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Impacts of Hydrogeological and Environmental Geological Disasters on the Ecological Environment and Restoration Measures

Dan-Yi Cheng*

Shanxi Institute of Geological Survey Co., Ltd., Ltd, Taiyuan, Shanxi, 030006, China

***Correspondence to:** Dan-Yi Cheng, Shanxi Institute of Geological Survey, Taiyuan, Shanxi, 030006, China, E-mail: 493061958@qq.com

Abstract: Hydrogeological and environmental geological disasters, encompassing various types such as landslides, debris flows, and ground collapses, result from the combined effects of natural factors and human engineering activities. This paper focuses on these disasters, beginning with an introduction to common types including landslides and debris flows, land subsidence and collapse, and reservoir-induced seismicity. It provides an in-depth analysis of the multifaceted impacts of these disasters on the ecological environment, covering hydrological systems, soil environment, biodiversity, and long-term changes in geological structures. In response to these impacts, a series of ecological restoration measures are proposed, including engineering restoration, bioremediation, combined physical-chemical remediation, reconstruction of wetland ecosystems, and optimization of monitoring and early warning systems. The aim is to provide theoretical support and practical references for mitigating the damage caused by hydrogeological and environmental geological disasters to the ecological environment and achieving sustainable ecological development.

Keywords: Hydrogeological and Environmental Geological Disasters; Ecological Environment Impact; Ecological Restoration Measures

Introduction

With the rapid development of the social economy, various engineering construction activities have become increasingly frequent, leading to a rise in the frequency and scope of impact of hydrogeological and environmental geological disasters. These disasters not only directly threaten human life and property safety but also cause severe damage to the ecological environment, affecting the balance and stability of ecosystems. The ecological environment is the foundation for human survival and development, and its health status is directly related to the sustainable development of human society. Therefore, in-depth research on the impacts of hydrogeological and environmental geological disasters on the ecological environment and the exploration of effective ecological restoration measures are of significant practical importance for protecting the ecological environment and achieving harmonious coexistence between humans and nature.

1. Types of Hydrogeological and Environmental Geological Disasters

1.1 Landslides and Debris Flows

A landslide is a natural phenomenon where soil or rock on a slope, influenced by factors such as river erosion, groundwater activity, earthquakes, and artificial slope cutting, slides downward as a whole or in fragments along a specific weak surface or zone under the influence of gravity. Their scale varies significantly; small landslides may involve only a small amount of earth and rock, whereas large landslides can displace massive volumes of rock and soil, possessing immense destructive power. Debris flow is a special torrent containing large amounts of mud, sand, and rocks, triggered by water sources such as heavy rain or meltwater from snow and ice in mountain gullies. It is characterized by suddenness, high velocity, large discharge, high material density, and strong destructive power. Wherever it passes, houses, roads, farmland, etc., can be scoured away and buried, posing a great threat to the ecological environment and the safety of human life and property.

1.2 Land Subsidence and Collapse

Land subsidence refers to a local downward movement where the ground surface elevation decreases due to the consolidation and compression of underground unconsolidated strata, caused by either natural factors or human engineering activities. Excessive extraction of groundwater and oil and gas resources are primary anthropogenic causes of land subsidence. Ground collapse is a geological phenomenon where surface rock and soil subside downward due to natural or human factors, forming collapse pits (or sinkholes) on the ground. Mining-induced subsidence and karst collapse are relatively common. Mining activities create extensive underground goafs, and when the overlying rock and soil can no longer support their own weight, collapse occurs. In karst areas, collapse is prone to occur due to the development of underground caves and the influence of factors like groundwater activity. Both types disrupt the surface ecology and infrastructure.

1.3 Reservoir-Induced Seismicity

Reservoir-induced seismicity refers to earthquake phenomena triggered by human activities, such as reservoir impoundment, which alter the local geological stress state. After a reservoir is filled, the increased water load and the infiltration of reservoir water into the underground change the physical and mechanical properties of the rock mass and the stress distribution. When stress accumulates to a certain extent, it can induce earthquakes. The epicenters are generally distributed in and around the reservoir area, and the magnitude is usually small, although there are instances of stronger events. Reservoir-induced seismicity can not only cause damage to water conservancy facilities like dams, affecting the normal operation of the reservoir, but can also impact surrounding areas, adversely affecting the safety of residents' lives and property and the ecological environment [1].

2. Impacts of Hydrogeological and Environmental Geological Disasters on the Ecological Environment

2.1 Impacts on Hydrological Systems

Hydrogeological and environmental geological disasters can significantly alter the natural cycle of hydrological systems. Engineering projects, such as dam construction, can block the natural flow paths of rivers, affecting water distribution and seasonal variations upstream and downstream, leading to downstream channel shrinkage and insufficient ecological water requirements. Reservoir impoundment can cause a rise in the groundwater level around the reservoir area, resulting in soil salinization and affecting the growth of surrounding vegetation. Meanwhile, excessive groundwater extraction can create regional drawdown cones, altering groundwater recharge, runoff, and discharge conditions. This may lead to the drying up of springs and a reduction in river baseflow. In addition, geological disasters such as landslides and debris flows can transport large amounts of sediment into water bodies, changing river morphology and disturbing the balance between erosion and deposition, thereby affecting navigation and flood control safety.

2.2 Impacts on Soil Environment

Hydrogeological and environmental geological disasters have multiple detrimental effects on the soil environment. Large-scale excavation and filling during engineering construction destroy the original soil structure, reduce porosity and permeability, and impair water retention and gas exchange capabilities. Waste rock and tailings from mining activities, if indiscriminately dumped, occupy land, and the heavy metals and acidic substances they contain can leach into the soil with rainwater, causing soil pollution and reduced fertility. Over-extraction of groundwater can lead to soil desiccation and desertification, making it difficult for vegetation to grow. Additionally, soil erosion washes away the fertile topsoil, reducing land productivity and creating a vicious cycle of 'increased cultivation leads to greater poverty, which in turn leads to more cultivation,' threatening sustainable agricultural development.

2.3 Impacts on Biodiversity

Hydrogeological and environmental geological disasters pose a serious threat to biodiversity. Water conservancy projects alter aquatic environments, destroying the habitats and breeding grounds of aquatic organisms and leading to a decline in species such as fish and amphibians. Mining activities destroy surface vegetation, causing terrestrial animals to lose food sources and shelter, triggering species migration or extinction. Unsustainable irrigation and the use of chemical fertilizers and pesticides in agricultural activities alter the chemical properties of soil and water bodies, affecting the survival of microorganisms and plants, thereby disrupting the foundation of the food chain. Furthermore, ecosystem fragmentation caused by geological disasters hinders species exchange, reduces genetic diversity, and weakens the ecosystem's resistance to disturbance and its resilience.

2.4 Long-term Impacts on Geological Structures

The long-term impacts of hydrogeological and environmental geological disasters on geological structures cannot be ignored. Over-exploitation of groundwater can cause the loss of support for underground rock and soil masses, triggering land subsidence and collapse, damaging the stability of building foundations, and threatening urban safety. Reservoir impoundment increases pressure on the rock and soil masses of the reservoir banks, potentially inducing geological disasters such as landslides and collapses, thereby altering the original geological landscape. Large-scale excavation and blasting in mining activities destroy the integrity of rock masses, leading to geological problems such as goaf collapse and ground fissures, causing surface deformation and damage to structures. Moreover, changes in the distribution of crustal stress may induce secondary disasters such as earthquakes, causing more severe damage to the regional geological environment and affecting the stability and sustainable development of ecosystems [2].

3. Ecological Restoration Measures for Hydrogeological and Environmental Geological Disasters

3.1 Engineering Restoration Techniques

(1) **Anti-Slide Pile Systems** involve installing reinforced concrete piles or steel pipe piles at key locations within a landslide body. These systems utilize the lateral friction and embedment effect between the piles and the surrounding rock and soil to generate anti-slide force, preventing the movement of the sliding mass. During construction, pile diameter, length, and spacing must be calculated based on the landslide thrust to ensure the piles are embedded into stable strata. This technique is suitable for stabilizing medium to deep-seated landslides. It features minimal construction disturbance and strong anti-slide capacity, effectively controlling landslide deformation and ensuring the safety of engineering projects and the stability of the surrounding ecological environment.

(2) **Grouting Reinforcement** involves injecting cement-based or chemical grouts into fissures or pores within rock and soil masses. This fills voids and consolidates loose structures, thereby enhancing the integrity and strength of the stratum. Prior to construction, water pressure tests are typically conducted to determine the grout diffusion radius and optimize parameters such as grouting pressure and concentration. This technique is applicable for repairing geological defects like fault fracture zones and weak interlayers. It can reduce the permeability of surrounding rock, mitigate groundwater erosion of engineering structures, enhance foundation bearing capacity, and inhibit the occurrence of geological disasters.

(3) **Ecological Slope Protection** employs a combination of living plants and engineering materials. Herbaceous and shrub root systems anchor the soil, while structures like three-dimensional vegetation mats or eco-concrete provide structural support, forming a flexible protection system. Design must follow the principle of "ecology first, functional coordination,"

selecting drought-tolerant, fast-growing, deep-rooted native species. This technique can effectively control surface erosion, regulate soil temperature and moisture, promote microbial activity, and achieve the dual objectives of slope stability and ecological restoration, thereby enhancing the regional landscape value.

3.2 Bioremediation Techniques

(1) **Plant Community Reconstruction** involves the artificial configuration of native plants selected for their strong adaptability and well-developed root systems, simulating the structure of natural vegetation communities. This effectively restores the functions of damaged ecosystems. Plant root systems consolidate soil and reduce water and soil loss, while their transpiration regulates soil moisture and the microclimate, providing habitats for microorganisms and animals. Furthermore, plants can absorb and accumulate pollutants (e.g., heavy metals, organic compounds), reducing their bioavailability and promoting material cycling and energy flow. During reconstruction, competitive and synergistic relationships among plants must be considered to form multi-layered, multi-functional stable communities. This enhances the ecosystem's resistance to disturbance and self-recovery capacity, gradually restoring biodiversity and ecological service functions in the damaged area.

(2) **Microbial Remediation** utilizes the metabolic activities of indigenous or exogenous microorganisms to degrade pollutants in soil and water bodies, offering advantages such as low cost and environmental friendliness. For different pollutants, specific functional strains can be screened (e.g., Pseudomonas for degrading petroleum hydrocarbons, sulfate-reducing bacteria for treating heavy metals). By optimizing environmental conditions (e.g., pH, temperature, oxygen content) or adding nutrients, microbial activity and degradation efficiency can be enhanced. Microbial remediation can synergize with phytoremediation, forming a combined "plant-microorganism" remediation system. This accelerates the transformation and removal of pollutants while promoting the restoration of soil fertility and the reconstruction of ecological functions, enabling the sustainable remediation of polluted environments.

3.3 Combined Physical-Chemical Remediation

(1) **Aeration and Oxygenation** is a remediation method that involves introducing air into polluted water bodies or soil to increase the dissolved oxygen content. In water bodies, it improves anaerobic conditions, promotes the activity of aerobic microorganisms, accelerates organic matter decomposition and nitrogen cycling, and reduces the formation of black, odorous water and harmful substances. In soil remediation, it enhances soil aeration, benefiting plant root respiration and microbial metabolism. By rationally selecting aeration equipment and controlling aeration parameters, redox conditions can be effectively regulated, pollutant forms can be altered, toxicity can be reduced, thereby creating a favorable environment for ecological restoration.

(2) **Chemical Precipitation** removes pollutants by adding specific chemical agents to convert dissolved pollutants into insoluble precipitates. For heavy metal contamination, reagents react with metal ions to form stable precipitates, reducing their mobility and biotoxicity. For phosphorus-containing wastewater, adding iron or aluminum salts can combine with phosphates to form flocculent precipitates. Operation requires precise control of reagent dosage, reaction pH, and other conditions to prevent residual excess reagents. Precipitates must be properly treated to avoid secondary pollution and are often used in combination with other technologies to improve remediation efficiency.

3.4 Wetland Ecosystem Reconstruction

(1) **Constructed Wetlands** are engineered systems designed to simulate the ecological functions of natural wetlands for restoring damaged water environments. They utilize the synergistic effects of substrate, plants, and microorganisms for multi-stage wastewater purification. The substrate provides sites for physical filtration and adsorption, plants absorb nutrients and release oxygen, and microorganisms decompose organic matter. Construction requires rational planning and layout, selection of suitable plants and substrate, and control of hydraulic conditions. Constructed wetlands not only improve water quality but also provide habitats for organisms, enhancing ecosystem stability and self-repair capacity.

(2) **Ecological Floating Beds** are an ecological technology that uses floating carriers to grow aquatic plants for water purification. The floating carrier

provides a stable growth platform for plants, whose roots extend into the water, adsorbing pollutants and absorbing nutrients. They can inhibit excessive algal growth, increase dissolved oxygen in the water, and improve water quality and landscape. Ecological floating beds are flexibly deployable in different water bodies and do not consume land resources. Regular maintenance ensures their continuous purification function, promoting the restoration and balance of aquatic ecosystems.

3.5 Optimization of Monitoring and Early Warning Systems

(1) **InSAR Technology** monitors millimeter-scale surface deformation with high precision by comparing phase information from radar satellite images taken at different times, overcoming the spatial coverage and timeliness limitations of traditional monitoring methods. It does not require ground-based sensors, can operate all-weather penetrating clouds and fog, and can capture minor displacements of hazard bodies like landslides and land subsidence in near real-time, providing early warning of potential risks. However, factors like atmospheric delay and vegetation cover can interfere with monitoring accuracy, requiring multi-temporal data and model corrections to improve the reliability of deformation inversion, thereby providing crucial spatiotemporal data support for geological disaster prevention and control.

(2) **IoT Sensors** enable the construction of a real-time perception network by deploying multiple sensors (e.g., for displacement, stress, pore water pressure) to accurately capture the dynamic changes of geological hazard bodies. They offer timely data transmission, wide coverage, and support multi-parameter collaborative analysis, allowing for the rapid identification of early signs of disasters such as landslides and debris flows. However, challenges related to sensor power supply, durability, and data redundancy need to be addressed. Integration through IoT platforms can achieve an upgrade from local monitoring to regional early warning, providing second-level decision support for emergency response [3].

Conclusion

Hydrogeological and environmental geological disasters act like a "double-edged sword," impacting the ecological environment across multiple dimensions—they disrupt the natural cycle of hydrological systems, leading to water resource imbalance; erode soil structure, reducing land productivity; fragment biological habitats, threatening species survival; and disturb the balance of geological stress, inducing secondary disasters. Facing these challenges, ecological restoration must uphold the philosophy of "prioritizing natural recovery, supplemented by artificial intervention." Through methods such as engineering soil stabilization, biological revegetation, and physical-chemical purification, the function and stability of damaged ecosystems can be rebuilt.

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