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Progress and Prospects in Mine Ecological Restoration in China

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Abstract:

Mineral resource development has triggered and generated a series of ecological problems in mining areas. Large-scale, high-intensity mineral extraction stands as the most active and

dominant anthropogenic geological force affecting and altering the ecological environment of mining regions, acting as a "catalyst" that exacerbates ecological changes therein. Once changes in the mine geological environment exceed its carrying capacity, a host of acute ecological issues arise, including sudden geological disasters, degradation of water and soil environmental quality, loss of biodiversity and disruption of ecological balance, and blockage of water system connectivity—all of which threaten the safety of normal mine production and human settlement environments.Guided by General Secretary Xi Jinping's vision that Lucid waters and lush mountains are invaluable assets, China has made remarkable progress in mine environmental governance. Nationwide, 52 holistic ecological conservation and restoration projects for mountains, rivers, forests, farmlands, lakes, grasslands, and deserts and 49 demonstration projects for ecological restoration of historically abandoned mineshave been launched. A complete set of ecological restoration technologies has been developed, and in 2022, China's Shan-Shui Initiative (the holistic conservation and restoration project) was selected as one of the UN's first batch of 10 World Restoration Flagships.

1. History of Mine Ecological Restoration

In the 1990s, mine land reclamation evolved from a spontaneous and scattered state to a purposeful, organized, planned and phased stage. In 1995, the National Environmental Protection Administration organized the "Investigation and Research on the Damage and Restoration of Ecological Environment in Mining Areas", making mine land reclamation a hot topic (Hu Zhenqi et al., 2008). Since 2001, the former Ministry of Land and Resources and the Ministry of Finance have carried out comprehensive treatment of historical mine geological environments through the proceeds from exploration and mining rights, including the prevention and control of mine geological disasters, treatment of coal mining subsidence areas, reclamation of abandoned land, and treatment of coal gangue piles. During the same period, the China Geological Survey successively deployed a series of investigations and prevention efforts for mine geological environments. The Xi'an Center of China Geological Survey launched the "Environmental Geological Survey on the Development of Different Types of Mineral Resources in Northwest China", initiating national mine geological environment surveys (Xu Youning et al., 2022). In 2007, the former Ministry of Land and Resources issued the industry standard Specification for Compilation of Mine Environmental Protection and Comprehensive Treatment Plans (DZ/T 223—2007), advancing the prevention and control of mine geological environments from a management and regulatory perspective.

The year 2009 marked a milestone: China officially promulgated the first law on mine ecological restoration, the Provisions on the Protection of the Geologic Environment of Mines (Order No. 44 of the Ministry of Land and Resources of the People's Republic of China), which set clear objectives and requirements for ecological protection and reclamation in mining areas. In 2011, the State Council of the People's Republic of China promulgated Order No. 592, the Regulation on Land Reclamation of the People's Republic of China, standardizing mine land reclamation. In 2016, the former Ministry of Land and Resources issued the Guidelines for Compilation of Mine Geological Environment Protection and Land Reclamation Plans, formally integrating the compilation of Land Reclamation Plans and Mine Geological Environment Protection and Restoration Plans. By 2018, China had essentially established a fund system for mine geological environment restoration and treatment, improved supervision and management systems, built technical support systems, and accelerated the restoration of geological environments for both active and historical mines. Historical mine geological environment problems have been gradually addressed, and the overall quality of mine geological environments has improved. With the proposal of the Five-sphere Integrated Plan for ecological civilization construction, China has made groundbreaking progress in territorial space ecological restoration, established a comprehensive treatment system for the systematic restoration of mountains, rivers, forests, farmlands, lakes, grasslands and deserts, and initially formed a new pattern of ecological restoration. China has gradually adopted Nature-based Solutions (NBS) to address mine ecological issues. In August 2024, the Ministry of Natural Resources issued a series of specifications titled Mine Land Reclamation and Ecological Restoration. On November 8, 2024, the Mineral Resources Law of the People's Republic of China (Revised Draft) (hereinafter referred to as the "New Mineral Resources Law") was adopted at the 12th Session of the Standing Committee of the 14th National People's Congress and will come into force on July 1, 2025. The new law establishes a highly operable system for mine ecological restoration.

2. Major Progress in Mine Ecological Restoration Technologies

Geological Hazard Elimination Technology,Geological safety hazards refer to geological phenomena endangering human life and property in and around mining areas induced by natural factors or human activities, mainly including collapse, landslide, debris flow, ground subsidence, ground fissures, land settlement and other geological disasters. Based on respecting, conforming to and protecting nature, priority is given to eliminating potential geological risks in mine restoration. Core technologies include unloading & counter-pressure stabilization, anti-slope retaining structures, anchor bolt and cable reinforcement, grouting consolidation, drainage diversion measures, and vegetation protection engineering.

Aquifer Reconstruction Technology,Open-pit and underground mining severely disturb the original aquifer structure, damage water connectivity and primitive habitats, alter groundwater recharge-runoff-discharge conditions, reduce precipitation infiltration capacity, and further weaken regional water conservation and threaten water quality safety. Physical reconstruction methods are widely adopted, such as floor reconstruction technology to control water inrush hazards in strongly confined aquifer intercepting zones of mines.

Landform and Landscape Reconstruction Technology,Mining activities cause severe damage to landforms, cultural landscapes and geological relics. Restoration technologies are classified by slope gradient:(1)Flat excavation restoration: Large abandoned mining pits with huge elevation differences can be reconstructed into reservoirs, fish ponds, water parks or industrial water supply reservoirs. Open pits with unique geological features can be partially preserved as geopark relics.(2)Gentle slope restoration (slope < 30°, maximum 45°): After cleaning loose rocks and dangerous boulders on slopes, conventional technologies include 3D vegetation net greening, ecological vegetation blanket protection, ecological grouting restoration, hydraulic seed spraying, geocell protection, and gabion retaining wall greening.(3)Steep rocky slope restoration (slope > 45°): Representative technologies cover green barrier construction, filling slope reshaping & greening, platform excavation greening, ecological bag protection, waste slope protection with discarded tires, fish-scale pit afforestation, planting hole/trough greening, and net-s spraying mixed soil vegetation restoration.

Water and Soil Remediation Technology Water and soil pollution is a critical environmental problem caused by mining, making targeted remediation essential. Common approaches consist of biological, physical and chemical remediation. Biological remediation introduces specialized microorganisms and plants to degrade pollutants; physical remediation removes contaminants via physical separation; chemical remediation treats and reduces pollutants through chemical reactions, including electrokinetic remediation and chemical passivation.

Land Reclamation Technology Soil remediation occupies a core position in mine ecological restoration. Mining destroys soil structure, reduces soil fertility, and accumulates heavy metal pollutants, undermining ecosystem stability and sustainability. Soil improvement is the mainstream measure: adding organic matters, optimizing soil structure and adjusting chemical properties to enhance soil permeability, water retention capacity and fertility. Rational soil management also curbs soil erosion, preserves soil horizon integrity and promotes natural self-repair of soils.

Vegetation Reconstruction Technology Vegetation restoration rapidly rebuilds surface vegetation cover, stabilizes soil structure, enhances soil and water conservation capacity, and improves the anti-interference ability of ecosystems. It alleviates soil erosion and water pollution, provides diversified ecological services, and increases local residents' economic income. It is divided into two categories: artificial vegetation restoration and natural spontaneous restoration.

Biodiversity Restoration Technology Biodiversity underpins stable ecosystems, and its loss triggers ecological imbalance. A series of targeted measures are adopted to protect and reconstruct species communities around mines, including species conservation, habitat reconstruction, ex-situ protection of wild fauna and flora, and ecological compensation mechanisms.

3. Typical Modes of Mine Ecological Restoration in China

Loess Plateau Region Small watersheds are the basic unit for soil erosion research and comprehensive management in loess plateau mining areas. China's small watershed governance has achieved remarkable outcomes in grain yield improvement, sediment retention and grain-for-green projects. The integrated small-watershed system proposed by Chen Zuyu — combining distributed photovoltaic power, hydropower, ecological agriculture, animal husbandry and energy storage to realize solar-wind-water-terrace-agriculture-energy integration — provides an innovative pathway for mine ecological restoration in the Yellow River Basin. Based on pumped storage hydropower principles, wind and solar energy are converted and stored as water potential energy for power generation on demand, realizing holistic wind-solar-water coordinated management, which has been practiced in the Northern Shaanxi Energy & Chemical Base.

Qinba Mountainous Area Bedrock mountain areas feature thin soil and limited land resources, while favorable natural conditions make them suitable for developing mine geoparks and scientific research demonstration bases. The regional ecosystem covers basic geological backgrounds, ecological environments, residual mineral resources, and cultural landscapes formed by historical mining activities. Traditional restoration focused merely on hazard elimination, wasteland reclamation and greening. With ecological civilization elevated as a national strategy, modern restoration integrates natural ecosystems and socio-economic systems to optimize ecological services for local residents. An integrated governance system coupling natural environment, geological conditions, value exploration and fund guarantee has been established, represented by Tongguan National Geopark.

Ganzhou Region (Yangtze River Basin, Rare Earth Hubs): Known as the "Homeland of Rare Earths", Ganzhou has suffered long-term ecological degradation from over 40 years of rare earth exploitation. four mature restoration modes for abandoned rare earth mines have been formed:(1)Forest-Fruit-Grass Mode (Longnan): Multi-species configuration with pine trees on hilltops, herbaceous plants on slopes, mulberry on terraces and bamboo in valleys.(2)Forest(Fruit)-Grass-Fishery(Livestock) Mode (Longnan): Slopes renovated into forest，orchard，grassland; valleys and tailings ponds impounded after sewage purification for aquaculture and agricultural water supply; forage grasses support livestock breeding.(3)Pig-Biogas-Forest(Fruit) Circular Mode (Xinfeng): Swine manure decomposed by saprophytic organisms forms organic fertilizer, reacting physically and chemically with rare earth tailings to develop high-quality fertile soil, supporting economic forest cultivation and forming low-carbon circular eco-agriculture.(4)Industrial Park Reutilization Mode (Xunwu): Leveled abandoned rare earth mining land is transformed into industrial land for intensive rare earth deep-processing industries, promoting tailings resource utilization, which realizes multiple benefits in land conservation, resource recycling and environmental protection.

Hilly Coastal Areas of East China (Fankou Lead-Zinc Mine, Shaoguan) Sulfide minerals associated with lead-zinc mines oxidize chemically to generate heavy-metal acidic wastewater, resulting in acidified barren soil unsuitable for plant growth and threatening regional ecological safety. Local authorities adopted source control and diffusion interception measures, including in-situ substrate improvement + direct vegetation restoration, sewage diversion and centralized wastewater treatment. Up to now, native stable plant communities have been established on 320 mu of tailings ponds and 490 mu of tailings stacking areas, forming maintenance-free sustainable ecosystems. A national demonstration base for tailings ecological restoration has been built. Meanwhile, curtain grouting interception projects reduce underground mine drainage by over 7 million tons annually, ensuring safe mining of 5.3

million tons of high-grade ores valued at more than 15 billion RMB, delivering prominent ecological and economic benefits. This mode offers valuable experience for water hazard control and aquatic ecosystem restoration in karst underground mining areas across China.

4. Development Prospects

First, it is urgent to develop integrated sky-ground-human all-element, full-watershed monitoring technologies with real-time, high-efficiency and low-cost advantages for mine ecological restoration supervision. Second, establish a standardized evaluation system for restoration effectiveness tailored to regional geographical backgrounds, ecosystem types, mining modes and ecological damage degrees.

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