GIS in monitoring mine disasters. This study aims to (1) map research trends 2009–2024, (2) classify applications by hazard type and sensor/technique, (3) assess methodological gaps and propose future directions.

2. Materials and Methodology

The performed research followed two steps. Firstly, choosing appropriate databases and keywords for the search was the first stage. There were three primary groups of keywords. The terms “remote sensing and GIS”, “satellite remote sensing and GIS” were used in the first group, which was linked to methods. The terms “open cast”, “open pit”, “surface mine” “quarry”, “underground mine”, “mine industry”, “mine area” were utilized in the second group, which was related to study area. The terms “deformation”, “slope stability”, “landslide”, “harmful gas” in the third group, which was involved with applications or the interest field. Table 1 provides a summary of the search syntaxes used for the study retrieval. Secondly, collecting appropriate research from documents on the internet. Data from numerous significant sources, such as Google Scholar, Web of Science, IEEE, Science Direct, etc., were used in this study. After the removal of duplicates, screening is done using titles and abstracts to verify eligibility requirements. Subsequently, the whole manuscripts were retrieved in order to incorporate them into the review. A total of 44 publications including book chapters, journal articles, and conference papers published in English between 2009 and May 2024 related to mining risk identification and the above keywords. Detailed steps are as shown in figure 1.

Tab. 1. The search syntaxes

Terms related to used method	Terms related to applications	Terms related to study area
Remote sensing and GIS	Deformation	Open cast/ open pit/ surface mine
Satellite remote sensing and GIS	Slope stability	Quarry
Remote sensing	Landslide	Underground mine
Satellite remote sensing	Harmful gas	Closed/ abandoned mine

3. Application remote sensing and GIS in mine management

According to (Raju & Patel, 2022), there are many applications of RS in mining such as slope instability, slope deformation, monitoring of harmful gases, vegetation monitoring, spatial analysis in open pit mines, and monitoring land dynamic uses. This section only focuses on reviewing research on applications of this method in risk management in mining areas.

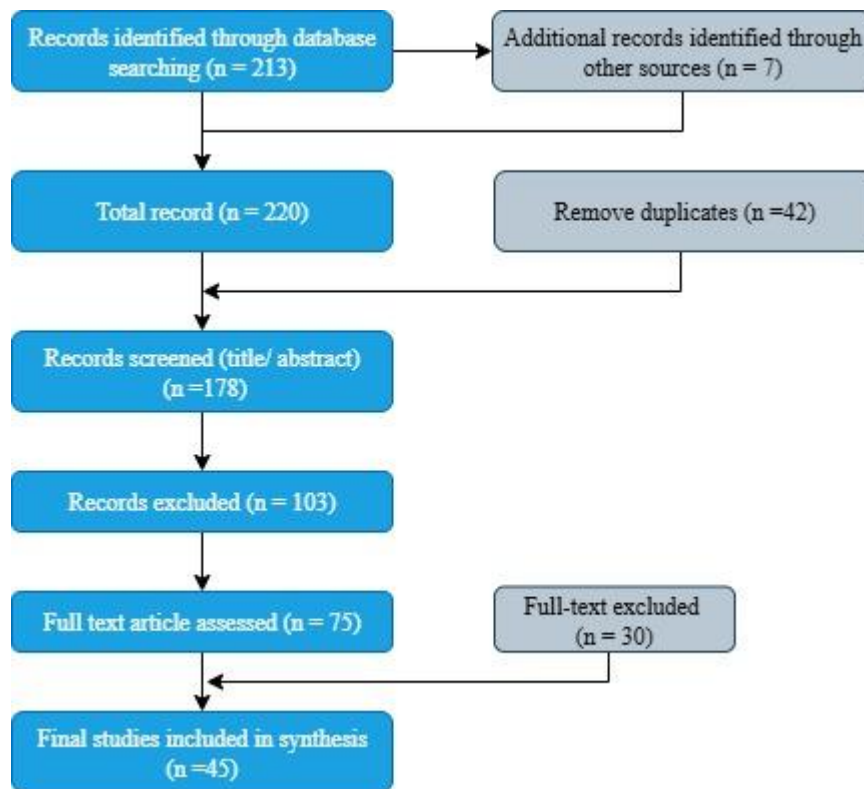


Fig. 1. PRISMA flow diagram for systematic study

3.1 Monitoring of deformation

Subsidence phenomena can result from underground mining, particularly if orebodies are surficial or found in soft rocks. Unauthorized subsurface excavation, however, is far riskier since it might result in surficial collapses that are unanticipated in poorly monitored areas. To enhance risk management, it is necessary to provide data on the temporal and spatial evolution of unregulated subterranean operations. To achieve this aim, (Ammirati, Mondillo, Rodas, Sellers, & Di Martire, 2020) used the DInSAR technique to monitor mining-induced subsidence. Besides, since mining activities create large-gradient ground subsidence, diversified topography, and dense vegetation, it is typically challenging to correctly monitor deformation in both time and space. Thus, (Zhang et al., 2021) determined mining deformation across densely vegetated areas using multi-platform SAR imagery. The obtained results indicated that in mining sites with extensive vegetation, retrieving the ground deformation is aided by the use of multiplatform SAR datasets. Similarly, (W. Yuan, Wang, Fan, & Li, 2017) used the DInSAR technology to determine ground subsidence in mining regions. It has been demonstrated that the DInSAR technology is a useful tool for monitoring the ground deformation induced by underground mining. Additionally, Coal mining generates surface subsidence, which damages homes, highways, and industrial facilities in addition to having a significant negative influence on the geological and biological ecosystems. To recognize the trend of subsidence in the mountainous mining areas of northwestern China, (M. Yuan et al., 2021) offered a useful technique for forecasting the borders of subsidence and the probability of landslides based on SBAS-InSAR. Besides, surface disturbances brought on by mining operations, especially open-pit mining operations, can have a significant impact on the delicate ecosystem of alpine mining sites. Using the 89-scene Sentinel-1A SLC products, (Huang, Du, Chen, & He, 2021) applied SBAS-InSAR technology to acquire three years' worth of surface subsidence data covering a mining area. The obtained results show that the SBAS-InSAR observations required less manpower and money and produced deformations with excellent accuracy across a large area.

On the other hand, understanding and assessing the impact of surface sinking can help with the development and upkeep of different types of ground facilities. Thus, (Liu, Mei, Sun, & Xu, 2021) used GIS approaches and small-baseline set interferometric synthetic aperture radar monitoring to look into regions of possible damage and surface subsidence caused by mining in Yangquan City, Shanxi Province. Figure 2 displays the outcome of the average subsidence rate map. Also using radar data, (Trofymchuk, Anpilova, Yakovliev, & Zinkiv, 2020) discussed the use of GIS models and Radar data to estimate the post-

mining deformation of the upper section of the Carpathian region's geological structures.

According to (Hu, Wu, Zhang, Liu, & Xu, 2017), understanding the deformation process and space distribution, as well as estimating the deformation laws and trends, can be accomplished by the detection and extraction of mining-induced ground deformation. Thus, they used Chinese ZY-3 stereo imagery to monitor ground deformation, in particular severe deformation like landslides or massive fractures in mining areas. In addition to active mines, the subsidence of closed mines also affects the surrounding environment. Long-term subsidence over abandoned coal mines can have a negative effect on more recent surface construction, whether it be for residential or commercial purposes. Therefore, (Peters, Livo, & Hauff, 1996) have studied the subsidence over abandoned coal mines using RS techniques, as well as the inventorying and characterization of noncoal abandoned mine areas. The findings indicated that the evaluation of subsidence risk can be improved by using RS to gather data on less visible geologic formations that affect subsidence.

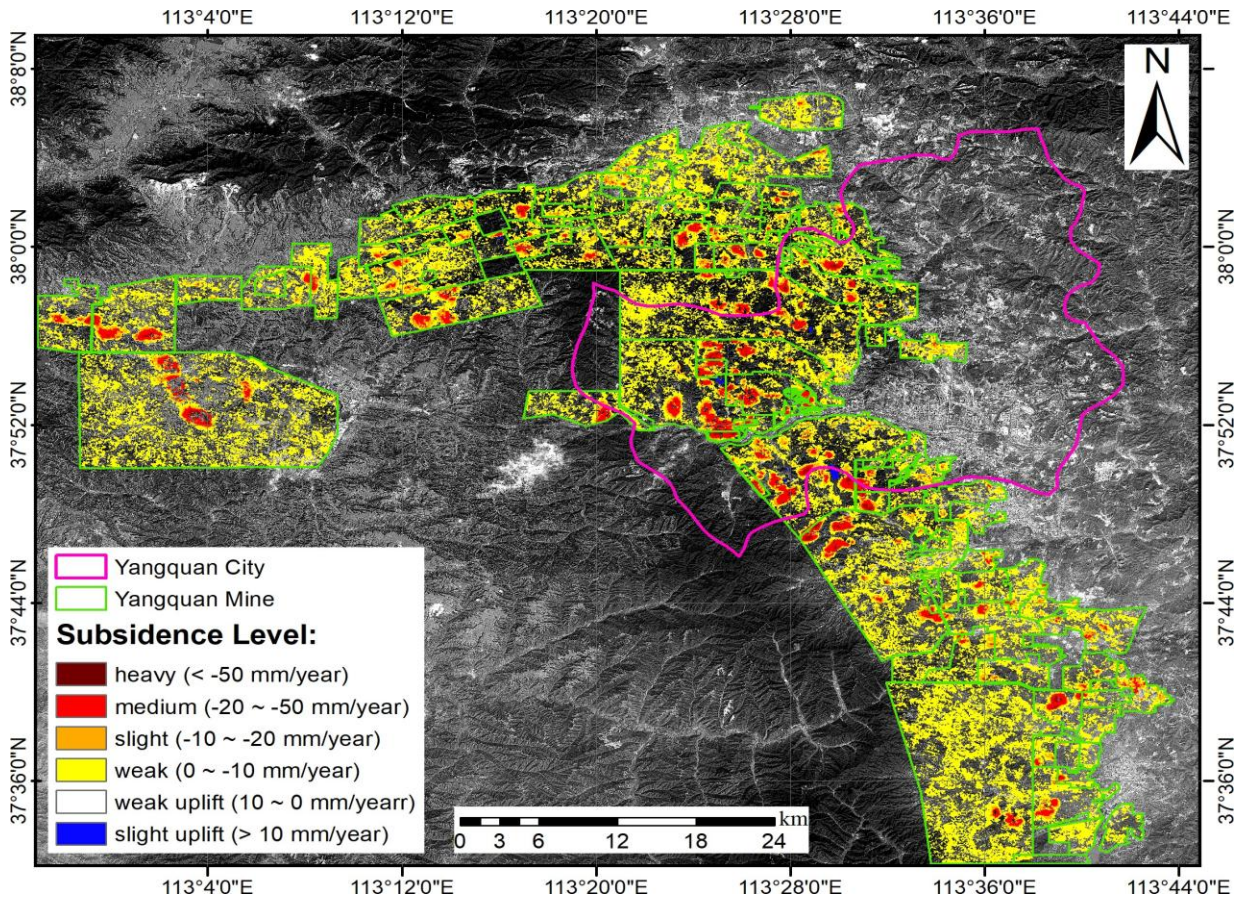


Fig. 2. The distributions of the graded results and main subsidence areas (Liu et al., 2021)

3.2 Monitoring of slope instability

In mining operations, analyses of both temporal and spatial changes from RS data offer useful information for risk management, planning, and monitoring of possible instability. (Vanneschi, Eyre, Francioni, & Coggan, 2017) examines the advantages of combining various RS methods with traditional measuring tools to create the extensive database needed for the creation of a successful slope monitoring and risk management program (Figure 3). According to (Hutchinson et al., 2015), rock slope change data was formerly hard to gather, but recent advancements in speedy, precise, and sophisticated RS techniques have made this data possible. Therefore, they used this technology to recognize and control the hazards of rock slope failure. In order to study the open-pit quarry slopes, (Francioni et al., 2015) presented a novel method by integrating RS technology, 3D finite difference method (FDM) stress models, and simple kinematic analysis techniques. Also, (Francioni, Salvini, Stead, & Coggan, 2018) discussed the usage of data for stability analyses of rock slopes, in which every RS survey approach can produce data sets that can be used with a variety of slope stability analysis methodologies. In addition, they presented the application of various RS survey techniques and highlighted the significance of each data set in enhancing the accuracy and dependability of rock slope evaluations. In order to assess the stability of the quarry slope, (Francioni, Salvini, Stead, & Litrico, 2014) integrated RS technology and distinct element analysis. In this study, using

measurements of photographic images, this remote sensing approach determines the geometric features of things. In conjunction with terrestrial laser scanning, RS is utilized to gather the geometrical parameters required to comprehend the structural configuration and conduct the rock slope stability analysis. In another study (Francioni, Stead, Sciarra, & Calamita, 2019), the authors provided a new method for geomechanical rock slope analysis that combines the Slope Mass Rating (SMR) classification system, geographic information systems (GIS), and RS. Using this multifaceted approach, creating 3D models of rock slopes is made simple, and all data is stored in a GIS database. By optimizing data integration and analysis, this method makes it easier to define the best mitigation activities. RS with satellite-based Interferometric Synthetic Aperture Radar (Insar) offers a special chance to monitor slope deformation during the evaluation of large surface mine slope kinematics. (Styles et al., 2011) presented the results of the combination of Insar data and numerical modeling in monitoring slope instability at Bingham Canyon mine. The obtained results unambiguously indicate the considerable potential for enhancing our comprehension of the kinematics of slope deformation mechanisms in vast open pits by the joint application of InSAR and numerical modeling.

Slope steepness, continuous instability caused by rockfalls, challenging terrain, and other safety issues may make it impossible to collect data using conventional field methods. Therefore, using RS techniques is essential to carrying out an efficient assessment. The study (Stead, Donati, Wolter, & Sturzenegger, 2019) presented the use of RS and field methods to characterize rock slopes at different scales and distances. The results show that RS is an essential tool in characterizing and analyzing the stability of high rock slopes. In recent years, collecting data from remote sensing satellites has become easy for the quarry industry. The size and geographical distribution of the rock blocks sitting on the slope (endpoint positions) were established by analyzing a series of aerial photos in order to ascertain the evolution phases of the rockfall (Robiati et al., 2019).

According to (Sengupta, Krishna, & Roy, 2018), by processing and analyzing relevant satellite data, it is possible to envision how slopes in open-pit coal mines could fail in different ways. Thus, they created slope failure danger zonation maps using RS image processing techniques in and surrounding the Singrauli coalfield in India. In addition to using the RS and GIS in analyzing slope instability of mines, this approach also was utilized in waste disposal areas of mining. (López-Vinielles et al., 2021) proposed a method to analyze slope instability at a regional scale using InSAR satellites combined with 2D finite element (FE) models mining waste disposal areas.

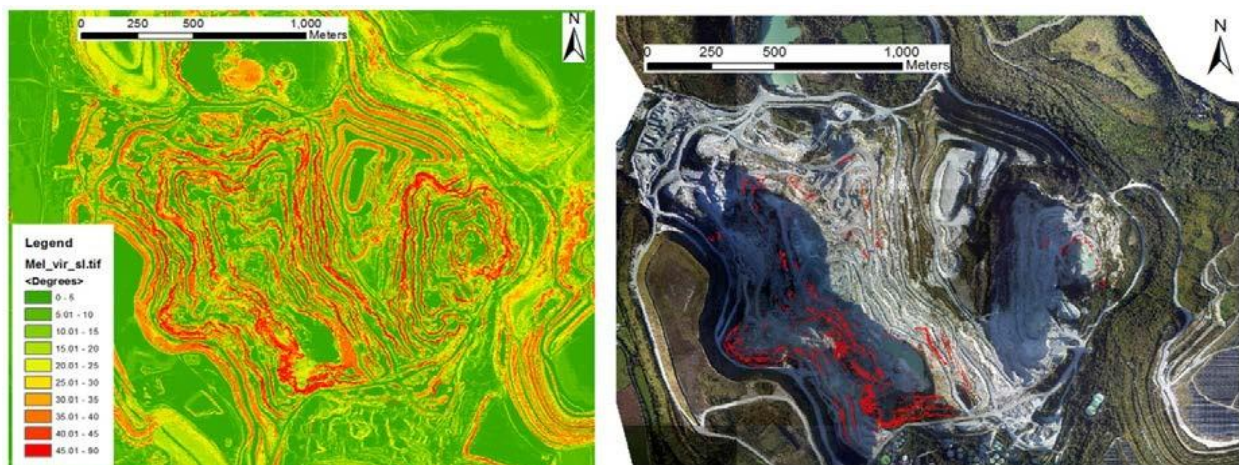


Figure 3. (a) Slope angle analysis in surface mine; (b) the identification of regions with a slope face angle greater than 45 and high grade alteration material (Vanneschi et al., 2017)

There are usually significant financial losses and fatalities in mining areas due to landslides caused by mining. Analyzing slope monitoring data is essential for determining the origin, extent, and time evolution of disasters as well as for estimating their possible dangers in the future. Thus, a study of the Songmugou Landslide was conducted using multisource RS methods. The findings suggest that it is possible to back-analyze and make reasonable predictions about the evolutionary mechanism of landslides using RS techniques (Liu, Mei, & Sun, 2022).

3.3 Monitoring of harmful gases

According to (Y. Li, Zhao, & Fan, 2015), with the use of multispectral techniques, ground RS equipment simultaneously monitors the mine site, the amount of dust present, and the source of air pollution. Furthermore, mining can cause harmful gases to the natural environment as well as affect human

health. Once the vegetation has been polluted, the infrared reflection's capacity may decrease. Even its texture, hue, and dynamic indications are utilized to be differentiated from the typical vegetation. By monitoring these changes, multispectral imaging instruments can map the distribution and extent of ground pollution and develop additional ground pollution control strategies (Raju & Patel, 2022). In addition, the influence of mining operations on the air quality is one of the highest effects. The study (Pashkevich, Danilov, & Matveeva, 2021) calculated the contaminants that the Korkino lignite mine in the Southern Urals emits using RS. In the study area, determining chemical envelopes of contamination in the lowest air layer with different pollutants has been made possible by the application of the suggested approach.

4. Results and discussion

Literatures indicated that RS is a highly effective tool for managing mine disasters including monitoring of deformation, slope stability, and harmful gases. The aforementioned analysis, however, shows that the usage of RM and GIS technology in monitoring mine disasters is still in its infancy, with current research mostly concentrating on slope stability assessment, followed by deformation detection, and harmful gas identification. Although there have not been many studies applying the proposed method to study the risks caused by mining, the results obtained also show that RS technology is a potential method in this field. With the use of RS technologies, dangerous situations including unstable slopes, subsidence, and earth movements can be monitored in real-time. This proves that in the future, it is necessary to further develop this approach to research mining risks in particular and work related to the mine industry in general. When compared to ground-based research and monitoring, the primary benefits of RS are its cost-effectiveness, high temporal frequency, and expanded coverage area. Figure 4 shows the number of studies using satellite remote sensing and GIS to monitor mine disasters.

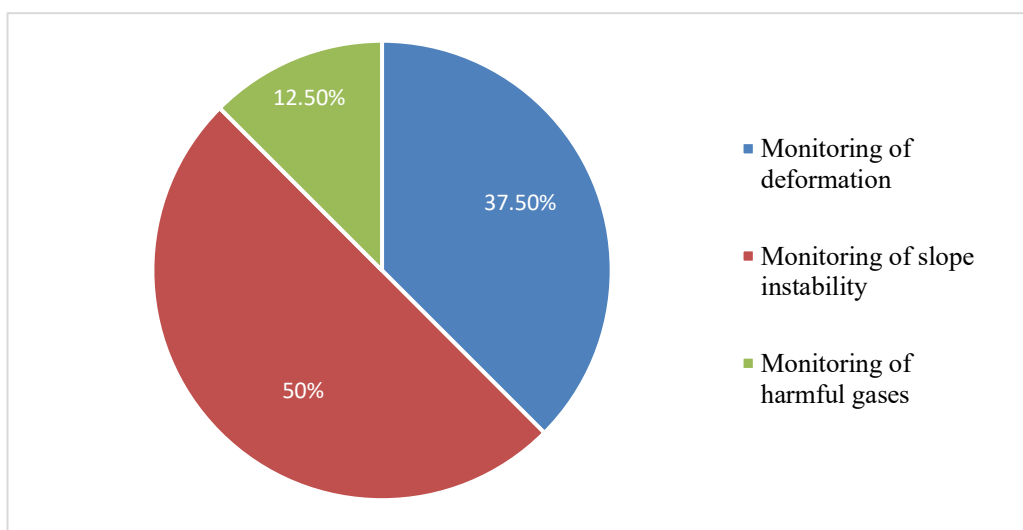


Fig. 4. Number of studies using satellite remote sensing and GIS to monitor mine disasters

However, for monitoring slope stability and landslide of mine areas, (Stead et al., 2019) suggested that in order to get vital geological and geotechnical data, such as intact rock strength, discontinuity infill properties, and joint conditions, traditional field methods are still necessary. Therefore, RS methods should be viewed as supplementary instruments that can significantly advance the understanding of the processes and mechanisms determining the stability of rock slopes and landslides rather than as a replacement for conventional geotechnical field methods. Furthermore, with no need for in situ labor, the RS and GIS technique can monitor surface subsidence on a broad scale and with millimeter-level accuracy over an extended period of time. Additionally, time series subsidence may be mapped to each surface facility using the integration of SBAS-InSAR monitoring and GIS methodologies, allowing for a more precise identification of possible damage areas based on each facility's permitted subsidence (Liu et al., 2022).

Satellite remote sensing and GIS provide valuable tools for wide-area monitoring of mining disasters, but they still face several important limitations. Optical imagery is often restricted by cloud cover, smoke, or seasonal conditions, while SAR/InSAR methods are affected by coherence loss in vegetated areas, layover and shadow in steep mine slopes, and atmospheric disturbances. Many satellite datasets also lack the spatial and temporal resolution needed to capture small-scale deformations or rapid changes, and the detection of harmful gases remains challenging without specialized hyperspectral or thermal sensors.

Moreover, satellite-based results require systematic ground validation and QA/QC to ensure reliability. Therefore, integrated approaches combining multi-source satellite data, UAV or LiDAR surveys, and field measurements are recommended to overcome these challenges.

In the future, integrating RS satellite technology and machine learning should be considered. This approach has the advantages of high precision, low cost, quick speed, and real-time monitoring of changes in the coal mine area over conventional monitoring techniques (He et al., 2019). On the other hand, (Jabłońska et al., 2024) demonstrated the potential applications of satellite data and machine learning algorithms in mining area monitoring. These effective methods can offer invaluable information into mining activities such as deformation detection, slope stability determination, harmful gas identification, etc. Additionally, in order to predict slope deformation in the mine area, first collect the necessary data from the open pit mine using ground-based interferometric radar (GB-SAR). Then, it was suggested to use an ensemble learner to mine the GB-SAR field data and produce a slope deformation prediction model by combining a number of weaker learners (Du et al., 2019).

5. Conclusion

This study discusses the use of RM and GIS for monitoring mine disasters utilizing publications from 2009 to May 2024. The review investigated 45 publications published in scholarly journals, book chapters, and M.Sc./Ph.D related to the use of RS and GIS to identify risks in mining regions. From there, a summary of the content of the research is presented as well as the advantages, disadvantages and future trends of the usage of RS technology in detecting mine hazards are also mentioned. The review has revealed that a combination of RS and GIS is an effective useful solution to perform operations related to monitoring deformation, determining slope stability, and detecting harmful gases in the mining areas. Besides, findings show that in some cases RM technology should not completely replace traditional methods but should only be used to supplement data in hard-to-reach or dangerous areas. In the future, the integration of RS, GIS technology, and machine learning promises to provide many benefits for identifying disasters in mining areas.

References

- Ammirati, L., Mondillo, N., Rodas, R. A., Sellers, C., & Di Martire, D. (2020). Monitoring land surface deformation associated with gold artisanal mining in the Zaruma City (Ecuador). *Remote Sensing*, 12(13), 2135.
- Biswal, S. S., Raval, S., & Gorai, A. K. J. I. j. o. r. s. (2019). Delineation and mapping of coal mine fire using remote sensing data—a review. 40(17), 6499-6529.
- Buczyńska, A. (2020). Remote sensing and GIS technologies in land reclamation and landscape planning processes on post-mining areas in the Polish and world literature. Paper presented at the AIP Conference Proceedings.
- Chen, W., Li, X., He, H., & Wang, L. (2017). A review of fine-scale land use and land cover classification in open-pit mining areas by remote sensing techniques. *Remote Sensing*, 10(1), 15.
- Choi, Y., Baek, J., & Park, S. J. A. S. (2020). Review of GIS-based applications for mining: Planning, operation, and environmental management. 10(7), 2266.
- Du, S., Feng, G., Wang, J., Feng, S., Malekian, R., & Li, Z. (2019). A new machine-learning prediction model for slope deformation of an open-pit mine: an evaluation of field data. *Energies*, 12(7), 1288.
- Düzgün, H. Ş., & Demirel, N. (2011). *Remote sensing of the mine environment*: CRC Press USA.
- Francioni, M., Salvini, R., Stead, D., & Coggan, J. (2018). Improvements in the integration of remote sensing and rock slope modelling. *Natural hazards*, 90, 975-1004.
- Francioni, M., Salvini, R., Stead, D., Giovannini, R., Riccucci, S., Vanneschi, C., & Gulli, D. (2015). An integrated remote sensing-GIS approach for the analysis of an open pit in the Carrara marble district, Italy: Slope stability assessment through kinematic and numerical methods. *Computers and Geotechnics*, 67, 46-63.
- Francioni, M., Salvini, R., Stead, D., & Litrico, S. (2014). A case study integrating remote sensing and distinct element analysis to quarry slope stability assessment in the Monte Altissimo area, Italy. *Engineering Geology*, 183, 290-302.
- Francioni, M., Stead, D., Sciarra, N., & Calamita, F. (2019). A new approach for defining Slope Mass Rating in heterogeneous sedimentary rocks using a combined remote sensing GIS approach.

- Bulletin of Engineering Geology and the Environment, 78, 4253-4274.
- He, D., Le, B. T., Xiao, D., Mao, Y., Shan, F., & Ha, T. T. L. (2019). Coal mine area monitoring method by machine learning and multispectral remote sensing images. *Infrared Physics & Technology*, 103, 103070.
- Hu, W., Wu, L., Zhang, W., Liu, B., & Xu, J. (2017). Ground deformation detection using China's ZY-3 stereo imagery in an opencast mining area. *ISPRS international journal of geo-information*, 6(11), 361.
- Huang, Q., Du, J., Chen, J., & He, Y. (2021). Coupling control on pillar stress concentration and surface cracks in shallow multi-seam mining. *International Journal of Mining Science and Technology*, 31(1), 95-101.
- Hutchinson, D. J., Lato, M., Gauthier, D., Kromer, R., Ondercin, M., van Veen, M., & Harrap, R. (2015). Applications of remote sensing techniques to managing rock slope instability risk. Paper presented at the Canadian Geotechnical Conference, Quebec City.
- Jabłońska, K., Maksymowicz, M., Tanajewski, D., Kaczan, W., Zięba, M., & Wilgucki, M. (2024). MineCam: Application of Combined Remote Sensing and Machine Learning for Segmentation and Change Detection of Mining Areas Enabling Multi-Purpose Monitoring. *Remote Sensing*, 16(6), 955.
- Li, J., Pei, Y., Zhao, S., Xiao, R., Sang, X., & Zhang, C. J. R. S. (2020). A review of remote sensing for environmental monitoring in China. 12(7), 1130.
- Li, Y., Zhao, H., & Fan, J. (2015). Application of remote sensing technology in mine environment monitoring. Paper presented at the MATEC Web of Conferences.
- Liu, Z., Mei, G., & Sun, Y. (2022). Investigating deformation patterns of a mining-induced landslide using multisource remote sensing: The songmugou landslide in Shanxi Province, China. *Bulletin of Engineering Geology and the Environment*, 81(5), 216.
- Liu, Z., Mei, G., Sun, Y., & Xu, N. (2021). Investigating mining-induced surface subsidence and potential damages based on SBAS-InSAR monitoring and GIS techniques: A case study. *Environmental Earth Sciences*, 80(24), 817.
- Loots, M., Grobelaar, S., & Van der Lingen, E. (2022). A review of remote-sensing unmanned aerial vehicles in the mining industry. *Journal of the Southern African Institute of Mining and Metallurgy*, 122(7), 387-396.
- López-Vinielles, J., Fernández-Merodo, J. A., Ezquerro, P., García-Davalillo, J. C., Sarro, R., Reyes-Carmona, C., . . . Alvioli, M. (2021). Combining satellite insar, slope units and finite element modeling for stability analysis in mining waste disposal areas. *Remote Sensing*, 13(10), 2008.
- McKenna, P. B., Lechner, A. M., Phinn, S., & Erskine, P. D. J. R. S. (2020). Remote sensing of mine site rehabilitation for ecological outcomes: A global systematic review. 12(21), 3535.
- Minh, D. T., & Dung, N. B. J. J. o. S. M. (2023). Applications of UAVs in mine industry: A scoping review. 22(2), 128-145.
- Nguyen, B. D. J. I. M. (2023). Identifying the Potential Application of Unmanned Aerial Vehicle Technology in Mine Waste Dumps. (2).
- Nguyen, L. Q., Dang, M. T., Bui, L. K., Ngoc, Q. B., & Tran, T. X. (2022). Application of Unmanned Aerial Vehicles for Surveying and Mapping in Mines: A Review. Paper presented at the International Conference on Geo-Spatial Technologies and Earth Resources.
- Omali, T. U. J. I. J. S. R. i. M. S. (2021). Utilization of remote sensing and GIS in geology and mining. 7(4).
- Owczarz, K. (2020). A review of geodetic and remote sensing methods used for detecting surface displacements caused by mining. Paper presented at the IOP Conference Series: Earth and Environmental Science.
- Park, S., & Choi, Y. J. M. (2020). Applications of unmanned aerial vehicles in mining from exploration to reclamation: A review. 10(8), 663.
- Pashkevich, M., Danilov, A., & Matveeva, V. (2021). Remote sensing of chemical anomalies in the atmosphere in influence zone of Korkino open pit coal mine. *Eurasian mining*, 1, 79-83.
- Peters, D. C., Livo, K. E., & Hauff, P. L. (1996). Remote sensing for analysis of mine subsidence and mine

- wastes. *Environmental Geosciences*, 3(1), 11-27.
- Raju, C. V., & Patel, M. V. K. (2022). Application of Remote Sensing In Mining. *Thematics Journal of Applied Sciences*, 11(5), 70-75.
- Ren, H., Zhao, Y., Xiao, W., Hu, Z. J. I. J. o. C. S., & Technology. (2019). A review of UAV monitoring in mining areas: Current status and future perspectives. 6, 320-333.
- Robiati, C., Eyre, M., Vanneschi, C., Francioni, M., Venn, A., & Coggan, J. (2019). Application of remote sensing data for evaluation of rockfall potential within a quarry slope. *ISPRS international journal of geo-information*, 8(9), 367.
- Sengupta, S., Krishna, A., & Roy, I. (2018). Slope failure susceptibility zonation using integrated remote sensing and GIS techniques: A case study over Jhingurdah open pit coal mine, Singrauli coalfield, India. *Journal of Earth System Science*, 127, 1-17.
- Sikakwe, G. U. J. R. S. A. S., & Environment. (2023). Mineral exploration employing drones, contemporary geological satellite remote sensing and geographical information system (GIS) procedures: A review. 100988.
- Song, W., Song, W., Gu, H., Li, F. J. I. J. o. E. R., & Health, P. (2020). Progress in the remote sensing monitoring of the ecological environment in mining areas. 17(6), 1846.
- Stead, D., Donati, D., Wolter, A., & Sturzenegger, M. (2019). Application of remote sensing to the investigation of rock slopes: Experience gained and lessons learned. *ISPRS international journal of geo-information*, 8(7), 296.
- Styles, T., Stead, D., Eberhardt, E., Rabus, B., Gaida, M., & Bloom, J. (2011). Integrated numerical modelling and insar monitoring of a slow moving slope instability at bingham canyon mine. *Proceedings of the Slope Stability*.
- Trofymchuk, O., Anpilova, Y., Yakovliev, Y., & Zinkiv, I. (2020). Ground deformation mapping of Solotvyno mine area using radar data and GIS. Paper presented at the Geoinformatics: Theoretical and Applied Aspects 2020.
- Vanneschi, C., Eyre, M., Francioni, M., & Coggan, J. (2017). The use of remote sensing techniques for monitoring and characterization of slope instability. Paper presented at the ISRM EUROCK.
- Werner, T., Bebbington, A., & Gregory, G. (2019). Assessing impacts of mining: Recent contributions from GIS and remote sensing. *The Extractive Industries and Society*, 6(3), 993-1012.
- Yuan, M., Li, M., Liu, H., Lv, P., Li, B., & Zheng, W. (2021). Subsidence monitoring base on SBAS-InSAR and slope stability analysis method for damage analysis in mountainous mining subsidence regions. *Remote Sensing*, 13(16), 3107.
- Yuan, W., Wang, Q., Fan, J., & Li, H. (2017). Mining land subsidence monitoring using Sentinel-1 SAR data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 655-658.
- Zhang, B., Wu, S., Ding, X., Wang, C., Zhu, J., & Li, Q. (2021). Use of multiplatform SAR imagery in mining deformation monitoring with dense vegetation coverage: A case study in the Fengfeng Mining Area, China. *Remote Sensing*, 13(16), 3091.

