

Main Accident Factors in Underground Mining Operations and Measures for Their Mitigation in Uzbekistan

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Abstract

Underground mineral extraction in Uzbekistan plays a strategic role in the national economy yet entails substantial geotechnical, hydrogeological, and organizational risks. This article identifies the principal accident factors in underground mining and proposes a hierarchy of countermeasures adapted to the mining-geological and regulatory conditions of Uzbekistan. The study integrates a narrative review of international and national literature, an analysis of the existing industrial safety framework, and a qualitative ranking of six hazard groups. The findings indicate that the most critical factors are rock mass and excavation instability, inadequate ventilation and atmospheric control, gas and dust accumulation, mine water inflow, seismicity and blast-induced loading, machinery failures in potentially explosive environments, and human and organizational deficiencies. These hazards are compounded by the seismically active setting of central and southern Uzbekistan and by the formal classification of underground operations as hazardous production facilities. Recommended countermeasures include geomechanical monitoring, adaptive support design, continuous gas and dust sensing, hydrogeological forecasting, digital personnel-tracking and sensor networks, enhanced competency-based training, and mine-rescue readiness. The article argues that durable accident reduction requires integrated, barrier-based risk management rather than compliance with isolated technical requirements. The proposed framework is intended to support industrial safety audits and the preparation of risk-oriented safety management plans.

Keywords

Underground Mining, Accident Factors, Risk Reduction, Mine Safety, Geomechanical Hazards

1. Introduction

Underground mineral extraction remains one of the most hazardous types of industrial activity, because accidents are rarely caused by a single factor alone. They usually develop as a result of the interaction of several factors, such as geomechanical instability, ventilation failure, gas or dust accumulation, hydrogeological uncertainty, equipment malfunction, and unsafe human actions (Badri et al., 2012; Tubis et al., 2020; Qiang et al., 2025). At greater depths or in complex ore bodies, the interconnection among these factors becomes stronger, making accident prevention and incident control dependent on continuous risk assessment rather than on checklist-style compliance alone (Fairhurst, 2017).

For Uzbekistan, this issue has practical importance. The mining sector remains one of the country's key industrial sectors, and official sources indicate the continued development of underground operations, including new underground projects for gold, copper, and coal extraction, as well as ongoing underground drilling and mining activities of major companies (Government of Uzbekistan, 2024; Ministry of Mining Industry and Geology of the Republic of Uzbekistan, 2025; AMMC, 2024; NMMC, 2024). At the same time, the Law of the Republic of Uzbekistan on Industrial Safety classifies such sites as hazardous production facilities and requires state regulation, expert review, certification of technical equipment, and supervision of compliance with industrial safety requirements (Law of the Republic of Uzbekistan, 2006).

The Uzbek context also includes factors that intensify the risks associated with underground mining operations. National regulation now extends technical requirements to equipment used in potentially explosive environments, which directly applies to underground workings where methane, blasting gases, coal dust, or combustible aerosols may accumulate (Cabinet of Ministers of the Republic of Uzbekistan, 2025). In addition, central and southern Uzbekistan are characterized by considerable seismic hazard, which should be taken into account in mine design, support selection, and emergency planning (Ibragimov et al., 2025).

Beyond regulatory texts, publicly available national evidence further corroborates the practical relevance of the hazard groups examined here. The Mining and Geology Control Inspectorate publishes open data on accidents at supervised enterprises, the severity of their consequences, and inspections documenting deficiencies and work suspensions for violations of industrial and radiation safety requirements. Its Gas Analysis Laboratory identifies continuous monitoring of methane, carbon monoxide, carbon dioxide, oxygen, ventilation, and dust conditions as core underground safety functions. At the enterprise level, NMMC's 2024 sustainability report attributes recorded incidents to violations of safety regulations in open-pit and underground operations, non-compliance with traffic rules for quarry equipment, and inadequate control of safe conditions at repair sites. Collectively, these sources substantiate the Uzbekistan-specific salience of ventilation and atmospheric hazards, fire and explosion risks, equipment and transport failures, and organizational safety deficiencies in underground mining.

Although the international literature contains many studies on roof falls, ventilation, spontaneous combustion, water inrush, risk assessment, and safe behavior, there remains a shortage of integrated review studies focused specifically on accident factors in underground mining under the conditions of the Republic of Uzbekistan. Most published works address either a single hazard or general occupational safety issues (Duzgun & Einstein, 2004; Xue et al., 2024; Yetkin et al., 2024; Khojiev, 2025).

The aim of this article is therefore to identify and systematize the principal accident factors in underground mining operations in Uzbekistan and to propose a prioritized hierarchy of mitigation measures. The results are intended to serve as a practical reference for researchers, mine managers, safety engineers, and regulatory authorities.

2. Materials and Methods

The study rests on three complementary elements. First, a narrative review of international publications on underground mine safety was conducted to identify recurrent accident mechanisms and effective control strategies. Second, Uzbek legislative and institutional sources were analyzed to situate these findings within the national regulatory context. Third, a qualitative risk ranking was constructed by evaluating each hazard group against two criteria: the likelihood of occurrence under typical underground mining conditions and the severity of potential consequences for personnel, production continuity, and mine infrastructure. Both criteria were scored on a five-point scale, and the two scores were combined through a qualitative risk matrix to assign overall priority levels. The final categorization was based on an author-based qualitative assessment informed by the reviewed literature, the regulatory framework, and more than ten years of the author's professional experience in the mining industry of Uzbekistan. Hazard groups associated with both high likelihood of occurrence and severe potential consequences were classified as "Very high," whereas hazards with lower combined significance or greater dependence on site-specific conditions were classified as "High" or "Medium-high."

Literature review and source selection. Relevant literature was identified through structured searches of Scopus, Web of Science, and Google Scholar, supplemented by a targeted examination of Uzbek legislative, regulatory, and institutional materials. The primary search window encompassed publications from 2000 to 2025; foundational studies predating this period were retained where their contribution to underground mining risk analysis remained substantively relevant. Search terms included "underground mining safety," "accident factors," "rock mass instability," "roof fall," "mine ventilation," "gas hazard," "dust hazard," "spontaneous combustion," "water inflow," "hydrogeological risk," "seismicity," "blasting," "equipment safety," "human factors," "Uzbekistan," and "industrial safety," applied individually and in combination. International sources were included if they addressed accident mechanisms, risk assessment methods,

or mitigation practices in underground mining contexts. Uzbek sources were included where they provided legal, regulatory, institutional, or operational context relevant to the conditions under examination.

This approach is not intended to substitute for site-specific quantitative risk analysis. Rather, it provides a structured primary screening framework that can be calibrated to individual mines, ore types, depths, ventilation configurations, and hydrogeological settings. It is particularly appropriate where comprehensive accident databases are incomplete or not publicly accessible—a condition common in national level comparative studies. The methodological logic follows established practice in risk-oriented mining research that combines hazard identification, qualitative ranking, and management prioritization (Shariati, 2014; Tripathy & Ala, 2018; Tubis et al., 2020).

Scope of application. The proposed framework applies to both underground metal and coal mines in Uzbekistan, while recognizing that hazard profiles differ systematically by mine type. Gas, dust, fire, and explosive-atmosphere hazards are generally more pronounced in coal operations; geomechanical instability, water inflow, and seismic and blast-induced effects are critical across both categories, though their relative significance varies with local geological and operational conditions.

3. Main Accident Factors in Underground Mining Operations in Uzbekistan

Table 1 indicates that rock mass instability, ventilation and atmospheric hazards, and human and organizational weaknesses constitute the highest-priority risk categories. Water inflow, seismic and blast-induced loading, and equipment failure follow at somewhat lower but still significant priority levels. Each category is examined below with specific reference to Uzbekistan's conditions.

Table 1. Qualitative ranking of the main accident factors in underground mining operations in Uzbekistan.

Accident factor	Typical manifestations	Probability (1 - 5)	Severity (1 - 5)	Priority
Instability of the rock mass and underground workings	Roof falls, wall failure, stope collapse, support damage	4	5	Very high
Ventilation-, gas-, and dust-related hazards	Toxic gases, oxygen deficiency, fire or explosion, dust exposure	4	5	Very high
Water inflow and flooding	Inundation, weakening of support, pump overload, blocked escape routes	3	5	High
Seismicity and blast-induced instability	Dynamic failure, loosening of rock, secondary collapse	3	4	High

Continued

Failures of machinery and electrical equipment	Transport accidents, fires, electric shock, ignition sources	3	4	Medium-high
Human and organizational factors	Rule violations, weak supervision, delayed response, poor communication	4	5	Very high

3.1. Geomechanical Instability and Failure of Underground Workings

Instability of the rock mass and underground workings remains one of the leading causes of injury and production stoppage in underground mines. Roof falls, wall failure, unsupported openings, degradation of support systems, stress concentration around excavations, and instability in stopes or haulage workings can rapidly turn local rock movement into a serious accident. [Duzgun and Einstein \(2004\)](#) showed that the risk of roof falls in underground workings can be systematically assessed through probability and consequence analysis, and later studies confirmed that accident development in underground mines often begins with weak control over rock mass behavior and delayed recognition of warning signs ([Qiang et al., 2025](#)).

For Uzbekistan, this factor is critical because underground mining is conducted under variable lithological, structural, and depth-related conditions, and some operations may face stress redistribution, tectonic disturbances, weakened fractured zones, and seismic loading. Where geological mapping, support design, and monitoring are insufficient, accidents related to rock mass instability become a major cause of fatalities and emergency situations in mining enterprises.

3.2. Ventilation Deficiencies, Gas Contamination, and Dust Hazards

Ventilation is the principal engineering barrier separating normal underground mining from a hazardous atmospheric state. Insufficient airflow leads to oxygen deficiency, accumulation of blasting gases, methane or other combustible gases, diesel aerosols, and high dust concentrations. Contemporary ventilation literature shows steady growth in research devoted to integrated management of airflow, contaminants, and thermal conditions, indicating the need to treat mine ventilation as a dynamic safety system rather than as a fixed design parameter ([Xue et al., 2024](#)).

In coal-bearing or fire-prone environments, gas and dust hazards are further intensified by spontaneous combustion processes. [Yetkin et al. \(2024\)](#) demonstrated that fault tree analysis can be used to identify the main pathways leading to spontaneous combustion in underground coal mines. This factor is relevant for Uzbekistan because regulations on explosive atmospheres now formally apply to equipment selection and operation, and official plans indicate further develop-

ment of underground coal mining (Cabinet of Ministers of the Republic of Uzbekistan, 2025; Government of Uzbekistan, 2024).

3.3. Hydrogeological Uncertainty and Water Inflow

Hydrogeological hazards are often underestimated during routine operation, especially when mine workings approach fractured aquifers, fault zones, or insufficiently explored water-bearing strata. Unexpected water inflow can flood workings, weaken support systems, damage power supply systems, interrupt transportation, and block escape routes. Yang et al. (2017) showed that mine water risk can be assessed more effectively when geological, hydrogeological, and operational factors are analyzed jointly rather than separately.

For Uzbekistan, this hazard is relevant in mines where groundwater conditions vary spatially and where underground workings interact with disturbed or karst-modified rocks. Even a moderate inflow can become severe if combined with weak dewatering design, insufficient pumping reserve capacity, or delayed detection.

3.4. Seismicity, Blasting, and Dynamic Loads

In a seismically active region, underground workings may be affected not only by conventional excavation damage and blast vibration, but also by regional tectonic stresses and locally induced dynamic loads. Ibragimov et al. (2025) presented an updated seismic hazard assessment for central and southern Uzbekistan, and Fairhurst (2017) emphasized that deep mining is increasingly sensitive to stress concentration, structural complexity, and dynamic response.

Even where mine seismicity is not extreme, repeated blasting and stress redistribution can destabilize already fractured rock masses and interact with water-related factors and support conditions. This makes seismic criteria important not only for mine siting, but also for support design, extraction sequencing, and emergency planning.

3.5. Machinery, Power Supply, and Explosive Atmospheres

Accidents in underground workings are also associated with transport collisions, hoisting failures, conveyor incidents, electrical faults, fires, and failures of equipment used in hazardous environments. Uzbek national regulation approved in 2025 establishes technical safety requirements for equipment used in potentially explosive atmospheres, which directly applies to underground mines with gas or dust hazards (Cabinet of Ministers of the Republic of Uzbekistan, 2025; NMMC; AMMC).

Local Uzbek studies also emphasize the role of personnel safety information systems and management algorithms in improving the safety of underground transport and machinery (Kalandarov et al., 2024). In practice, equipment-related risk increases when maintenance is reactive rather than preventive, spare parts supply is delayed, or gas analysis and power shutoff systems are not integrated with operating procedures.

3.6. Human and Organizational Factors

Human and organizational factors are cross-cutting causes rather than a separate secondary category. Unsafe behavior, poor workplace organization, a weak safety culture, poor communication, insufficient supervision, weak contractor control, and inadequate worker training can activate or intensify almost any technical hazard. [Bahn \(2013\)](#) showed that worker participation in hazard identification improves recognition of emerging risks, while [Ali and Pal \(2022\)](#) identified a significant relationship between safe behavior and injury risk in underground coal mining.

Uzbek authors also note the importance of legal frameworks, training systems, monitoring, and modern information systems for safe underground work ([Kalandarov & Xojiev, 2025](#); [Khojiev, 2025](#)). When production pressure begins to dominate risk communication, the probability of repeated incidents rises sharply.

4. Measures for Accident Reduction

Table 2 summarizes the main control measures proposed in this article. The organizing principle is barrier management: each major hazard is associated with specific technical, organizational, or procedural controls whose failure would materially increase the likelihood or severity of a major accident. For the framework to be operationally effective, these barriers must be explicit, verifiable, and subject to active monitoring.

Table 2. Recommended measures for reducing accident risk in underground mining operations in Uzbekistan.

Hazard group	Recommended measures	Expected effect	Implementation priority
Rock mass and excavation stability	Geological mapping, adaptive support design, convergence and microseismic monitoring	Reduced probability of roof falls and stope failure	Immediate
Ventilation, gas, and dust	Fan redundancy, gas monitoring, dust suppression, post-blast re-entry control	Improved air quality and reduced fire and explosion risk	Immediate
Hydrogeology	Advance drilling, grouting, dewatering planning, emergency pumping reserve	Reduced risk of flooding and production stoppage	High
Seismicity and blasting	Seismic zoning, optimization of blasting parameters, dynamic support in fault zones	Reduced dynamic instability and secondary collapses	High

Continued

Machinery and power supply	Preventive maintenance, certified equipment, interlocks, lockout procedures	Reduced risk of ignition and mechanical failure	High
Human and organizational factors	Training, near-miss reporting, contractor control, emergency drills	Strengthened safety culture and faster response	Immediate

4.1. Rock Mass Control and Geomechanical Monitoring

Effective accident reduction begins with geomechanical discipline. The minimum set of measures includes detailed geological mapping, rock mass classification, support design adapted to local conditions, regular inspection of support elements, convergence monitoring, and rapid response to deformation or water-induced weakening of rocks. The risk-oriented methods of stability control proposed by [Duzgun and Einstein \(2004\)](#) remain useful because they force operators to assess both the probability of roof falls and the cost of their consequences.

Under the conditions of Uzbekistan, these procedures should be combined with seismic zoning and special design criteria for workings located near faults or in highly fractured zones. Where possible, microseismic monitoring, laser scanning, extensometers, and instrumented support should be used in high-risk stopes, panels, and development workings.

4.2. Ventilation, Gas Monitoring, and Dust Suppression

Key measures include redundancy of main and auxiliary fans, ventilation network audits, continuous gas monitoring, automatic alarm thresholds, post-blast re-entry procedures, and dust suppression during drilling, blasting, loading, and haulage. Contemporary mine ventilation literature emphasizes the need for integrated management of airflow, contaminants, and thermal conditions rather than merely achieving regulatory air volumes ([Xue et al., 2024](#)).

In coal-bearing or fire-prone workings, the risk of spontaneous combustion should be included in standard hazard assessment and emergency planning ([Yetkin et al., 2024](#)). Since regulation of explosive atmospheres is now formalized in Uzbekistan, equipment selection and certification must be coordinated with ventilation design rather than treated as separate compliance tasks.

4.3. Hydrogeological Forecasting and Dewatering

Water-related accidents can be reduced through advance drilling along the direction of excavation, hydrogeological mapping, piezometric monitoring, grouting of high-risk zones, construction of drainage workings, and properly designed sumps and pumping stations. [Yang et al. \(2017\)](#) show that water-related risk assessment becomes more reliable when structural, hydraulic, and operational indicators are considered together.

A practical rule at mine level is simple: every area with water inflow potential should have both a prevention plan and a response plan. Prevention is based on forecasting and control; response relies on reserve pumping capacity, protection of escape routes, and rapid isolation of affected zones.

4.4. Digital Monitoring and Mine Information Systems

Digitalization cannot eliminate hazards, but it can reduce detection time and improve response quality. Local Uzbek studies emphasize the significance of personnel safety information systems and algorithmic management in underground mining, while international studies demonstrate the value of multisensor monitoring of mined-out spaces and underground voids (Kalandarov et al., 2024; Wang et al., 2019).

Recommended tools include personnel positioning, gas and dust sensor networks, equipment condition monitoring, digital dispatching, and centralized control rooms. Data integration is crucial because isolated sensors provide only fragments of information, whereas accident prevention requires pattern recognition and early warning of abnormal combinations of factors.

4.5. Training, Safety Culture, and Emergency Preparedness

Worker training should focus not only on rules, but also on hazard recognition, decision-making under stress, self-rescue, and communication in emergency situations. Worker participation in hazard identification improves the practical quality of risk assessment (Bahn, 2013). Safety culture should be strengthened through regular near-miss reporting, training under realistic underground conditions, pre-shift and refresher safety briefings, induction training for contractors, and evaluation of supervisory behavior. Continuous updating of risk assessments and consideration of workers' views improve the quality of safety management.

In Uzbekistan, emergency preparedness is also institutionally supported by mine rescue units and mining technical inspectorates by sector, which should be used as an element of permanent readiness rather than only as a reactive mechanism (Inspectorate for Control in the Field of Mining Industry and Geology, 2026).

4.6. Risk-Oriented Management and Regulatory Compliance

Uzbekistan's industrial safety legislation provides an established basis for the certification, supervision, and expert review of hazardous production facilities (Law of the Republic of Uzbekistan, 2006). The substantive challenge lies in moving beyond formal compliance toward risk-oriented implementation—understood here as the systematic identification, prioritization, monitoring, and periodic re-assessment of the hazards and controls most consequential to actual accident scenarios at a given mine. In practice, this requires maintaining current hazard registers, applying management-of-change procedures when operating conditions shift, auditing critical barriers at defined intervals, and aligning inspection prior-

ities with credible accident development pathways rather than administrative categories.

The international mining risk literature shows that integrated approaches are stronger than fragmented ones because they combine technical, human, and managerial hazards into a single decision-making system (Badri et al., 2013; Shariati, 2014; Tubis et al., 2020).

5. Discussion

The synthesis carried out in this study shows that accidents in underground mining in Uzbekistan should not be interpreted as isolated failures of workers or equipment. They arise from the interaction of rock mass behavior, atmospheric control, water, technology, and organization. This view is consistent with contemporary studies of accident evolution in underground mines, which show that initial technical deviations develop into severe events when monitoring, communication, and management barriers fail simultaneously (Qiang et al., 2025).

The analysis also indicates that not all hazards are equally important in strategic terms. For Uzbekistan, the highest-priority factors are instability of the rock mass and underground workings, ventilation-, gas-, and dust-related hazards, hydrogeological uncertainty, and human and organizational weaknesses. Seismicity functions more as a multiplier than as a constant everyday hazard; however, in affected areas it can sharply increase the consequences of design errors or support deficiencies. Equipment failure similarly represents an intermediate hazard whose impact depends on whether it develops in a gas-bearing, water-rich, or geomechanically unstable zone.

The practical implication is that mine safety plans should be built around critical barrier systems rather than around administrative categories. A working plan for a specific mine should define exactly which measures prevent roof falls, gas accumulation, flooding, transport accidents, and delayed evacuation, and then verify whether these measures are monitored, tested, and supported by trained personnel. This approach is more robust than a purely descriptive safety manual because it allows new sensors, automation, or regulatory changes to be incorporated without rewriting the entire system from the beginning.

This article has limitations. It is a review and synthetic study that does not rely on a closed national accident database or on the full operational dataset of a single mine. Therefore, the ranking presented here is qualitative and should be recalibrated for specific deposits, ore types, mining methods, and organizational management systems. Nevertheless, as a screening framework for Uzbekistan, it helps transform the broad problem of mine safety into a prioritized engineering agenda.

6. Conclusion

This study shows that the main accident factors in underground mining operations in Uzbekistan are rock mass and excavation instability, ventilation- and gas-dust-related hazards, hydrogeological uncertainty, seismicity and blast-induced

instability, machinery and electrical equipment failures, and human and organizational weaknesses. These factors do not operate independently. The most severe accident scenarios emerge when geological and technical hazards are intensified by weak monitoring, insufficient maintenance, and unsafe worker behavior.

The analysis also indicates that Uzbekistan already has an important regulatory basis for industrial safety; however, meaningful accident reduction depends on mine-level implementation through risk-oriented control of critical hazards rather than formal compliance alone. The most effective preventive measures include geomechanical monitoring, adaptive support design, ventilation control, continuous gas and dust monitoring, hydrogeological forecasting, digital safety systems, enhanced worker training, and emergency preparedness.

Overall, reducing accident rates in underground mining in Uzbekistan requires an integrated safety management approach that combines technical, organizational, and regulatory measures within a single system of critical barriers. Future research should therefore focus on developing mine-specific quantitative models of accident frequency and consequence severity based on operational data from underground mines in Uzbekistan.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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