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Research on Prevention and Control Strategies of Hydrogeological and Environmental Geological Hazards

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Abstract: Hydrogeological and environmental geological hazards exhibit diverse types and complex formation mechanisms, resulting from the combined effects of natural and anthropogenic factors. This paper elaborates on typical hazard types such as landslides and debris flows and analyzes their causes. It introduces both traditional and modern monitoring technologies and constructs an early warning system. Furthermore, it explores comprehensive prevention and control strategies, including engineering measures, ecological restoration, and multi-measure collaborative approaches. Management measures are also proposed from the perspectives of policies and regulations, inter-departmental coordination, and emergency management, providing a comprehensive reference for the prevention and control of hydrogeological and environmental geological hazards.

Keywords: Hydrogeological and environmental geological hazards; prevention and control strategies; monitoring and early warning

Introduction

Hydrogeological and environmental geological hazards pose serious threats to human life and property, the ecological environment, and the safety of engineering facilities. These hazards are characterized by diverse types, wide distribution, and complex formation mechanisms involving both natural and human-induced factors. Moreover, different types of hazards are often interrelated, leading to compounded and intensified impacts. With ongoing social and economic development, the requirements for geological hazard prevention and control are continuously increasing. Under this background, in-depth research on prevention and control strategies for hydrogeological and environmental geological hazards, and the enhancement of overall prevention and mitigation capacity, are of great practical significance and urgency.

1. Types and Causes of Hydrogeological and Environmental Geological Hazards

1.1 Major Types of Hazards

Hydrogeological, engineering geological and environmental geological disasters refer to various geological disasters triggered by hydrogeological, engineering geological and environmental geological

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conditions that endanger human lives and property, damage the ecological environment and engineering facilities. They are diverse in types and widely distributed, mainly including karst collapse, goaf collapse, ground fissures, ground subsidence, unstable slopes, landslides, rockfalls, debris flows, etc.Karst collapse mostly occurs in karst-developed areas due to changes in groundwater level and underground engineering activities. Goaf collapse is common in mining areas, where the overlying rock and soil layers lose support and collapse after underground ore bodies are extracted. Ground subsidence and ground fissures are mainly related to excessive groundwater exploitation and underground engineering construction, and are mostly found in cities. Unstable slopes have the risk of sliding. Landslides and rockfalls mostly occur in mountainous and hilly areas, significantly affected by topographic and geomorphic features as well as the properties of rock and soil masses, often causing road interruptions and house damage. Debris flows mostly occur accompanied by rainstorms, carrying a large amount of sediment and rock blocks with extremely strong destructive power. Soil erosion and salinization are mainly distributed in arid and semi-arid areas and along river banks, damaging land resources and agricultural production.

1.2 Mechanisms of Hazard Formation

The occurrence of hydrogeological and environmental geological hazards is not caused by a single factor, but rather by the long-term interaction and superposition of natural and anthropogenic factors, forming complex mechanisms of hazard development. Natural factors constitute the fundamental conditions for hazard occurrence and mainly include topography and geomorphology, rock and soil properties, meteorological and hydrological conditions, and geological structures [1]. In areas with steep terrain and loose, fragmented rock and soil masses, stability is poor, making landslides and collapses more likely. Heavy rainfall, concentrated precipitation events, or snowmelt can increase the water content of rock and soil masses, reduce shear strength, and intensify surface runoff erosion, thereby triggering debris flows and related hazards. In tectonically active regions, fractured rock strata and well-developed faults further weaken the integrity of rock and soil masses, significantly increasing the probability of landslides, collapses, and debris flows. For karst collapses, the degree of karst development and the natural dynamic fluctuations of groundwater are important natural inducing factors. Goaf collapses are closely related to geological conditions such as ore body occurrence characteristics and mining methods. Anthropogenic factors serve as the primary driving force that intensifies hazard development. Excessive groundwater extraction leads to groundwater level decline, inducing land subsidence and ground fissures. Engineering construction and mining activities damage surface vegetation and rock–soil structures, altering local geological environments. Unreasonable land use and vegetation destruction exacerbate soil erosion and soil salinization. In addition, improper underground engineering activities accelerate the occurrence of karst collapses and goaf collapses. The synergistic effects of these factors ultimately result in the occurrence, development, and expansion of hydrogeological and environmental geological hazards.

2. Monitoring and Early Warning Technologies for Hydrogeological and Environmental Geological Hazards

2.1 Traditional Monitoring Methods

Traditional monitoring methods for hydrogeological and environmental geological hazards are mainly based on manual monitoring, relying on on-site investigations and instrument measurements conducted by professional personnel. These methods are characterized by simple operation, relatively low cost, and strong specificity, and have been widely applied in various geological hazard monitoring scenarios. The main monitoring contents include rock–soil displacement of landslides, collapses, and unstable slopes; groundwater levels and fissure variations in areas prone to ground collapse and ground fissures; and precipitation in debris-flow-prone areas. Commonly used instruments include crack meters, water level gauges, rain gauges, and theodolites [2]. During the monitoring process, personnel regularly visit monitoring points to read instrument data, record crack widths, and observe rock–soil deformation, followed by manual data compilation and analysis to assess hazard development trends. Traditional monitoring methods are suitable for areas with limited monitoring ranges and single hazard types and can meet basic monitoring requirements. However, they suffer from limitations such as low monitoring efficiency, poor data timeliness, relatively large human-induced errors, and difficulty in achieving continuous large-scale monitoring.

2.2 Modern Monitoring Technologies

With advances in science and technology, modern monitoring technologies for hydrogeological and environmental geological hazards have evolved toward automation, intelligence, wide coverage, and high precision. These technologies effectively compensate for the shortcomings of traditional methods and have become the core means of geological hazard monitoring. They mainly include remote sensing monitoring, Global Positioning System (GPS) monitoring, Geographic Information System (GIS) technology, Internet of Things (IoT) monitoring, and unmanned aerial vehicle (UAV) surveys. Remote sensing monitoring, based on satellite or aerial platforms, can rapidly acquire large-scale geological environmental information and monitor in real time rock–soil deformation of landslides, collapses, and unstable slopes, as well as changes in vegetation cover, land subsidence, and ground fissures. It is particularly suitable for large-area identification of potential hazard sites. GPS monitoring enables high-precision, real-time measurement of rock–soil displacement in landslides, collapses, and unstable slopes, with accuracy controlled at the millimeter level, allowing the timely detection of subtle deformations and early prediction of hazard risks. IoT-based monitoring deploys sensors at monitoring points to automatically collect, transmit, and analyze hazard-related data without manual intervention, significantly improving monitoring efficiency and data timeliness. UAV surveys can rapidly access hazardous areas that are difficult for personnel to reach, obtain high-resolution imagery, and accurately identify potential hazard sites such as landslides, collapses, karst collapses, and goaf collapses.

2.3 Construction of an Early Warning System

The construction of an early warning system for hydrogeological and environmental geological hazards is based on monitoring data as the foundation, early warning models as the core, and emergency response as the goal. By integrating monitoring technologies, data processing, risk assessment, and information dissemination, a closed-loop system of "monitoring–analysis–warning–response" is formed, providing strong support for the prevention and control of geological hazards such as landslides and collapses. The early warning system mainly consists of a data acquisition module, a data processing and analysis module, a risk assessment module, an early warning information release module, and an emergency response module. The data acquisition module integrates various monitoring devices to collect real-time monitoring data such as displacement, groundwater level, and rainfall. The data processing module cleans, verifies, and integrates the collected data, removing abnormal values to ensure data accuracy. The analysis module, based on historical and real-time data, applies early warning models to calculate the probability of hazard occurrence and risk levels, and classifies warning grades into general, relatively serious, serious, and extremely serious levels. The early warning information release module disseminates warning information to relevant departments and threatened populations in a timely manner through multiple channels, including short message services, broadcasting systems, official social media platforms, and early warning terminals, clearly specifying the warning scope, risk level, and corresponding prevention requirements.

3. Engineering Measures for the Prevention and Control of Hydrogeological and Environmental Geological Hazards

3.1 Engineering Control Technologies

Engineering control technologies are the core means of preventing and controlling hydrogeological and environmental geological hazards. These measures should be selected according to the characteristics of different hazard types, aiming to enhance rock–soil stability and control hazard development, thereby reducing disaster impacts at the source. For landslides, collapses, and unstable slopes, commonly adopted measures include anti-slide piles, retaining walls, anchor (cable) support systems, slope cutting and load reduction, and drainage works. These measures function by blocking rock–soil sliding, enhancing the integrity of rock–soil masses, reducing slope self-weight, and lowering water content to improve shear strength. For debris flows, interception, diversion, and sediment retention structures are widely used to block debris flow movement and guide it safely out of hazardous zones, thereby preventing impacts on residential areas and engineering facilities. For ground collapse, ground fissures, karst collapse, and goaf collapse, grouting reinforcement, backfilling and compaction, and groundwater recharge are adopted to strengthen fractured rock strata, restore groundwater levels, and restrain the expansion of subsidence and collapse. For soil erosion, engineering measures such as terracing, retaining walls, and drainage channels are implemented to slow surface runoff and reduce soil erosion.

3.2 Ecological Restoration Strategies

Ecological restoration strategies are guided by the concept of harmonious coexistence between humans and nature. By restoring and improving the ecological functions of the geological environment, these strategies enhance ecosystem stability and resistance to disturbance, thereby achieving long-term prevention and control of geological hazards. They are particularly suitable for areas with fragile ecological environments and dispersed hazard-prone sites such as landslides, collapses, unstable slopes, and debris flows. The main measures include vegetation restoration, soil improvement, and water body management. Vegetation restoration is the core measure. Based on regional climatic and geological conditions, plant species with strong adaptability and high soil-fixing and water-retention capacities are selected to establish mixed vegetation communities composed of trees, shrubs, and grasses. This enhances soil resistance to erosion, reduces soil and water loss, and stabilizes rock–soil masses on landslides, collapses, and unstable slopes. Soil improvement targets degraded soils through the application of organic fertilizers, topsoil replacement, and drainage and desalination measures, thereby improving soil fertility, water-holding capacity, and physicochemical properties. Water body management addresses issues such as groundwater pollution and disordered surface runoff by implementing wastewater treatment, groundwater purification, and river channel regulation measures, restoring aquatic ecological functions, maintaining stable groundwater levels, and preventing hazards such as ground collapse and ground fissures [3].

3.3 Case Study of Multi-Measure Collaborative Prevention and Control

Given the complex causes and diverse impacts of hydrogeological and environmental geological hazards, single prevention and control measures often fail to achieve satisfactory results. Multi-measure collaborative prevention and control integrates engineering treatment, ecological restoration, and monitoring and early warning technologies to achieve complementary advantages and improve the scientific validity and long-term effectiveness of hazard mitigation. A representative case is presented below. At a landslide-prone site in a mountainous area characterized by steep terrain, loose rock–soil masses, and concentrated summer rainfall, landslides and collapses were likely to occur, with additional risks posed by unstable slopes in the surrounding area. A collaborative prevention and control model combining engineering treatment + ecological restoration+ monitoring and early warning was adopted. Engineering measures included the installation of anti-slide piles and drainage channels to block slope movement and discharge surface and groundwater, thereby reducing rock–soil water content. Ecological measures involved planting soil- and water-conserving vegetation to restore slope vegetation cover, enhance rock–soil stability, and eliminate unstable slope hazards. Meanwhile, GPS monitoring points and rain gauges were deployed to establish an early warning system capable of real-time monitoring of slope deformation and precipitation and timely dissemination of warning information.

Through the implementation of this collaborative approach, the frequency of landslide occurrences in the area was significantly reduced, and slope stability was markedly improved. This not only ensured the safety of local residents' lives and property but also enhanced the regional ecological environment, providing valuable experience for the prevention and control of similar geological hazards in mountainous regions and demonstrating the scientific rationality and effectiveness of multi-measure collaborative prevention and control.

4. Management Strategies for the Prevention and Control of Hydrogeological and Environmental Geological Hazards

4.1 Policies, Regulations, and Standard Systems

Policies, regulations, and standard systems constitute the institutional guarantee for the prevention and control management of hydrogeological and environmental geological hazards. Improving relevant laws and regulations and formulating unified technical standards can regulate various hazard prevention and control activities and clarify the responsibilities of different stakeholders. China has established a policy and regulatory framework covering the entire process of geological hazard prevention and control, issuing multiple laws and administrative regulations that clearly define the responsibilities of governments, enterprises, and the public, and standardize related procedures. At the same time, technical standards for monitoring, engineering treatment, and risk assessment have been developed, specifying requirements for data accuracy, engineering quality, and technical implementation, thereby providing a scientific basis for prevention and control practices. These measures effectively constrain human activities, enhance the standardization and institutionalization of prevention and control management, and promote the normalization and long-term effectiveness of hazard mitigation efforts.

4.2 Inter-Departmental Coordination and Public Participation

The prevention and control of hydrogeological and environmental geological hazards require strengthened inter-departmental coordination and active public participation, forming a governance framework characterized by government leadership, departmental coordination, and public participation. In terms of inter-departmental coordination, relevant departments such as natural resources and water resources should clarify their respective responsibilities, cooperate closely, and establish coordination mechanisms so that each department fulfills its duties and jointly forms a strong prevention and control force. With respect to public participation, disaster prevention knowledge should be disseminated through education and training to enhance public awareness and capabilities in disaster prevention, self-rescue, and mutual aid. In addition, public supervision mechanisms should be established to encourage the reporting of potential hazards and illegal activities, guiding the public to participate in hazard identification, monitoring, and emergency response, thereby strengthening the grassroots defense line for disaster prevention and mitigation.

4.3 Emergency Management and Post-Disaster Reconstruction

Emergency management and post-disaster reconstruction are critical components of hydrogeological and environmental geological hazard prevention and control. By improving emergency response systems and conducting scientific post-disaster reconstruction, losses caused by various hazards can be minimized, affected populations can be assisted in restoring production and daily life, and secondary disasters can be effectively prevented. In terms of emergency management, comprehensive geological hazard emergency response plans should be established, clearly defining emergency organizational structures, response procedures, and disposal measures, with corresponding plans formulated for different hazard levels. Emergency material reserves should be strengthened, including rescue equipment, disaster relief supplies, and medical materials, to ensure rapid allocation and deployment after disasters. Emergency drills should also be conducted regularly to enhance the practical response capabilities of rescue teams and inter-departmental coordination, ensuring rapid response and effective handling of emergencies [4]. Regarding post-disaster reconstruction, the principles of scientific planning, adaptation to local conditions, and people-centered development should be upheld. Geological environmental assessments should be carried out in affected areas to identify secondary hazards and to rationally plan reconstruction site selection. Damaged infrastructure should be repaired, agricultural production and ecological environments should be restored, and monitoring and early warning mechanisms for secondary hazards should be established. Through the organic integration of post-disaster reconstruction and hazard prevention and control, sustainable development of affected areas can be promoted.

Conclusion

The prevention and control of hydrogeological and environmental geological hazards constitute a long-term and complex systematic undertaking, encompassing multiple hazard types such as landslides, collapses, debris flows, karst collapses, goaf collapses, ground fissures, land subsidence, and unstable slopes. Through the integrated application of monitoring and early warning technologies, engineering control measures, and ecological restoration strategies, together with the improvement of policies and regulations, the strengthening of inter-departmental coordination and public participation, and the establishment of efficient emergency management and post-disaster reconstruction systems, disaster risks and losses can be effectively reduced. In the future, continuous technological innovation and strategic optimization are required to further enhance prevention and control capacities, thereby safeguarding sustainable socio-economic development and the safety of people's lives and property.

References

[1] Liu Zhuangde. Research and Practice on Comprehensive Prevention and Control Strategies of Hydrogeological and Environmental Geological Hazards in Mining Areas [J]. China Disaster Reduction, 2025(5): 50–51.

[2] Zhao Ming. Risk Assessment and Prevention Countermeasures of Geological Hazards Based on Mining Hydrogeological and Environmental Conditions [J]. China Metal Bulletin, 2024(15): 234–236.

[3] Liang Yi. Application of Hydrogeological and Environmental Geological Technology in Geological Hazard Prevention and Control [J]. Zhongzhou Construction, 2023(1): 29–30.

[4] Xu Zhantao. Risk Assessment and Prevention Technologies of Hydrogeological and Environmental Geological Hazards in Mining Areas [J]. World Nonferrous Metals, 2023(19): 142–144.