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Eco rehabilitation of degraded coal mines through forestry: A comprehensive review

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ABSTRACT

The environmental degradation caused by coal mining has raised global concerns, prompting the need for sustainable and innovative approaches to restore these degraded landscapes. Eco rehabilitation, mainly through forestry practices, has emerged as a promising solution. This review paper aims to comprehensively examine the principles, methodologies, challenges, and ecological benefits of eco rehabilitation in degraded coal mines using forestry techniques. By analysing a wide range of scientific literature and case studies, we highlight the potential of forestry-based eco rehabilitation as a means to not only remediate the damage but also promote biodiversity, carbon sequestration, and socio-economic development in mining-affected regions.

Key Words - Kaviraj, Vitaceae, Cementing, Breakage, Stomata, Pharmacognostic

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INTRODUCTION

The global demand for coal has led to extensive mining activities, resulting in the degradation of landscapes, loss of biodiversity, and significant ecological and environmental consequences. Mining is the extraction of geological materials or other valuable minerals from either the surface or deep down the earth, mainly from an orebody. According to studies (Amponsah-Tawiah and Dartey-Baah, 2011; Jain *et al.*, 2016a), "mining is defined as the process of excavating into the earth to extract naturally occurring minerals usually of high value." It strengthens and underpins the industrial development of many countries. Mining also provides economic and social development, employment, and the supply of essential raw materials for society and has the potential to bring economic, social, and infrastructure development to remote and poorly developed areas (Coelho *et al.*, 2011; Haddaway *et al.*, 2019; Hossain *et al.*, 2013). There are mainly two types of mining, thus surface mining and underground mining. Surface mining purposely exhumes ores at the surface or close to the earth's surface, including open-pit mining and dredging. Underground mining, however, removes minerals such as in hard-rock mining by extracting under the surface and removing the ore (Aryee *et al.,* 2003; Balasubramanian, 2017; Gibria, 2014; Northey *et al.*, 2013). Surface mining, particularly the open-pit method, is practised in many developing nations, especially in Africa, by illegal small-scale and artisanal miners (Balasubramanian, 2017). It requires relatively less initial capital investment and is executed mainly by small indigenous artisans with fewer workers (Mensah *et al.,* 2015). However, underground mining uses high-level machinery with a considerable level of sophistication and high demand for labour. It is mainly used to exhume hard minerals, usually those containing metals deep down from the ground (Balasubramanian, 2017). As the world population continues to surge, coupled with industrialization, the quest for mineral exploration increases daily (Gathuru, 2011). The outcome of these mineral explorations on the environment and nearby communities poses both negative and positive impacts (Haddaway *et al.*, 2019). Moreover, the amount of waste generated from mining and its overall adverse effect on the land, environment, water, soil, and air are enormous. Mining reaps agricultural lands of their value, which creates many hardships in the lives of people living within the mines (Haddaway *et al.*, 2019). Once the environment is destroyed, prices of most necessities such as food, accommodation, and water shoot up (Festin *et al.,* 2018). Mining ultimately alters the entire ecosystem, which leads to substantial land-use changes that generally affect the global economy. Recognizing the need for sustainable reclamation strategies, eco rehabilitation through forestry has gained attention as a practical approach to mitigate the negative impacts of coal mining and restore the ecosystem's health. This review paper aims to provide a comprehensive overview of the eco-rehabilitation of degraded coal mines using forestry techniques, highlighting the key concepts, methodologies, challenges, and ecological benefits.

Jharkhand, a state in eastern India, has a significant coal mining industry. Gondalpara Coal Fields in Jharkhand, located in Hazaribagh, Jharia, is the largest coal field in the state. Other coal fields include Chakla (Latehar), Choritand Tiliaya (Bokaro), Rajhara North (Central and Eastern Palamu), and Chitarpur (Latehar), Giridih, Ramgarh, Karanpura, and Daltonganj. Jharkhand has a total of 120 coal mines, contributing to approximately 26% of all coal mines in India (Singhal *et al.*, 2022).

Coal mining has a significant impact on habitats and ecosystems, particularly through deforestation. One of the primary environmental consequences of coal mining is widespread deforestation. Large-scale mining operations often necessitate clearing vast expanses of land, leading to the loss of critical ecosystems and biodiversity (Bauerek, 2024). Mining activities involve excavation pits and the creation of access roads, both of which contribute to habitat destruction (Maxwell, 2023). Cleared for mining operations, forested areas lose their ecological functions, disrupt wildlife habitats, and reduce overall biodiversity. Beyond direct deforestation, there are indirect impacts associated with mining. These include Infrastructure Development, as mining requires energy, processing, and storage facilities. As a result, infrastructure (such as power plants, processing plants, and storage areas) is built near the mine site, leading to further deforestation. Mining operations employ a workforce, resulting in in-migration and the expansion of settlements. As these settlements grow, so does development in the area, leading to additional habitat loss. Gold and coal are the major drivers of deforestation due to mining. Together, they have resulted in an estimated 6,877 square kilometres (4,273 square miles) of forest loss over the last two decades. Other minerals like bauxite, iron ore, and copper also contribute to deforestation.

Ecological restoration of coal mining areas plays a crucial role in achieving sustainable development goals. Surface mining, the most common coal mining technique, severely disrupts soil profiles, leading to soil fertility loss and reduced carbon stocks. Reforestation and sustainable land management practices can enhance ecosystem carbon pools and sequester atmospheric CO_2. This helps offset CO_2 emissions resulting from coal mining and contributes to climate change mitigation. Restoration efforts restore biodiversity, soil stability, and hydrological balance. By reinstating natural ecosystems, we ensure ecosystem services such as clean water, nutrient cycling, and habitat provision. Restoration creates jobs and supports local communities. It also prevents water contamination and stabilizes soil, promoting sustainable land use. In summary, ecological restoration is a "green and sustainable strategy" that benefits both the environment and society.

Principles of Eco Rehabilitation in Coal Mines

2.1. Reforestation and afforestation

• Planting trees and other vegetation to establish a green cover on the barren or disturbed land. Selecting suitable tree species based on their adaptability to local conditions, ability to improve soil structure, and support biodiversity.

2.2. Soil improvement and erosion control

• Trees play a crucial role in preventing soil erosion by stabilizing the soil structure with their root systems. The accumulation of organic matter from leaf litter and root decomposition enhances soil fertility and nutrient content.

2.3. Native species selection

Prioritizing the use of native plant species to restore and maintain the original ecosystem structure. Native species are often better adapted to local conditions, provide habitat for indigenous wildlife, and contribute to overall ecosystem resilience.

Some Plant Species	Ecological Significance
1. *Vetiver* Grass	Soil binding, erosion control, and water filtration.
2. Willow (Salix spp.)	Effective in stabilizing soils due to deep roots.
3. *Acacia* spp.	Nitrogen fixation, soil improvement, and habitat creation.
4. *Eucalyptus* spp.	Fast-growing, soil stabilization, and wood production.
5. *Casuarina* spp.	Drought tolerance, soil improvement, and windbreaks.
6. *Leucaena leucocephala*	Nitrogen fixation, biomass production, and erosion control.
7. *Pinus* spp.	Soil binding, carbon sequestration, and timber production.
8. *Jatropha curcas*	Biodiesel production, soil improvement, and erosion control.
9. *Sesbania sesban*	Nitrogen fixation, fodder production, and soil improvement.
10. *Aloe vera*	Medicinal properties, drought tolerance, and soil binding.

2.4. Monitoring and adaptive management

Implementing a robust monitoring system to assess the success of rehabilitation efforts over time. Adapting management strategies based on monitoring results to address challenges and optimize outcomes.

METHODOLOGIES AND TECHNIQUES

3.1. Planting techniques

The eco-rehabilitation of degraded coal mines through forestry involves the implementation of various methodologies and techniques to restore ecosystems and promote sustainable vegetation growth. Planting techniques are a crucial aspect of this process, and they need to be adapted to the specific conditions of the site Here are some key methodologies and planting techniques commonly used in the forestry-based rehabilitation of degraded coal mines:

Before initiating any planting activities, conduct a thorough site assessment to understand the soil conditions, topography, climate, and the extent of degradation. This information helps in selecting appropriate plant species and designing effective planting strategies.

Soil Preparation:

Prepare the soil by addressing issues such as compaction and lack of nutrients. Techniques such as ploughing, subsoiling, or adding organic amendments can improve soil structure and fertility, creating a more favourable environment for plant establishment.

Species Selection:

Choose native plant species that are well-adapted to the local climate, soil conditions, and ecosystem. Native species are more likely to thrive, contribute to biodiversity, and support the area's overall ecological health.

Nursery Propagation:

Establish nurseries to propagate and grow seedlings. Use seeds or cuttings from locally adapted plant species. This allows for the production of a sufficient number of healthy and genetically diverse seedlings for transplantation.

Direct Seeding:

Direct seeding involves sowing seeds directly into the degraded site. This technique can be cost-effective and suitable for large-scale projects. Adequate soil preparation and protection against seed predation are essential for successful direct seeding.

Container Planting:

A common technique is planting seedlings grown in containers. Container planting allows for better control over seedling quality, and the established root system enhances the chances of survival after transplantation.

Shelterbelts and Windbreaks:

Establishing shelterbelts and windbreaks using fast-growing and hardy tree species can help protect other plants from harsh environmental conditions, such as strong winds. These structures create a microclimate that supports the growth of more sensitive species.

Mycorrhizal Inoculation:

Inoculating plant roots with mycorrhizal fungi can enhance nutrient absorption and improve plant growth. This technique is particularly useful in degraded soils with low nutrient levels.

Water Management:

Implement water management strategies, such as contour trenching or check dams, to prevent soil erosion and improve water retention. Adequate water supply is crucial for the establishment and survival of newly planted vegetation.

Mulching:

Apply mulch to the soil surface around newly planted seedlings to reduce moisture evaporation, suppress weed growth, and protect against temperature extremes. Organic materials like straw or wood chips are commonly used for mulching.

Monitoring and Adaptive Management:

Monitor the planted area regularly for plant health, survival rates, and any signs of stress. Implement adaptive management strategies to address challenges such as invasive species, diseases, or unfavorable weather conditions.

Community Engagement:

Involve local communities in the planting process to foster a sense of ownership and ensure the long-term success of the rehabilitation project. Community participation can also provide valuable knowledge about local ecosystems.

Post-Planting Care:

Provide post-planting care, including irrigation, weeding, and protection from herbivores. This care is critical during the initial stages of plant establishment to increase survival rates.

Succession Planning:

Plan for ecological succession, considering the natural progression of vegetation over time. This involves selecting species that are adapted to different stages of ecosystem development.

3.2. Watershed management

Mitigating the impact of mining activities on water quality and hydrological systems. Trees help regulate water flow, reduce runoff, and filter pollutants, contributing to improved water quality.

3.3. Wildlife habitat restoration

Creating habitat corridors and promoting diverse plant and animal species. Monitoring the recovery of biodiversity, including the reintroduction of native species and the establishment of sustainable ecosystems.

3.4. Community involvement

Involving local communities in the rehabilitation process, considering their traditional knowledge and needs. Providing employment opportunities through forestry activities and fostering community stewardship.

4.1 Challenges and Limitations

Eco-rehabilitation of degraded coal mines through forestry can be hindered by various financial constraints. Overcoming these challenges requires careful planning, resource mobilization, and the establishment of sustainable funding mechanisms. Here are some common financial constraints associated with the eco-rehabilitation of degraded coal mines through forestry:

Initial Capital Costs:

The upfront costs associated with soil remediation, reforestation, and other rehabilitation activities can be substantial. Acquiring the necessary funds for initial capital investments can be a significant challenge, particularly for large-scale projects.

Government Budget Constraints:

Governments often play a crucial role in funding or supporting eco-rehabilitation projects. However, budget constraints and competing priorities may limit the allocation of sufficient funds for large-scale rehabilitation initiatives.

Lack of Access to Financial Instruments:

Communities or organizations involved in eco-rehabilitation projects may face challenges in accessing financial instruments, loans, or grants. Limited financial resources can impede the implementation and success of rehabilitation efforts.

Market Dynamics:

The lack of market incentives for ecological services, such as carbon sequestration or water purification provided by reforested areas, can pose challenges for generating revenue to support ongoing maintenance and management activities.

Risk Perception:

Financial institutions and investors may perceive eco-rehabilitation projects as having higher risks compared to traditional investments. Mitigating these risks through effective planning and communication is crucial for attracting funding.

4.2 Capacity Building:

Insufficient expertise and capacity within local communities or organizations responsible for eco-rehabilitation can limit their ability to attract funding. Building the necessary skills and knowledge is essential for successful project implementation.

4.3. Long-term maintenance

Successful rehabilitation requires ongoing monitoring and maintenance to ensure the health and resilience of the reforested ecosystems. Adequate resources and commitment are needed to address challenges such as wildfires, disease outbreaks, and other disturbances that may affect the restored areas.

4.4. Invasive species and pest management

Degraded areas are often susceptible to the invasion of non-native and invasive plant species, which can out-compete native vegetation and hinder ecosystem recovery. Monitoring and management plans are essential to control invasive species and prevent pest infestations that may impact the success of reforestation initiatives.

4.5. Regulatory and policy issues

Developing and implementing effective regulatory frameworks for eco-rehabilitation, including land reclamation and environmental protection measures, is essential. Inconsistent or inadequate regulations may impede the progress of rehabilitation projects and lead to uncertainties in the long-term success of forestry-based initiatives.

Ecological Benefits of Forestry-based Eco Rehabilitation

5.1. Biodiversity conservation

Restoration of native vegetation through forestry helps create or enhance habitats for a diverse range of plant and animal species. Well-managed forests provide food, shelter, and breeding grounds for various wildlife, contributing to the conservation of biodiversity.

5.2. Carbon sequestration and climate change mitigation

5.3. Improved water quality

Forests act as natural water filters by trapping sediments and pollutants, improving water quality. Tree canopies reduce water runoff, allowing water to infiltrate into the soil, replenishing groundwater and maintaining streamflow.

5.4. Aesthetic and recreational value

Improved Microclimate:

Forests influence local climate conditions by regulating temperature and humidity. They provide shade, reduce temperatures, and cool the surrounding environment. Trees release water vapour through transpiration, contributing to the formation of clouds and influencing precipitation patterns.

Habitat Connectivity:

Well-planned forestry-based eco-rehabilitation projects can establish corridors between fragmented habitats, promoting connectivity for wildlife movement. Connected habitats allow for the natural migration of species, maintaining genetic diversity and ecological balance.

Prevention of Invasive Species Spread:

Reforestation efforts can help suppress the spread of invasive plant species by establishing competitive native vegetation. Healthy forests are less susceptible to invasions, contributing to ecosystem resilience.

Case Studies

6.1. Appalachia, USA

Alley cropping is an agroforestry practice that involves planting rows of trees and/or shrubs to create alleys within which agricultural or horticultural crops are produced. It is particularly appealing to producers interested in growing multiple crops on the same land to manage risk and improve whole-farm production and profitability. Alley cropping is also supported by the USDA Natural Resources Conservation Service as a Conservation Practice (311). NRCS describes alley cropping as having several conservation purposes, including reducing surface water runoff and erosion, improving soil health, altering subsurface water quantity or water table depths, enhancing wildlife and beneficial insect habitat, increasing crop diversity, and increasing carbon storage.

6.2. Ruhr, Germany

The Ruhr region is located in the heart of the North-Rhine Westphalia state in western Germany. It is one of the largest metropolitan areas of Europe with more than 5 million inhabitants extending over 130 km from west to east and 35 km from south to north, covering an area of ?4600km2 between the valleys of the Ruhr, Emscher, Lippe, and Rhine rivers. The Ruhr district heating network supplies 6500GWhyear?1 with an installed thermal capacity of 2310 MWth (Bartelt *et al.* 2013).

6.3. Jharia Coalfield, India

Jharia is also infamous for the widespread development of surface and subsurface fires due to unsustainable mining practices. These fires are burning over nearly a century and are a major cause of air pollution, loss of vegetation and subsidence.

CONCLUSION

Eco rehabilitation through forestry in degraded coal mines offers a multifaceted solution to address the environmental and ecological challenges posed by coal mining activities. This comprehensive review has highlighted the principles, methodologies, challenges, and ecological benefits associated with forestry-based eco rehabilitation. While there are challenges to be overcome, the positive outcomes in terms of biodiversity conservation, carbon sequestration, improved water quality, and socio-economic development make this approach a compelling option for restoring the ecological balance in mining-affected regions.

The successful implementation of forestry-based eco rehabilitation requires a multidisciplinary approach, involving collaboration between government agencies, mining companies, environmental organizations, and local communities. As we move forward, continued research, technological innovations, and policy enhancements will be essential to maximize the effectiveness of eco-rehabilitation efforts and ensure a sustainable future for regions impacted by coal mining.

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