Original Research Article

Hydrogeological risk assessment and management strategies in mining engineering geological exploration

Ningbo Pei[1] , Panpan Meng[2], Xiuli Zhang[3]

1 Yantai Health Vocational College, Yantai, Shandong, 265500, China

2 Yantai Land Reserve and Utilization Center, Yantai, Shandong, 264005, China

3 Yantai Environmental Monitoring Center, Yantai, Shandong, 264003, China

Abstract: This study examines the critical role of hydrogeological conditions in mining engineering exploration. Groundwater dynamics, aquifer characteristics, and water table fluctuations significantly impact mine stability and safety. Risks include water ingress, flooding, and groundwater-induced instability. Effective management strategies such as dewatering, grouting, and environmental monitoring are essential. Advanced exploration techniques like geophysical methods and numerical modeling aid in accurate risk assessment. Proper hydrogeological management ensures efficient and sustainable mining operations.

Keywords: Hydrogeology; Mining engineering; Geological exploration; Risk assessment; Management strategies

1. Introduction

The exploration phase of mining engineering is critical for understanding the subsurface geological conditions that will influence the entire mining operation. Among various geological factors, hydrogeological conditions are particularly significant due to their potential to impact the stability of the mine, the efficiency of extraction processes, and the overall safety of the site. Groundwater, in particular, can pose serious challenges due to its dynamic nature and the complex interactions it has with the surrounding rock and soil.

Hydrogeological risks can arise from natural variations in groundwater levels, the presence of aquifers and aquitards, and the influence of geological structures such as faults and fractures. Additionally, human activities, including mining itself, can alter the natural hydrogeological balance, leading to unforeseen problems. Therefore, a thorough understanding of hydrogeological conditions is essential for effective mine planning and risk management.

2. Hydrogeological conditions and their characteristics

2.1. Groundwater systems

Groundwater systems are integral to the hydrogeological environment of a mining site. These systems can be categorized into confined and unconfined aquifers, each with distinct characteristics and behaviors. Confined aquifers are bounded by impermeable layers, which can lead to significant water pressure variations, while unconfined aquifers are directly influenced by atmospheric precipitation and surface water infiltration.

In many mining regions, the presence of multiple aquifer layers complicates the hydrogeological conditions. For instance, in some areas, the upper layers may consist of loose sediments with high permeability, while deeper layers may contain more consolidated rocks with lower permeability[1]. Understanding the interaction between these layers is critical for predicting groundwater flow and potential flooding risks.

2.2. Water table fluctuations

The water table, which marks the upper surface of the saturated zone, can fluctuate due to seasonal variations, climatic changes, and human activities. Seasonal rainfall and snowmelt can cause significant rises in the water table, increasing the risk of water ingress into mines. Conversely, prolonged dry periods or excessive groundwater extraction can lead to a lowering of the water table, which may result in land subsidence and other geological hazards.

In mining operations, the water table's position is particularly important because it directly affects the stability of the mine's infrastructure[2]. A rising water table can lead to increased pore water pressure in the rock mass, potentially causing rock failure and mine instability. Therefore, continuous monitoring and accurate prediction of water table fluctuations are essential for safe mining practices.

2.3. Aquifers and aquitards

Aquifers are geological formations that can store and transmit significant quantities of groundwater, while aquitards are layers with low permeability that restrict the movement of water. The presence of aquifers near a mine site can pose a significant risk of water ingress, especially if they are hydraulically connected to the mine workings. On the other hand, aquitards can act as protective barriers, reducing the likelihood of water inflow from deeper sources.

Identifying and characterizing aquifers and aquitards is a fundamental aspect of hydrogeological exploration. This involves determining their thickness, extent, and hydraulic properties, such as permeability and storativity. Geophysical methods, such as electrical resistivity tomography and seismic surveys, are often employed to map these formations. Additionally, drilling and sampling provide direct information on the lithology and water-bearing characteristics of the subsurface.

3. Hydrogeological risks in mining

3.1. Water ingress and flooding

One of the most immediate and severe hydrogeological risks in mining is water ingress and flooding. When groundwater enters mine workings, it can lead to rapid inundation, posing a direct threat to the safety of miners and the integrity of the mine structure. Water ingress can occur through various pathways, including open fractures, poorly sealed drill holes, and permeable strata[3].

Preventing water ingress requires a combination of proactive measures, such as grouting to seal off potential inflow points, and reactive measures, such as the installation of dewatering systems. Effective water management strategies are essential to mitigate the risk of flooding and ensure the safe operation of the mine.

3.2. Groundwater-induced instability

Groundwater can significantly affect the mechanical properties of rocks and soils, leading to instability in mine structures. The presence of water can reduce the effective stress within the rock mass, thereby decreasing its shear strength and increasing the likelihood of failure. This is particularly problematic in areas with high water pressure or where the rock mass is already weakened by geological structures such as faults and joints .

In open-pit mines, groundwater can cause slope instability, leading to landslides and rockfalls. In underground mines, water-induced instability can result in roof collapses and pillar failures [4]. To address these issues, it is necessary to conduct detailed hydrogeological and geotechnical assessments to identify potential instability zones and implement appropriate stabilization measures, such as dewatering, grouting, or structural reinforcement.

3.3. Water quality and environmental impact

Groundwater quality can also have significant implications for mining operations. Contaminated groundwater can pose environmental risks, particularly if it enters surface water bodies or is used for drinking or irrigation. Mining activities can also impact groundwater quality through the release of pollutants, such as heavy metals and acidic mine drainage.

Environmental regulations require mining companies to monitor and manage groundwater quality to minimize adverse impacts. This involves implementing water treatment systems, monitoring groundwater chemistry, and adopting best practices to prevent contamination. Additionally, understanding the hydrogeological conditions is crucial for predicting the potential pathways and impacts of contaminants, allowing for proactive environmental management.

4. Hydrogeological exploration techniques

4.1. Geophysical methods

Geophysical techniques are essential tools for hydrogeological exploration in mining. These methods include electrical resistivity tomography (ERT), seismic surveys, and ground-penetrating radar (GPR)[5]. ERT is particularly useful for mapping subsurface electrical properties, which can indicate the presence of water-bearing zones. Seismic surveys provide information on the geological structure and rock properties, while GPR can detect shallow subsurface features such as fractures and voids.

Geophysical methods offer a non-invasive means of obtaining detailed information on the subsurface hydrogeological conditions. They can be used to identify potential aquifers, map the extent of geological structures, and detect zones of anomalous water content. However, these techniques require careful interpretation and integration with other exploration data to provide accurate and reliable results.

4.2. Drilling and sampling

Drilling and sampling are fundamental to hydrogeological exploration, providing direct information on the lithology, groundwater quality, and hydraulic properties of the subsurface. Drill holes can be used to install piezometers for monitoring groundwater levels and to conduct pumping tests to determine aquifer characteristics.

Sampling of groundwater and rock cores allows for laboratory analysis to assess water quality and rock strength. This information is crucial for evaluating the potential risks associated with groundwater and for designing appropriate mitigation measures. Drilling and sampling programs should be designed to provide comprehensive coverage of the mine site, ensuring that all relevant hydrogeological features are identified and characterized.

4.3. Numerical modeling

Numerical modeling is an increasingly important tool for understanding and predicting hydrogeological conditions in mining. Computational models can simulate groundwater flow, contaminant transport, and the interaction between groundwater and mining activities. These models can be used to evaluate the potential impacts of mining on groundwater resources and to design effective water management strategies.

By integrating field data with numerical models, it is possible to create detailed simulations of the hydrogeological system. These simulations can be used to predict changes in groundwater levels, flow patterns, and water quality in response to mining activities. Numerical modeling provides a powerful means of optimizing exploration strategies and minimizing hydrogeological risks.

5. Risk management strategies

5.1. Dewatering systems

Dewatering is a common practice in mining to lower groundwater levels and reduce the risk of water ingress. This involves the use of pumps, wells, and drainage systems to remove water from the mine workings and surrounding strata. Effective dewatering can improve mine stability, reduce the risk of flooding, and enhance operational efficiency.

Dewatering systems should be designed based on a thorough understanding of the hydrogeological conditions. This includes selecting appropriate pumping rates, well locations, and drainage configurations to achieve the desired water level reductions. Continuous monitoring and adjustment of the dewatering system are essential to ensure its effectiveness and to minimize environmental impacts[6].

5.2. Grouting and sealing

Grouting is a technique used to seal off potential water ingress points and to reinforce weak rock masses. This involves injecting grout, a mixture of cementitious materials and water, into the subsurface to fill voids and fractures. Grouting can be used to create impermeable barriers around mine workings, reducing the risk of water ingress and improving overall stability.

Sealing of drill holes and other openings is also an important aspect of hydrogeological management in mining. Proper sealing prevents the migration of water and contaminants along these pathways, reducing the risk of groundwater contamination and mine flooding. Grouting and sealing should be carried out using appropriate materials and techniques to ensure long-term effectiveness.

5.3. Environmental management

Effective environmental management is crucial for minimizing the impact of mining on groundwater resources. This involves monitoring groundwater quality, implementing water treatment systems, and adopting sustainable water management practices. Mining companies should also engage in rehabilitation efforts to restore affected areas and mitigate long-term environmental impacts.

6. Conclusion

Hydrogeological issues are a critical aspect of geological exploration in mining engineering. Proper risk assessment and management strategies are essential to ensure the stability, safety, and efficiency of mining operations. By employing detailed exploration techniques, such as geophysical methods, drilling, and numerical modeling, and implementing effective risk management strategies, such as dewatering, grouting, and environmental management, mining companies can effectively manage hydrogeological risks and ensure the successful implementation of mining projects.

References

[1] Zhao, W., & Li, H. (2021). Hydrogeological issues in mining engineering: A review. Journal of Mining Science, 57(3), 456-472.

[2] Lu, Z. (2023). Research on the hazards of hydrogeological problems in mine engineering exploration. Metallurgy and Materials, 43(11), 12-15.

[3] Wu, S. (2022). Application of grey system theory in hydrogeological engineering prediction of mine engineering. World Nonferrous Metals, 1(1), 83-85.

[4] Yu, S. (2024). Application of hydrogeological exploration informatization technology in mine engineering exploration. Intelligent City, 10(8), 40-42.
[5] Yin, J., & Wei, Y. (2024). Study on the application of hydrogeological investigation in mine engineering construction. Construction & Design For Project, 2(2), 44-46.
[6] Shen, W. (2024). Research on hydrogeological problems in engineering geological exploration. Western Exploration Engineering, 1(1), 13-15.