



THE IMPORTANCE OF MONITORING SYSTEMS IN THE ASSESSMENT AND PREVENTION OF LANDSLIDES IN OPEN-PIT MINES AND WASTE DUMPS IN OLTENIA AND SIMILAR REGIONS

Alexandru-Marian EREMEI^{1*}, Maria LAZĂR²

¹ University of Petrosani, Petrosani, Romania, alexandru-marianeremei@upet.ro

² University of Petrosani, Petrosani, Romania, marialazar@upet.ro

DOI: 10.2478/minrv-2026-0039

received – 09.03.2026 / revised – 12.03.2026

accepted – 06.05.2026 / published – 22.09.2026

Abstract: *The paper entitled “The Importance of Monitoring Systems in the Assessment and Prevention of Landslides in Open-Pit Mines and Waste Dumps in Oltenia and Similar Regions” addresses the issue of slope stability in surface mining operations. The main objective of this study is to identify the risk factors underlying the occurrence of such events, as well as to highlight the need for the implementation of modern geotechnical monitoring systems.*

The paper presents the methods used to identify landslide-prone areas, based on field observations, geotechnical measurements and modern monitoring technologies. The main causes contributing to the occurrence of landslides are analyzed, including the geological structure of the terrain, hydrogeological characteristics, climatic variations, as well as the influence of anthropogenic activities, such as intensive mining operations and improper waste material deposition in dumps.

The paper includes relevant examples from the Oltenia region, where such events have affected the stability of open-pit mines and waste dumps, as well as a comparative study with similar regions from other countries, highlighting causes and solutions applied in different contexts. These examples contribute to a better understanding of how the risks associated with instability can be managed.

Furthermore, the paper presents monitoring systems used in practice, such as topographic, geotechnical and sensor-based monitoring, which allow the early detection of deformations and the implementation of preventive measures. Additional methods include satellite-based monitoring (InSAR technology), GPS/GNSS-based systems, continuous structural monitoring, the use of drones and aerial surveys for periodic inspections, as well as LiDAR (Light Detection and Ranging) technologies, which enable the generation of highly accurate 3D models of the terrain and monitored structures. The implementation of these systems significantly contributes to increasing personnel safety, protecting the environment, and reducing economic losses.

Finally, methods for the prevention and control of landslides are proposed, such as slope stabilization works, drainage systems and the efficient management of mining operations and material deposition. The paper highlights the importance of the use and implementation of modern technologies in ensuring safe and sustainable exploitation.

Keywords: *geotechnical monitoring, landslides, open-pit mines, waste dumps, slope stability, mining safety*

1. Introduction

The mining industry plays a fundamental role in supporting modern economies by providing essential mineral resources required for numerous industrial sectors. The availability of these raw materials directly influences industrial productivity, economic stability, and technological development. Consequently, maintaining the safety and operational efficiency of mining activities represents a major challenge for both researchers and industry specialists.

* Corresponding author: Alexandru-Marian Eremei, University of Petrosani, Petrosani, Romania, alexandru-marianeremei@upet.ro

Among the most significant issues encountered in surface mining operations is the stability of waste dumps and slopes, where deformation processes and landslides may seriously affect operational safety, equipment integrity, and environmental conditions. In this context, deformation monitoring and slope stability assessment have become essential components in the prevention of geotechnical failures and the optimization of mining activities.

The general aim of this study is to contribute to improving safety and efficiency in the mining industry by enhancing deformation monitoring and slope stability assessment processes in mining works. Through the identification and evaluation of factors influencing waste dump stability, the research seeks to support accident prevention, optimize mining operations, and reduce the risks and economic losses associated with ground instability phenomena.

Modern investigation techniques provide efficient tools for the analysis and monitoring of mining structures. Technologies such as remote sensing, terrestrial LiDAR, laser scanning, radar interferometry, deformation sensors, geotechnical modeling, and numerical simulations allow a more accurate evaluation of slope behavior and instability mechanisms [1], [2], [3], [4]. The integration of these technologies contributes to improved risk assessment and supports the implementation of preventive stabilization measures.

This study focuses on the internal and external waste dumps located in the Rovinari mining area, Gorj County, Romania, formed as a result of lignite exploitation within the Oltenia Energy Complex. These waste dumps are characterized by large-scale geometries, heterogeneous internal structures, and non-uniform material compaction generated by successive deposition processes.

The novelty of this research consists in the integrated evaluation of slope stability under different loading and hydrological conditions specific to the Rovinari mining perimeter. The study combines geotechnical, hydrogeological, and geometrical analyses in order to identify areas with increased landslide susceptibility and to evaluate the influence of saturation and external loading conditions on the stability of the waste dumps.

Several instability mechanisms specific to mining waste dumps are investigated within this paper, including:

- circular landslides, predominantly occurring in clayey materials and clayey-sandy materials under saturated conditions [1];
- planar landslides developing along interfaces between waste materials and foundation soils or between layers with different geotechnical characteristics [1];
- earth flows associated with fine-grained saturated materials and moderate slope inclinations [5];
- reactivation of previous landslides caused by geometric modifications, overload conditions, or hydrological variations [6].

The stability analysis was performed for multiple loading scenarios relevant to the local mining conditions:

- static conditions corresponding to the normal operational state of the waste dumps;
- post-rainfall conditions characterized by increased saturation and elevated pore water pressures;
- pseudo-static conditions considering the influence of mining-induced vibrations and low-intensity regional seismic actions [1], [5].

The obtained results contribute to a better understanding of instability processes affecting mining waste dumps and provide useful information for the assessment and management of geotechnical risks in the Rovinari mining basin

2. Monitoring solutions for deformations in mining works

Currently, the most effective methods used for monitoring the stability of mining waste dumps are based on modern measurement and analysis technologies capable of providing accurate information regarding ground displacements and deformation processes. These monitoring systems allow the early detection of instability phenomena and support the implementation of preventive measures aimed at reducing geotechnical risks.

Among the most widely used techniques are topographic and geotechnical monitoring, GPS/GNSS measurements, remote sensing technologies, InSAR analysis, LiDAR surveys, drone-based investigations, and continuous structural monitoring systems [1], [2], [3], [4]. The integration of these technologies improves the accuracy of deformation assessment and contributes to a better understanding of slope behavior under different loading and environmental conditions.

2.1. Remote sensing monitoring

Remote sensing monitoring represents an efficient investigation method for the analysis of topographic changes and ground deformations in mining areas. The method is based on the acquisition and processing of satellite or aerial images in order to identify surface displacements, instability zones, and deformation trends over time.

Remote sensing techniques operate by recording electromagnetic radiation reflected or emitted by objects located on the Earth's surface without direct physical contact [7], [2]. Depending on the data acquisition method, remote sensing systems may be classified as passive or active systems.

In mining applications, remote sensing provides valuable information regarding terrain evolution, slope deformation, subsidence processes, and the development of landslide-prone areas. The obtained datasets can be processed using digital image analysis and geospatial algorithms, allowing the generation of topographic models, displacement maps, and risk assessment studies [7], [2].

Due to its capability to cover large areas with high efficiency and accuracy, remote sensing has become an important tool for deformation monitoring and stability assessment in open-pit mining environments.

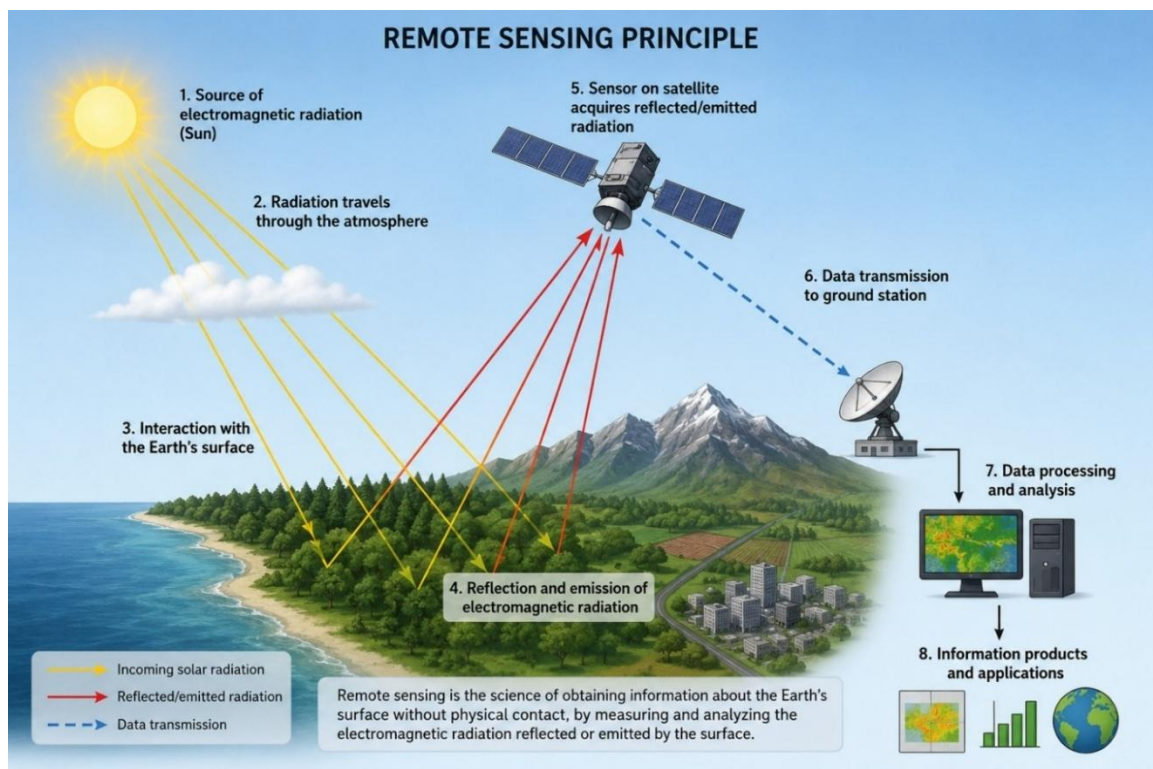


Fig. 1. Conceptual diagram illustrating the remote sensing principle, highlighting the acquisition of electromagnetic radiation reflected from the Earth's surface without physical contact

Photogrammetry is a remote sensing technique used for the generation of topographic and thematic maps based on precise measurements extracted from aerial or satellite images [7], [2]. The method allows the accurate determination of the geometry, dimensions, and spatial position of surface objects through digital image processing techniques.

Currently, digital photogrammetry represents one of the most widely used methods for the production of topographic and cadastral maps, providing high-resolution spatial data required for terrain modeling and deformation analysis. In mining applications, photogrammetric techniques are extensively used for monitoring slope displacements, evaluating geomorphological changes, and generating three-dimensional terrain models necessary for stability assessment studies [7], [2].

The evolution from early photogrammetric techniques to modern drone-based systems has led to significant improvements in the acquisition and processing of spatial data. These advances are mainly related to the transition from analogue aerial photography to digital image acquisition and automated data processing workflows.

Early photogrammetric surveys were performed using film-based cameras mounted on aircraft or balloons, which were characterized by limited resolution, high operational costs, and time-consuming data processing procedures. Image distortions introduced during acquisition and development also affected the overall accuracy of the results.

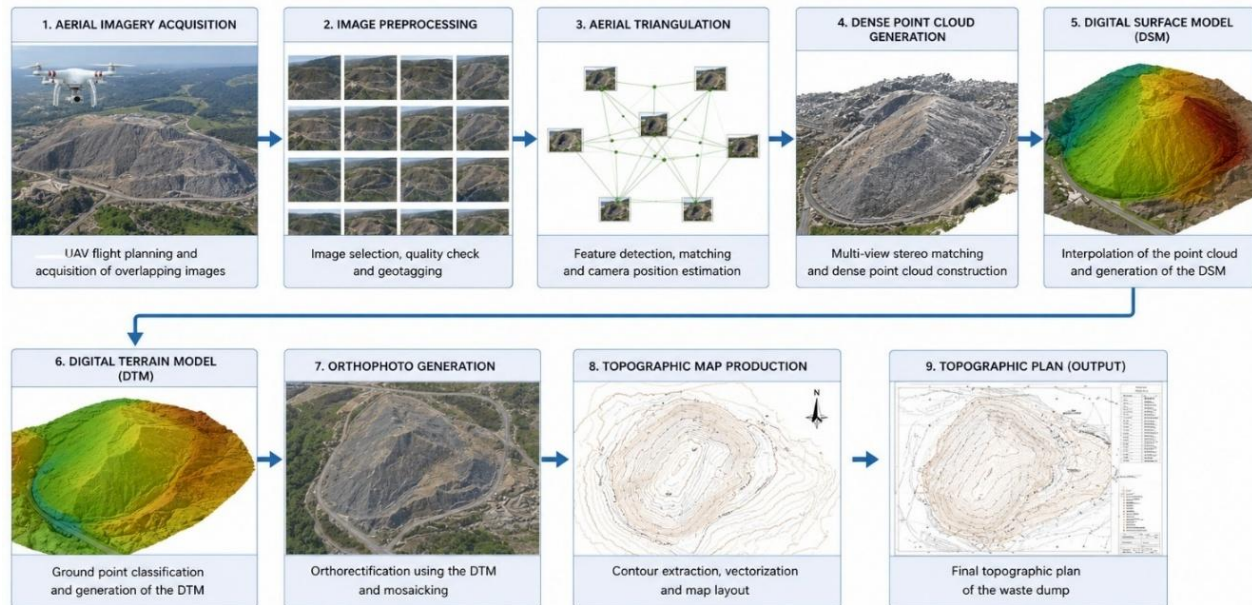


Fig. 2. Digital photogrammetry workflow for generating a topographic plan of an open-pit mine based on aerial imagery acquisition and processing

In contrast, unmanned aerial vehicles (UAVs) equipped with high-resolution digital cameras and sensors enable rapid, flexible, and cost-effective data acquisition. UAV systems allow the capture of high-resolution, georeferenced images with improved geometric accuracy and reduced operational constraints, particularly in inaccessible or hazardous areas.

Furthermore, digital photogrammetry significantly improves data processing efficiency through the use of automated image processing algorithms and specialized software for three-dimensional reconstruction and terrain modeling. This reduces manual intervention and increases the reliability and repeatability of spatial analyses [7], [2], [3].

Overall, UAV - based photogrammetry represents a major technological advancement over traditional aerial photogrammetry, offering enhanced spatial resolution, operational flexibility, and improved data processing capabilities. These characteristics have expanded its applications in cartography, topographic surveying, urban planning, architecture, and mining engineering.

In modern practice, UAV-derived orthophotos are widely used as primary spatial datasets, meeting strict accuracy requirements for topographic and engineering applications [2], [3].

Table 1. Geometric accuracy criteria – minimum requirements
Source: [\(Link to the source \(maratopcad.ro\)\)](#)

Orthophoto scale	Pixel size on orthophoto (m)	Accuracy MDT (M)	Orthophoto accuracy (m)
1:5000	± 0.50	± 1.00	± 1.50

MDT (Digital Terrain Model) data derived from photogrammetric processing provide detailed information regarding terrain morphology and surface geometry, with planimetric accuracies generally lower than 1.5 pixels [8].

Remote sensing monitoring represents an efficient and non-invasive method for collecting spatial information using sensors mounted on satellites, aircraft, helicopters, or unmanned aerial vehicles (UAVs). In mining engineering, these technologies are widely applied for monitoring terrain deformation, slope stability, and the evolution of mining infrastructure [7], [2], [3].

One of the main advantages of remote sensing techniques is their capability to provide continuous and large-scale observations of mining areas. Satellite and aerial imagery can be used to analyze topographic modifications, identify instability zones, and monitor the progression of excavation and waste dump activities over time [7], [2].

Remote sensing methods also allow the detection of terrain changes associated with landslides, subsidence phenomena, and mass movements. Multi-temporal image analysis enables the identification of deformation patterns and supports the assessment of geotechnical risks affecting mining slopes and waste dumps [7], [2], [3].

In addition to deformation monitoring, remote sensing technologies are frequently used for environmental impact assessment, including vegetation monitoring and water quality evaluation in mining areas. Satellite imagery can provide relevant information regarding land degradation, deforestation processes, and the spatial distribution of polluted water bodies [7], [2].

Furthermore, remote sensing datasets support land-use planning and sustainable management strategies by facilitating the analysis of terrain evolution and natural resource distribution. Due to their high efficiency, accessibility, and spatial coverage, remote sensing techniques have become essential tools for monitoring and risk assessment in modern surface mining operations [7], [2], [3].

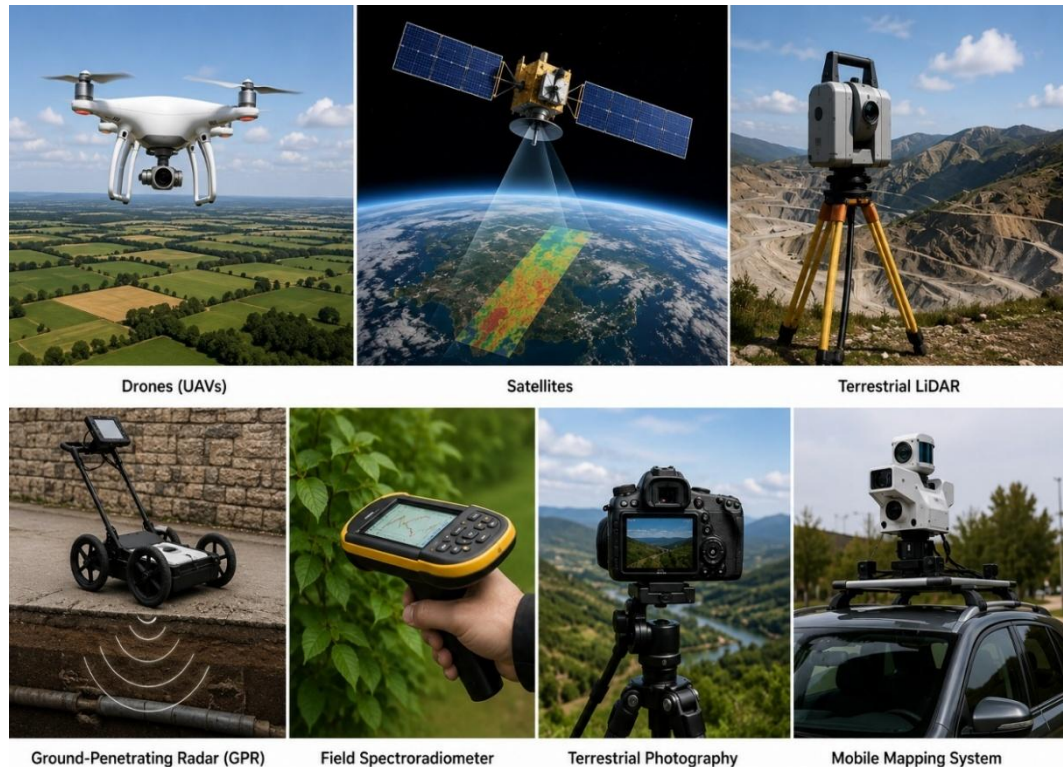


Fig. 3. Main remote sensing platforms for data acquisition: terrestrial, UAV, and satellite systems.

2.2. Terrestrial LiDAR and laser scanning

Terrestrial LiDAR and laser scanning technologies enable the acquisition of high-precision spatial data describing the geometry and structure of terrain surfaces in mining areas. These methods are widely used for generating detailed three-dimensional models of the ground and mining infrastructure, as well as for detecting surface deformations and morphological changes over time.

These technologies are based on the emission of laser pulses toward the target surface and the measurement of the reflected signals in order to determine accurate distances between the sensor and the scanned objects [3], [9]. The resulting point clouds provide high-resolution spatial information that can be processed to reconstruct digital elevation models and analyze terrain stability.

Terrestrial LiDAR

Terrestrial LiDAR is a ground-based laser scanning technique used for the precise measurement of distances between the sensor and object surfaces. The method generates dense point cloud datasets that allow the construction of highly detailed three-dimensional representations of terrain and mining structures, with sub-centimeter accuracy. In mining applications, terrestrial LiDAR is commonly applied for monitoring slope deformation, detecting ground movements, and evaluating the stability of mining infrastructure [3], [9].

Laser scanning

Laser scanning is a remote sensing technique based on the emission of laser beams to acquire precise spatial information about terrain surfaces and surrounding objects. The reflected signals are processed to generate high-resolution three-dimensional models of the scanned area.

In mining applications, laser scanning is commonly used for volumetric calculations of excavated materials, monitoring morphological changes in mining infrastructure, and identifying potential instability zones or geotechnical risks [3], [9].

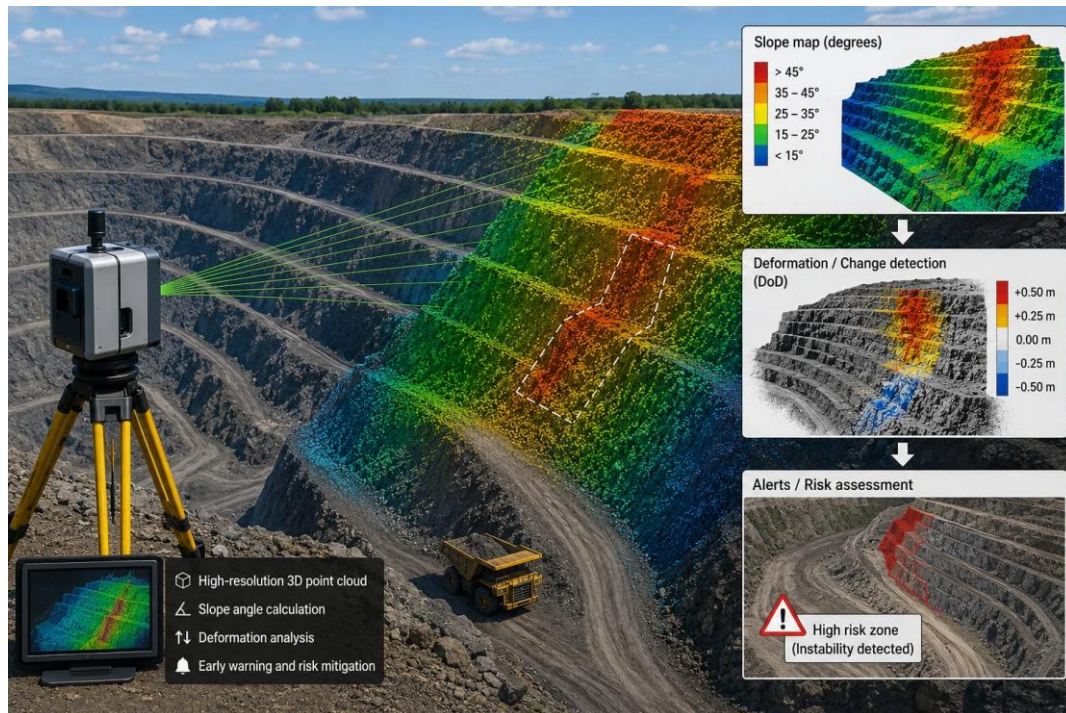


Fig. 4. LiDAR-based slope monitoring in surface mining areas Source:
Link to the source (ugr.ro)

Polaris Terrestrial Laser Scanner (TLS) Series

Polaris TLS delivers high-accuracy, high-density 3D point cloud data for a wide range of surveying and industrial applications.

- High Accuracy**
Up to 2 mm range accuracy
- Long Range**
Up to 500 m measurement range
- High Speed Scanning**
Up to 2,000,000 pts/s
- Robust & Reliable**
IP54 dust and water resistant
- Lightweight & Portable**
Compact design for easy transportation
- Versatile Data Output**
Multiple formats supported e.g., LAS, E57, PLY, PTX

Key Specifications	
Range	Up to 500 m
Accuracy	Up to 2 mm
Point Rate	Up to 2,000,000 pts/s
Laser Class	Class 1 (Eye Safe)
Field of View	360° (H) / 300° (V)
Weight	~7.0 kg (with battery)
Operating Temp.	-20°C to +50°C
Storage	512 GB SSD (replaceable)
Battery Life	Up to 4.5 hours
Protection	IP54

High-density 3D point cloud

Integrated camera for colorization

Surface mining monitoring

Plant & industrial inspection

Infrastructure surveying

Tunnel & underground mapping

Fig. 5. Polaris Terrestrial Laser Scanner (TLS) Series

Both terrestrial LiDAR and laser scanning technologies are highly effective tools for monitoring mining operations, providing high-resolution spatial data that support the assessment and management of geotechnical risks. These methods enable continuous observation of terrain deformation and changes in mining infrastructure, contributing to improved safety and operational efficiency in mining environments [3], [9].

2.3. Deformation sensors and accelerometers

Deformation sensors and accelerometers are widely used instruments for monitoring mining infrastructure and surrounding terrain. These devices measure structural displacements, vibrations, and strain variations, providing continuous or real-time data on the mechanical response of mining structures.

The collected measurements are essential for evaluating stability conditions and identifying early signs of potential failure. In mining applications, the integration of these sensors within monitoring systems enables rapid detection of critical changes and supports timely decision-making for risk mitigation strategies [4].

Deformation sensors

Deformation sensors are used to measure changes in the dimensions and geometric configuration of structures or terrain elements. These instruments can be installed on mining infrastructure or within the surrounding ground to detect even minor variations in shape or displacement. Depending on the application, different measurement principles may be used, including fiber optic systems or electrical resistance-based sensors [4].

Accelerometers

Accelerometers are devices designed to measure acceleration in one or more spatial directions. In mining applications, they are used to detect dynamic movements of terrain and infrastructure that may indicate instability conditions. By recording acceleration components in three axes, these instruments provide valuable information regarding movement intensity and direction [4].

2.4. Radar interferometry

Radar interferometry (InSAR) is an advanced remote sensing technique that uses satellite or airborne-based microwave radar to detect and measure ground deformations with high precision. The method is based on the interference between multiple radar images acquired over the same area, enabling the identification of subtle changes in elevation and surface displacement [3], [4].

In mining environments, InSAR is widely applied for the detection and monitoring of ground deformation phenomena such as landslides, slope instability, and subsidence. It also provides valuable information regarding the stability of mining infrastructure, including waste dumps and retaining structures, by identifying long-term displacement trends.

Due to its ability to cover large areas with high temporal and spatial resolution, InSAR represents an important tool for continuous deformation monitoring and risk assessment in surface and underground mining operations [3], [4].

2.5. Geotechnical modeling and numerical simulation

Geotechnical modeling and numerical simulation represent essential tools for evaluating the stability and mechanical behavior of terrain and mining infrastructure under various loading and environmental conditions. These techniques enable the analysis of stress distribution, deformation processes, and failure mechanisms affecting mining slopes, waste dumps, retaining structures, and underground workings [1], [5], [4].

Using specialized software, detailed two-dimensional and three-dimensional geotechnical models can be developed to reproduce the geometry and geomechanical characteristics of mining environments. Such models facilitate the investigation of terrain response under static, hydrological, and pseudo-static loading conditions, contributing to a better understanding of instability mechanisms and slope behavior [1], [5].

Numerical simulations are widely applied for the assessment of slope stability, identification of critical failure surfaces, and evaluation of landslide susceptibility in mining areas. These analyses also support the investigation of stress concentration zones and potential deformation patterns that may affect the safety of mining infrastructure.

In addition, geotechnical modeling plays an important role in the design and optimization of mining operations by supporting the selection of appropriate excavation geometries, waste dump configurations, and stabilization measures. The obtained results contribute to risk assessment and facilitate the development of efficient strategies for the prevention and management of geotechnical hazards [1], [5], [4].

3. Case study – stability analysis of a waste dump from the Pinoasa mining operation

3.1. Site description

The analyzed case study refers to the waste dumps associated with the Pinoasa open-pit mining operation, located within the Motru–Rovinari coal basin in southwestern Romania, an important lignite exploitation area characterized by extensive surface mining activities [10], [4].

The Pinoasa mining perimeter includes two main waste disposal areas: the internal dump located within the mining site and the external Valea Negomir waste dump. The present study focuses primarily on the external dump, which is currently under conservation conditions following the cessation of waste deposition activities in February 2018.

The waste dump was formed through successive deposition of overburden materials resulting from lignite excavation processes. The deposited material consists predominantly of clays, sandy clays, and silty soils characterized by heterogeneous stratification, low compaction levels, and variable geotechnical properties specific to anthropogenic deposits generated by staged dumping operations [1], [4].

The Valea Negomir external dump is situated approximately 2 km from the Barhoti area, with an average transport distance of approximately 5 km from the Barhoti distribution node. Due to limitations related to land availability and imposed operational constraints, the final geometric configuration of the dump differs from the initially designed layout.

To ensure long-term stability under conservation conditions, drainage channels were constructed at the base of the dump in order to control surface runoff and reduce water infiltration toward nearby inhabited areas. In addition, a system of topographic monitoring benchmarks was installed for continuous stability surveillance of the dump body.

The hydrogeological conditions of the area are strongly influenced by seasonal precipitation and relatively high groundwater levels. These factors may lead to increased material saturation, elevated pore water pressures, and reductions in effective shear strength, significantly influencing slope stability conditions [10], [5].

3.2. Topographic monitoring

The stability monitoring program implemented for the Valea Negomir waste dump included the installation of fixed topographic benchmarks in areas considered potentially vulnerable to deformation processes. Periodic topographic measurements were performed in order to identify horizontal and vertical displacements of the dump body and to assess the evolution of possible instability phenomena over time [2], [8], [4].

The monitoring data were used to evaluate deformation trends and to support the geotechnical interpretation of slope behavior under different environmental and hydrological conditions.

Table 2. Coordinates of the benchmarks for monitoring the stability of the Valea Negomir waste dump, based on topographic measurements for the year 2025

Semester	Point number	Coordinates		Elevation
		X	Y	Z
I	1	373177,849	354665,381	229,510
	2	373137,880	354670,910	228,315
	3	373118,671	354676,749	228,554
	4	373058,742	354650,541	227,619
	5	373003,225	354632,763	226,972
	6	372974,025	354605,781	226,274
	7	373087,500	354671,085	227,899
II	1	373177,849	354665,381	229,510
	2	373137,880	354670,910	228,315
	3	373118,671	354676,749	228,554
	4	373058,743	354650,540	227,617
	5	373003,225	354632,763	226,972
	6	372974,026	354605,780	226,273
	7	373087,500	354671,085	227,899

The comparative analysis of the benchmark coordinates measured during the first and second semesters of 2025 indicates only minor variations within the admissible topographic measurement tolerance limits. The recorded differences are geotechnically insignificant and do not suggest the occurrence of displacement or deformation phenomena affecting the waste dump body.

The monitoring results confirm the overall stability of the Valea Negomir waste dump during the analyzed period and demonstrate the effectiveness of the implemented topographic monitoring system for the continuous assessment of slope behavior and potential instability processes.

3.3. Geometry of the dump and analyzed slope

The analyzed dumps are the external waste dump at Valea Negomir [10], [4].

Table 3. Geometric characteristics of the Valea Negomir external waste dump

Parameter	Value
Dump height	125 m
Overall slope angle	4°
Bench height	12–33 m
Deposited volume (up to February 2018)	329.9 million m ³
Occupied area	462 ha
Distance to nearest object within influence zone	200 m

The analyzed case study refers to the external waste dump located at Valea Negomir, associated with lignite mining activities in the Motru–Rovinari Basin [10], [4].

The main geometric characteristics of the dump are summarized in Table 3. The dump occupies an area of approximately 462 ha, while the stability assessment was performed on a representative cross-section considered critical from both morphological and geotechnical perspectives. The analyzed geometry is characteristic of large external waste dumps developed in lignite open-pit mining operations within the Motru–Rovinari mining basin [10], [4].

The analyzed slope has the following geometric characteristics:

- dump height: $H=125\text{m}$;
- overall slope angle: $\beta=4^\circ$
- slope configuration formed through successive deposition stages with local reprofiling operations.

This geometry is representative of waste dumps associated with the Pinoasa mining operation and corresponds to the upper range of heights commonly encountered in unconsolidated fine-grained materials. Under such conditions, slope stability is strongly controlled by the geotechnical parameters of the deposited material and by the hydrological regime within the dump body [10],[5].

The adopted slope angle of 4° falls within the range typically used for external dumps predominantly composed of clayey and silty materials. Under normal moisture conditions, this geometry generally provides an acceptable stability condition. However, under saturated conditions, pore-water pressure increases may significantly reduce shear strength and consequently decrease the factor of safety below the recommended operational limits [1], [5].

Slope geometry represents a key component of the stability analysis because both slope height and inclination directly control the balance between resisting and driving forces. These parameters are fundamental inputs in limit equilibrium methods (LEM) used for calculating the factor of safety [1], [5].

3.4. Adopted geotechnical parameters

The geotechnical parameters used in the stability analysis were selected based on field investigations and laboratory data available for the waste material deposited in the Pinoasa mining operation, together with representative values reported in previous studies for waste dumps in the Motru–Rovinari Basin [10], [1], [4].

The deposited material consists predominantly of clays, sandy clays, and silty formations with variable moisture content and heterogeneous compaction conditions.

To evaluate the influence of hydrological conditions on slope stability, two distinct scenarios were considered in the analysis:

- dry or normal moisture conditions;
- saturated conditions associated with increased groundwater levels and reduced drainage capacity.

The comparison between these scenarios allowed the assessment of the variation in the factor of safety as a function of water saturation conditions.

In order to characterize the hydrological regime within the dump body, piezometric measurements recorded in boreholes FH01, FH02, and FH03 were analyzed. The recorded data indicated variations in groundwater levels and drainage discharge, highlighting alternating periods of normal hydrological conditions and episodes characterized by increased saturation potential within the waste mass [5], [4].

These variations suggest fluctuations in pore-water pressure within the dump body, which directly influence the effective stress state and consequently the shear strength of the material.

Based on these observations, two calculation scenarios were defined and implemented in the SLOPE/LEM stability model in order to evaluate the influence of hydrological conditions on slope stability.

Scenario 1 – Dry Conditions

The first scenario corresponds to normal or moderately moist conditions within the dump material, characterized by relatively low pore-water pressures.

The adopted geotechnical parameters were:

cohesion: $c=10\text{kPa}$;

internal friction angle: $\varphi=22^\circ$;

unit weight: $\gamma=18\text{kN/m}^3$.

These values are representative of sandy clays and loosely compacted fine-grained materials under natural moisture conditions, where shear strength is governed by both cohesion and internal friction [1], [4].

Table 4. Hydro-observation borehole parameters – Valea Negomir external dump

TRIM./Year	PARAM.	FH01	FH02	FH03
III-2024	Ns	43,70m	59,50m	41,50m
	Nd	98,60m	96,10m	72,00m
	Q	0,33l/s	0,22l/s	0,25l/s
IV-2024	Ns	43,00m	65,00m	41,10m
	Nd	98,30m	90,00m	70,00m
	Q	0,18l/s	0,21l/s	0,22l/s
I-2025	Ns	44,10m	65,00m	45,50m
	Nd	98,00m	90,00m	72,30m
	Q	0,18l/s	0,20l/s	0,22l/s
II-2025	Ns	43,50m	64,40m	40,60m
	Nd	98,10m	89,80m	70,00m
	Q	0,53l/s	0,20l/s	0,22l/s
III-2025	Ns	45,70m	65,20m	37,00m
	Nd	101,00m	90,10m	73,40m
	Q	0,70l/s	0,20l/s	0,25l/s
IV-2025	Ns	40,80m	64,80m	36,80m
	Nd	62,80m	88,30m	72,90m
	Q	0,20l/s	0,20l/s	0,26l/s

Note: Ns – static groundwater level; Nd – dynamic groundwater level; Q – drainage discharge rate.

Scenario 2 – Saturated Conditions

The second scenario simulates unfavorable hydrological conditions occurring after intense rainfall events, when the waste material reaches a high degree of saturation.

The adopted parameters were:

cohesion: $c=6\text{kPa}$;

internal friction angle: $\varphi=18^\circ$;

saturated unit weight: $\gamma_{\text{sat}}=20\text{kN/m}^3$.

Under saturated conditions, the increase in pore-water pressure reduces effective stress, according to Terzaghi's principle, leading to a decrease in shear strength. At the same time, the increase in unit weight amplifies the driving forces acting on the slope, resulting in lower stability conditions.

The comparison between the two scenarios highlights the strong sensitivity of the waste dump to hydrological variations and provides the input data required for the SLOPE/LEM stability analysis [10], [5], [4].

The presented data highlight variations in groundwater levels (Ns, Nd) and discharge rates (Q), indicating the existence of periods with high humidity and episodes of significant infiltration. These variations lead to an increase in pore water pressures within the dump mass, negatively influencing the shear strength of the material [5], [4].

3.5. Conclusions of the case study

Stability analyses were performed using the geotechnical software SLOPE/W, based on limit equilibrium methods (LEM). Within this framework, slope stability is quantified using the factor of safety (FS), defined as the ratio between resisting and driving forces acting along the potential failure surface:

$$FS = \frac{\sum T}{\sum R} \quad (1)$$

where:

R = resisting forces;

T = driving (destabilizing) forces.

The shear strength of the waste material was evaluated using the Mohr–Coulomb failure criterion:

$$\tau=c+\sigma'\tan\varphi \quad (2)$$

where:

τ = shear strength;

c = cohesion;

σ' = effective normal stress;

φ = internal friction angle.

The influence of hydrological conditions was incorporated through Terzaghi's effective stress principle:

$$\sigma' = \sigma - u \quad (3)$$

where:

σ = total stress;

u = pore-water pressure;

σ' = effective stress.

Under saturated conditions, the increase in pore-water pressure leads to a reduction in effective stress, which directly decreases shear strength and slope stability.

The analyses highlight that stability is strongly influenced by the hydrological regime of the material and by variations in geotechnical parameters [1], [4].

The obtained results indicate the following:

- in dry conditions, the calculated factor of safety was approximately $FS \approx 1.50$, which satisfies stability requirements and indicates a stable slope condition;

- in saturated conditions, the factor of safety decreased to approximately $FS \approx 1.15$, which is below the commonly accepted threshold value $FS = 1.30$, indicating a potentially unstable condition.

These results confirm the high sensitivity of external waste dumps in the Valea Negomir mining area to variations in groundwater conditions and pore-water pressure, in accordance with fundamental principles of soil mechanics applied to unconsolidated materials [1], [4].

Based on the performed analysis, the following geotechnical measures are required:

- systematic stability analyses under unfavourable hydrological scenarios, including intense rainfall events and increased saturation levels;

- implementation and maintenance of efficient drainage systems to reduce water accumulation within the dump body;

- continuous monitoring of critical zones through topographic surveys, piezometric measurements, and deformation observations [2], [8], [4].

Overall, the case study demonstrates that instability may occur even in slopes of moderate geometry when high saturation conditions develop within the waste mass. This emphasizes the need for rigorous geotechnical management, continuous hydrogeological monitoring, and periodic LEM-based stability assessments to ensure long-term operational safety [10], [5], [4].

4. Conclusions

The present case study emphasized the importance of integrating modern geotechnical monitoring techniques with numerical stability analysis for the assessment and prevention of landslide phenomena in mining areas.

The combined use of topographic measurements, geotechnical investigations, piezometric monitoring, and remote sensing techniques enabled the identification of slope deformations and provided a reliable basis for evaluating the stability conditions of large external waste dumps [2], [3], [4].

The stability assessment performed using the limit equilibrium method (LEM) within the SLOPE/W framework demonstrated that slope stability is strongly controlled by hydrological conditions and pore-water pressure variations. The results indicate a significant reduction in the factor of safety from approximately $FS \approx 1.50$ under dry conditions to $FS \approx 1.15$ under saturated conditions, confirming the high sensitivity of fine-grained waste materials to water infiltration.

These findings highlight that even slopes with moderate geometric characteristics may become unstable when subjected to increased saturation, emphasizing the critical role of effective stress reduction in controlling failure mechanisms.

Efficient drainage systems and the preservation of the designed slope geometry represent key engineering measures for mitigating instability risks. In addition, continuous monitoring using GPS/GNSS measurements, piezometric data acquisition, and geotechnical observations allows the early detection of potentially unstable zones and supports timely implementation of preventive actions [10], [1], [4].

The study further confirms that periodic geotechnical stability analyses are essential, particularly during periods characterized by intense precipitation and freeze–thaw cycles, which can significantly alter the mechanical behavior of unconsolidated materials and accelerate slope degradation processes [1], [5], [4].

Overall, the results demonstrate that the combined application of field monitoring and SLOPE/LEM stability modelling provides an effective framework for understanding and managing the geotechnical behavior of external mining waste dumps, ensuring long-term operational safety and reducing geotechnical risk.

References

- [1] **Duncan J.M., Wright S.G.**, 2005
Soil Strength and Slope Stability, John Wiley & Sons, Hoboken, NJ, USA, ISBN 978-0471691631.
- [2] **Rădulescu G.M.T., Rădulescu V.M.**, 2020
Remote Sensing, Part I: Fundamentals, University of Bucharest course materials, Bucharest, Romania
- [3] **Telegă D., Poncoş V.**, 2010
Radar interferometry (InSAR) and ground deformation monitoring, Technical report, Romania.
- [4] **Murgoci G.**, 1907
Tertiary Deposits of Oltenia with Reference to Salt, Petroleum and Mineral Waters, Carol Göbl Publishing House, Bucharest, Romania
- [5] **Iverson R.M.**, 2000
Landslide triggering by rainfall infiltration, Water Resources Research, 36(7), 1897–1910,
<https://doi.org/10.1029/2000WR900090>
- [6] **Bonn F., Rochon G.**, 1992
Précis de télédétection, Vol. 1: Principles and Methods, Presses de l'Université du Québec, Québec, Canada, ISBN 978-2760506741.
- [7] **Mihai B.A.**, 2008
Remote Sensing – General Concepts, University of Bucharest Publishing House, Bucharest, Romania
- [8] **Ortelecan M., Pop N.**, 2005
Topographic Methods for Monitoring the Behaviour of Structures and Surrounding Ground, AcademicPress Publishing House, Cluj-Napoca, Romania
- [9] **Brebu F.M., Marin M., Bala A.C.**, 2010
Monitoring of the Building Energy in Connection with the Requirements of the Sustainable Urban Development and of the Environmental Protection, Journal of Environmental Protection and Ecology, International Workshop Global and Regional Environmental Protection, Timișoara, ISSN 1311-5065, Vol. 2, pp. 266–270
- [10] **Faur F., Apostu I.-M. Lazar M.**, 2024
Reassessment of the Stability Conditions in the Lignite Open Pits of Oltenia (Romania) in Relation to the New Local Seismic Context as an Imperative for Sustainable Mining, Sustainability, 16(4), 1384,
<https://doi.org/10.3390/su16041384>



This article is an open access article distributed under the Creative Commons BY SA 4.0 license. Authors retain all copyrights and agree to the terms of the above-mentioned CC BY SA 4.0 license.