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Sustainability Analysis of Mine Rehabilitation Using Native Plants: A Case Study of the Qinling Mountains

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Abstract

This paper discusses the environmental impact of mining activities and the crucial role of native plants in ecological restoration. Case studies from the Qinling region demonstrate that native plants can effectively improve soil quality, increase biodiversity, reduce heavy metal pollution, and prevent soil erosion. By constructing a sustainability evaluation index system across ecological, economic, and social dimensions, the article assesses the long-term effects of restoration projects and proposes strategies to enhance their sustainability. Looking forward, technologies such as genetic engineering, microbe-plant interactions, intelligent management systems, and ecological engineering are set to further improve restoration efficiency. Artificial intelligence, in particular, will play a key role in data analysis, monitoring and early warning, automated management, and ecological model construction. In summary, the application of native plants in mine restoration is not only vital for ecological recovery but also significant for promoting socio-economic development. With the advancement of new technologies and societal participation, future mine restoration work will become more sustainable, bringing greater benefits to humanity and the natural environment.

Keywords

Phytoremediation; Mine Environment; Qinling; Sustainable.

1. Introduction

Mining activities, as a crucial means for humans to obtain natural resources, have always been a global environmental concern. Among various environmental issues, the ecological restoration of abandoned mines is particularly important[1-3]. Mining not only destroys the original landscape but also causes long-term negative impacts on soil structure, water quality, and biodiversity. Therefore, effectively restoring the ecosystems of abandoned mines has become an important research topic in environmental science and ecological engineering.

Among various restoration methods, using native plants for ecological restoration is considered an economical and efficient approach. Native plants are adapted to local climate and soil conditions, which can better promote the natural recovery of ecosystems[4, 5]. This is especially important in biodiversity hotspots like the Qinling region. The Qinling Mountains, marking the climatic divide between North and South China, are also habitats for a variety of plants and animals, making ecological restoration work crucial for maintaining biodiversity and regional climate balance[6].

This paper aims to discuss the sustainability of using native plants for mine restoration in the Qinling region. Starting with the current state of the mining environment in the Qinling area, it details the role of native plants in ecological restoration, evaluates the effects of restoration, and constructs an index system for assessing sustainability. Through these analyses, the paper hopes to provide references and insights for mine ecological restoration in the Qinling area and beyond.

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2. Current State of the Mining Environment in the Qinling Area

The Qinling Mountains, as the climatic divide between North and South China, are not only habitats for various rare plants and animals but also important biodiversity conservation areas in China. However, the rich mineral resources in the Qinling region have significantly impacted the natural environment due to long-term mining activities[7].

2.1. Impact of Mining Activities on the Environment

Mining in the Qinling area mainly focuses on metal and non-metal minerals, including iron, copper, gold, limestone, etc. These mining activities have directly led to the destruction of surface vegetation, soil structure, and a series of environmental problems such as soil erosion[8]. Rivers around the mining areas are severely polluted due to mineral extraction and waste disposal, damaging the ecosystem.

2.2. Environmental Characteristics of Abandoned Mines

Abandoned mines typically exhibit a lack of surface vegetation, reduced soil fertility, and increased heavy metal content. The natural recovery process of these lands is slow and requires human intervention to accelerate ecological restoration. The abandoned mines in the Qinling region face additional challenges due to the varied terrain and complex climate.

2.3. Current Restoration Challenges and Needs

Ecological restoration work in the Qinling area faces multiple challenges. Firstly, it is necessary to select plant species that are adapted to the local environment for restoration. Secondly, the restoration process must consider local climate conditions and how to effectively utilize limited water resources[9]. Additionally, the economic feasibility of restoration work and the monitoring and evaluation of restoration effects must be considered.

3. The Role of Native Plants in Ecological Restoration

Native plants, those naturally distributed and adapted to local environmental conditions, play an irreplaceable role in ecological restoration, not only greening and beautifying the environment but also restoring and maintaining the balance of ecosystems[10, 11].

3.1. Ecological Characteristics of Native Plants

Native plants are highly adaptable to the climate, soil, and other environmental factors of their growth location. They can grow under natural conditions, even in harsh environments; their growth cycles match the local seasons and climate, meaning they flower and fruit at the most suitable times, in sync with the life cycles of local insects and animals. Due to long-term evolution and natural selection, native plants often have good resistance to local pests and diseases, reducing dependence on pesticides; they are foundational to the ecosystem, providing food and habitat for local insects, birds, and other wildlife, key to maintaining biodiversity; their root systems contribute to the formation and maintenance of soil structure, improving soil aeration and water retention, and promoting nutrient cycling; the root structure of native plants helps stabilize the soil, reducing soil erosion, especially on slopes and in water catchment areas (Figure 1).

3.2. The Role of Native Plants in Soil Improvement

The roots of native plants can penetrate deep into the soil, forming root channels that increase soil porosity, thereby improving soil aeration and water permeability. Root growth also helps soil particles aggregate into clumps, improving soil structure, enhancing soil water retention and fertility; root exudates, such as organic acids and other metabolic products, can regulate soil pH, making the soil environment more suitable for plant growth. Rhizosphere exudates also

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increase the availability of nutrients in the soil, especially for insoluble nutrients like phosphorus;

The rhizosphere of native plants is a hotspot for microbial activity, with root-secreted nutrients supporting soil microbes, increasing microbial diversity and abundance. Soil microbes can decompose organic matter, release nutrients, promote nutrient cycling, and improve soil fertility;

Some native plants can absorb heavy metals from the soil through their roots, reducing the loss and spread of these harmful substances. Through accumulation and transformation within the plant, heavy metals are stabilized in plant tissues, reducing their risk to the environment and human health; the decomposition of plant residues is a major source of soil organic matter, and the death and decay of native plants provide rich organic matter for the soil. The increase in soil organic matter is crucial for improving soil fertility and biological activity, essential for restoring degraded soils; the roots of native plants can firmly fix the soil, reducing erosion by water and wind. Vegetation restoration is particularly important on slopes and in water catchment areas, effectively reducing soil erosion and protecting water quality.

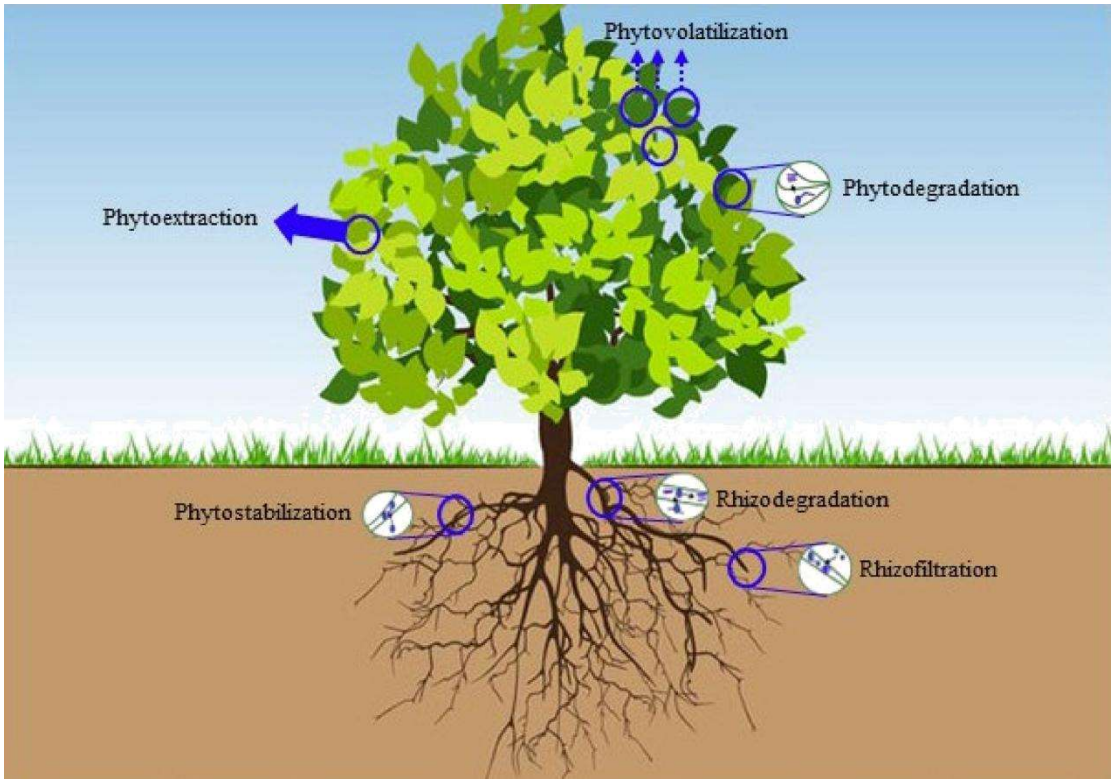

Figure 1. Various pollutant-removal phytoremediation techniques[1].

3.3. Advantages of Native Plants in Mine Restoration

Native plants are often closely connected with the culture and history of local communities, and their use helps protect and pass on local natural heritage and cultural traditions. Due to their strong adaptability to the local environment, native plants usually do not require additional fertilizers and water to maintain growth, thus reducing the long-term operational costs of restoration projects. The use of native plants contributes to the sustainability of restoration projects, as they can continue to grow and reproduce without human intervention. The use of native plants can stimulate public interest and participation in ecological restoration projects, enhancing awareness and responsibility for environmental protection.

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4. Case Analysis of Native Plant Restoration in the Qinling Area

In the practice of mine restoration in the Qinling area, the application of native plants has shown their important role in ecological recovery. By analyzing specific restoration cases, we can better understand the advantages and challenges of native plants in practical operations.

4.1. Restoration Cases in the Qinling Area

Case One: Ecological Restoration of an Abandoned Copper Mine at the Northern Foot of the Qinling Mountains

In an abandoned copper mine at the northern foot of the Qinling Mountains, a restoration project used various native plants for soil improvement and ecological restoration. The main plants included Qinling Viburnum and Qinling Maple, which not only adapted to the local climate conditions but also grew in soil contaminated with heavy metals. After several years of effort, these plants successfully improved soil structure, increased soil organic matter content, and provided habitats for insects and birds, promoting the recovery of biodiversity.

Case Two: Herbaceous Plant Cover in an Abandoned Limestone Mine on the Southern Slope of the Qinling Mountains

An abandoned limestone mine on the southern slope of the Qinling Mountains was restored using native herbaceous plants, mainly alfalfa and purple alfalfa. These plants covered the soil surface, effectively preventing soil erosion, while also providing resources for local pastoralism. The roots of alfalfa and purple alfalfa could stabilize the soil, improve soil fertility, and increase the nitrogen content in the soil through nitrogen fixation, thereby enhancing the overall productivity of the soil[12].

Case Three: Heavy Metal Pollution Remediation in an Abandoned Gold Mine in the Eastern Section of the Qinling Mountains

In an abandoned gold mine in the eastern section of the Qinling Mountains, the restoration project selected a heavy metal-tolerant native plant, Qinling Clematis, for soil remediation. Qinling Clematis could grow in soil with high concentrations of heavy metals, reducing the impact of these pollutants on the environment through absorption and accumulation by its roots. Additionally, the beautiful flowers of the plant attracted many pollinating insects, helping to increase biodiversity.

4.2. Assessment of Restoration Effects

In all cases, the introduction of native plants significantly increased the soil organic matter content, determined by measuring the organic carbon in the soil. The physicochemical properties of the soil, such as pH, electrical conductivity, and nutrient content (especially nitrogen, phosphorus, and potassium), were also improved, helping to enhance soil fertility and support more plant growth. After planting native plants, an increase in the number and variety of insects and birds was observed, indicating a restoration of biodiversity. This was assessed by regularly monitoring animal activity within the vegetated areas. Plant diversity also increased, not only the restoration plants themselves but also other native plants that subsequently colonized naturally. In the case of the abandoned gold mine, by measuring the heavy metal content in plant tissues and soil samples, it was found that native plants effectively stabilized heavy metals in the soil, reducing their bioavailability. In the case of the limestone mine area, vegetation cover reduced soil erosion, assessed by comparing soil erosion rates before and after restoration.

4.3. Existing Problems

Although native plants performed well in restoration, there were also some problems, such as the slow growth rate of some plants, making the restoration effects not immediately apparent. Additionally, for areas with severe heavy metal pollution, relying solely on native plants for

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restoration may not achieve the desired effects, and other restoration techniques need to be combined. In summary, the native plant restoration cases in the Qinling area provide valuable experience and lessons. Through these case analyses, we can better understand the role of native plants in mine restoration and how to optimize restoration strategies to improve sustainability.

5. Future Prospects

5.1. Application of Genetic Technology in Plant Restoration

Genetic editing technologies like CRISPR/Cas9 can be used to develop native plant varieties better adapted to harsh environments[13], such as improving plant tolerance to drought, saline-alkali soils, and heavy metals. Genetic technology can also enhance plant growth rates and biomass yield, thereby accelerating the restoration process.

5.2. Synergistic Restoration with Microbes and Plants

Research into plant rhizosphere microbial communities can lead to the development of microbial fertilizers that promote plant growth and soil restoration. Microbe-plant interaction techniques can improve the efficiency of nutrient absorption from the soil by plants, especially in nutrient-poor abandoned mine lands[14].

5.3. Intelligent Restoration Management Systems

Intelligent soil and vegetation monitoring systems can be developed, utilizing Internet of Things (IoT) technology to monitor environmental changes in restoration areas in real-time[15]. Combined with big data analysis and artificial intelligence, these systems can predict potential issues during the restoration process and propose solutions. Integrating ecological restoration with landscape design can create areas that are both ecologically functional and aesthetically pleasing. Ecological engineering methods, such as constructing wetlands and artificial water bodies, can enhance the self-recovery ability of ecosystems.

Artificial intelligence can process and analyze vast amounts of soil, climate, and biodiversity data, helping scientists identify patterns and trends during the restoration process. Machine learning algorithms can predict which native plants are most suitable for specific mine environments, thus increasing the success rate of restoration. AI technology can develop real-time monitoring systems to continuously observe environmental changes in restoration areas. AI systems can issue timely warnings when conditions unfavorable to plant growth arise, allowing for swift action. AI can also be used to build and optimize ecological models, simulating the long-term ecological effects of different plant restoration strategies. These models assist scientists and decision-makers in selecting the most effective restoration methods and predicting their impact on ecosystems.

6. Conclusion

Mining activities have significantly damaged the ecological environment, and ecological restoration work is crucial for the recovery of biodiversity and ecosystem services. Native plants, with their strong adaptability and ecological functions, play an irreplaceable role in mine restoration. They not only improve soil quality but also promote the recovery of biodiversity and enhance ecosystem stability. Case analyses from the Qinling region have shown the significant effects of native plants in improving soil quality, increasing biodiversity, reducing heavy metal pollution, and preventing soil erosion. The establishment of a sustainability evaluation index system is essential for monitoring and assessing the long-term effects of restoration projects. Cases from the Qinling region demonstrate that the use of native plants contributes to the sustainability of restoration efforts.

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