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# Technogenically Disturbed Lands of Coal Mines: Restoration Methods

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## ABSTRACT

The issues of human impact on the environment are evident and pose a threat to the health and well-being of future generations. Technogenic disturbances in coal mining sites, such as open pits, excavations, and industrial waste, pose risks to both human health and the environment. Open-pit coal mines not only frequently cause the destruction of natural ecosystems, including landscapes, vegetation, and biodiversity, but they also significantly contribute to greenhouse gas emissions into the atmosphere. Addressing the carbon footprint necessitates not only the use of renewable energy but also the restoration of disturbed landscapes and vegetation, including trees and shrubs. All of this is achieved by implementing biological remediation within technogenically disturbed territories. This process fosters a return of biological balance and establishes favorable conditions for plant and animal life, while at the same time reducing carbon footprint indicators. The biological remediation of areas affected by the mining activities of coal mines can create new economic opportunities. The reclaimed land can be utilized for various purposes such as agriculture, forestry, park development, and tourism, thereby contributing to local economic growth and job creation. When planning measures for land bioremediation, it is essential to analyze all quality indicators of the land. In this case, the selection of technologies such as plants, fertilizers, and microorganisms can effectively restore territories.

## INTRODUCTION

Human activities in general, and those associated with mining in particular, have a negative impact on ecosystems. The activities of the coal mining industry give rise to a range of environmental concerns that harm the environment. These include the destruction of ecosystems, which can lead to the loss of animal and plant species, deforestation, and a reduction in biodiversity; additionally, there is a risk of soil degradation and the release of greenhouse gases, which contribute to global climate change and the gradual warming of the planet; health of people, especially those living localized near the mine; pollution of water resources; damage to the landscape with deformation of the land surface). All of these factors necessitate the search for and development of environmentally friendly, green, and long-term alternative technologies for obtaining energy, producing goods in an environmentally responsible manner, and reducing the negative impact of mining activities on the environment. A targeted, comprehensive program is required to restore natural systems that have been damaged by human activities to preserve ecosystems for future generations. Measures to restore damaged landscapes and improve fertile soil quality hold a special place. In general, biological remediation of technogenically disturbed areas of coal mines contributes significantly to nature conservation, environmental rehabilitation, and the improvement of people's lives. Biological remediation can help to create a clean and healthy living environment, which benefits the overall health and well-being of the community.

We consider forestry and agricultural purposes of land reclamation to be the priority areas of land reclamation (Vesnina & Fotina 2023). The main stages of land remediation implementation are depicted in Fig. 1.

The choice of reclamation direction is primarily motivated by the need to organize efficient, cost-effective territory restoration. It is necessary to observe the following

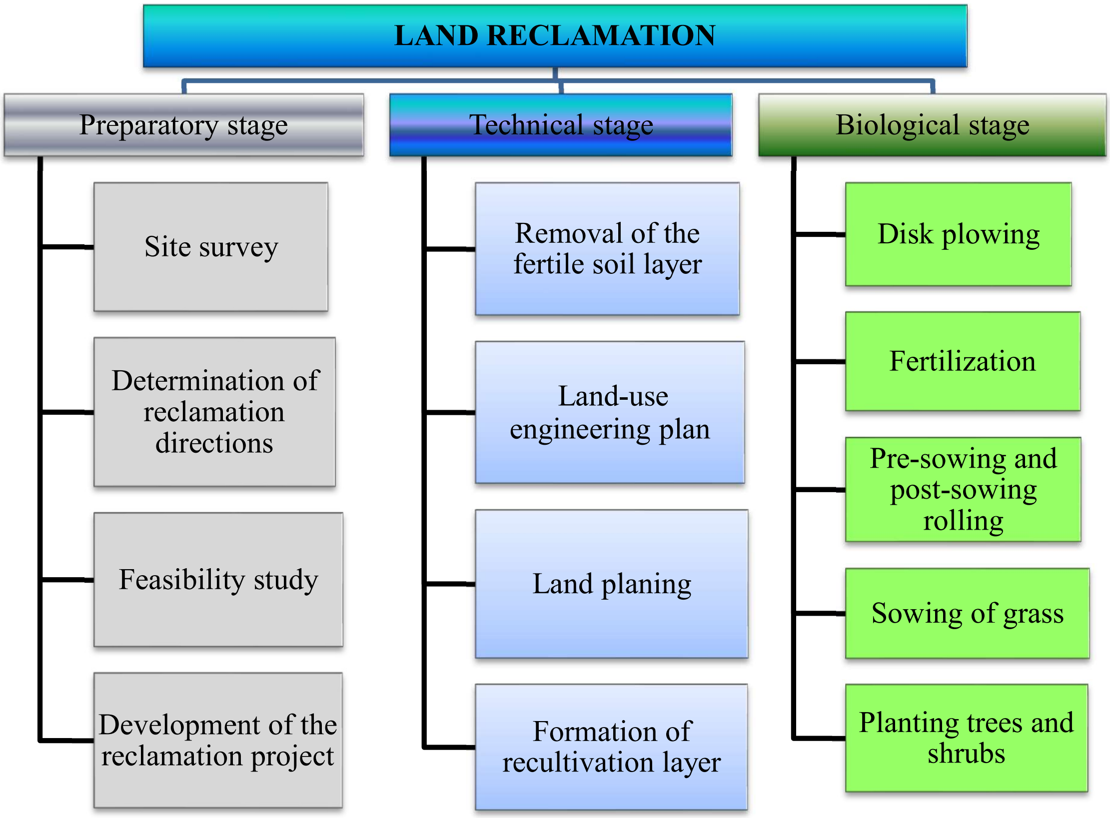


Fig. 1: Main stages of reclamation of technogenically disturbed lands.

conditions: Planning works to ensure soil stability in the process of realization of the technical stage of reclamation; the need to incorporate a comprehensive range of agro-technical and biological measures into the biological phase of biological reclamation of disturbed land to establish conditions for the restoration of biological productivity; production wastes of hazard class I-IV are not used in the reclamation process; to restore disturbed lands for forestry and/or agricultural use, all planned agrotechnical and phyto ameliorative measures will be carried out as part of the biological phase of reclamation (the application of mineral fertilizers, the sowing and planting of plants, and the maintenance of plants are carried out until the land is transferred to the owner; zonal biological rehabilitation of disturbed lands is carried out as part of the biological stage of land reclamation).

The study aimed to analyze existing foreign and domestic experience in the field of reclamation of technogenically disturbed lands.

## MATERIALS AND METHODS

### Objectives of the Study

The primary methods and technologies for reclaiming technogenically disturbed lands, including coal mines, were the focus of the research. The was based on a bibliographic search and subsequent critical analysis of net resources and scientific manuscripts devoted to environmental problems and solutions to coal mining.

### Research Methods

The explorer was based on a bibliographic search and subsequent critical analysis of net resources and scientific manuscripts devoted to environmental problems and solutions of coal mining. Materials from open Internet sources and Scopus citation database were used. Considering the dynamism of reclamation technique development and the problem of technogenically disturbed lands, the depth of the search was limited primarily to the last five years, with the utility of citing some earlier works on specific issues of restoration of disturbed lands, phyto- and reclamation determined by the uniqueness and peculiarity of the results provided in them.

## RESULTS AND DISCUSSION

Plants stimulate the growth and activity of soil microbes, releasing organic and nutritive substances and oxygen and enriching the microenvironment. It is also known that the synergistic interaction of microorganisms, plants, and the organic matter they excrete ensures the preservation of ecosystem integrity (Masciandaro et al. 2013). Phytoremediation is now recognized not only as the use of green plants to remove or neutralize environmental pollutants but also as a green biotechnology tool (Pilon-Smits 2005, Masciandaro et al. 2013). Plants create a rich micro-environment within the framework of this technology, providing microorganisms with activity and reproduction conditions via nutrients, oxygen, and organic materials. All of these together are necessary for the successful implementation of sustainable practices to restore environments such as air, water, and soil (Kurade et al. 2021, Wei et al. 2021). The soil structure restoration strategy is based on stimulating appropriate soil microbial communities and restoring nutrient flux function to disturbed soils. This flow of metabolites into the soil is ensured by plant-microbe interactions (Jansson & Hofmockel 2018).

This integration must take into account both the ability of microorganisms to utilize coal waste and/or carbon-containing pollutants to enrich soils during remediation and the ability of vegetation to capture both macro- and micronutrients by uptake through root cells. The main goal of reclamation remains the formation of necessary effective complexes in the soil to ensure the accumulation of humic compounds while ensuring the maintenance of plant and vegetation growth on the rehabilitated soil.

The mycophytoremdiation strategy was developed for *Fungcoa* rehabilitation of surface waste and coal dumps (Sekhohola-Dlamini et al. 2022, Cowan et al. 2016). This strategy utilizes the fungal-plant symbiotic relationship to achieve the biodegradation of any carbon-based pollutant while promoting the activation of soil constituents and plant growth to support long-term restoration at South African mining sites. On this issue, several extensive reviews on this issue have been published (Stahl et al. 1988, Claassens et al. 2006). Bacteria-plant interactions (bioremediation) were proposed as a potential approach to the remediation of hydrocarbon-contaminated soils. (Claassens et al. 2006, Šourková et al. 2005). The paper (Wenzel 2009) provides a comprehensive report on rhizosphere control of microorganism-plant associations, bioavailability of organic and metalloid pollutants, effects on biodegradation, and the prospects of rhizosphere processing for management in soil phytoremediation. Multi-polluted soils are complex and varied, necessitating a holistic approach rhizosphere management process. This process employs a complex approach of the coal-derived and/or utilizing hydrocarbon microbes, and phytoextraction of contaminants to achieve desired soil and land management objectives.

Thus, the combination of plants *A. retroflexus* L., *Salix schwerinii* E.L. Wolf and microorganisms *Pleurotus ostreatus, Pseudomonas frederiksbergensi* for soils containing excessive amounts of nickel; *Solanum nigrum* L. and *Klebsiella pneumonia* for soils with arsenic; plants *Brassica juncea* (L.) Coss, *Pinus sylvestris* Lour., *Solanum nigrum* L. with microorganisms *Aspergillus fumigatus Aspergillus niger*, *Azotobacter chroococcum, Cupriavidus taiwanesis, Enterobacter hormaechei Klebsiella pneumonia, Pseudomonas putida*, *Rhizobium leguminosarum* bv. *Trifolii* and *Penicillium rubens* for soils with cadmium.

The use of biodegradable geotextile material (which includes natural fibers) is promising for improving soil fertility (Wu et al. 2020). Geotextiles can provide optimal conditions for seed germination and soil microflora development because they contain a variety of nutrients, can accumulate an optimal amount of moisture, and are an effective means of controlling soil erosion (Broda et al. 2020).

Thus, measures utilizing plants and microorganisms capable of accumulating these substances are effective in reducing heavy metal content. There are known papers (Hernandez-Rivera et al. 2011, Ibrahim et al. 2013, Obayori et al. 2017, Bechtaoui et al. 2019, Olawale et al. 2020, Smułek et al. 2020) that show that microorganism strains effective in coal bioconversion stimulate plant growth, most likely due to the production of organic acids (Borgi et al. 2020). Eventually, bacterial-plant interactions may lead to the development of candidate strains for a bioprocess to treat, stabilize, and even restore disturbed soils (Titilawo et al. 2020).

The use of biochar has the potential to help normalize pH levels and increase soil fertility. Biochar (charcoal) is a carbon and ash-containing product of oxygen-free pyrolysis of plant biomass (Ahmad et al. 2014). According to studies, biochar application helps to increase low soil pH values, affects nitrification and ammonification processes, increases the C/N ratio, is a phosphorus source, and increases soil cation exchange capacity, resulting in less leaching due to nutrient retention. This favors the development of microorganisms even in soil with low organic matter content (Nurhidayati & Mariati 2014, DeLuca et al. 2015, Rogovska et al. 2020).

Liming (using organic lime-sugar beet lime) and the application of composted solid organic matter into the fertile soil layer to reduce soil acidity, data on the reclamation of a copper mine (Poderosa deposit, Spain) (Fernández-Caliani et al. 2021).

Gypsumization and acidification of soils are used to reduce the alkaline pH of soils to a neutral value. Sodium is replaced by calcium during gypsumization (the incorporation of gypsum and other industrial wastes into the soil, such as phosphogypsum-a waste product of mineral fertilizers, phosphoric acid, and phosphate fertilizers) (Bituh et al. 2021). During acidification, soils are acidified through the application of sulfur, sodium disulfate, etc. (Orlov et al. 1991).

One of the directions of phosphogypsum utilization considered in the paper (Chernysh et al. 2021) is the use of phosphogypsum as a mineral carrier for groups of useful microorganisms in bioprocesses of detoxication of environmental components, including technogenically disturbed lands of coal dumps.

Humic preparations have confirmed their effectiveness in heavy metal detoxification measures. Humic preparations for soil detoxification and remediation are natural solid, paste-like, or liquid substances produced by alkaline treatment of brown and oxidized hard coal (Gilmanova & Grekhova 2018, Stepanov et al. 2018). It has been found that humic preparations can bind metals, reducing their solubility, bioavailability, and mobility (Zhao et al. 2022).

Alternatively, specialized microorganisms can produce humic substances on-site from coal production waste. Under aerobic conditions, both abiotic and biotic processes oxidize coal to a weathered substance rich in humic substances (Romanowska et al. 2015). A group of bacterial enzymes, both primary and secondary, depolymerize and metabolize carbon, producing a diverse range of alcohols and short-chain organic acids in anaerobic environments (Valero et al. 2014). These low-molecular-weight organic compounds, which include acetogens and methanogens, serve as substrates for a variety of microbial communities (Jones et al. 2008, Yin et al. 2009, Strąpoć et al. 2011, Huang et al. 2013). The study (van Breugel et al. 2019) used weathered coal from South African mines to produce fungi with specific characteristics to produce fungocoal, which was intended to be used to rehabilitate the lands of exhausted territories as a source of humic material as well as biofertilizers (Canellas et al. 2012, Sekhohola et al. 2013).

The recommendations for rehabilitating mine wastelands are presented in Table 1.

## CONCLUSION

The reclamation of technologically disturbed coal mine lands is essential for humanity's conscious transition to sustainable development and the use of natural resources while preserving the environment for future generations. In this situation, it is impossible to do without recultivation of land disturbed by anthropogenic impacts. Often, a compelling reason to restore disturbed lands is legal requirements that coal and/or mining companies restore disturbed lands and

Table 1: Remediation methods for disturbed lands of mines.

| Indicators | Methods | References |
|---|---|---|
| Land rehabilitation | Bioremediation (phytoremediation + microorganisms) | (Stahl et al. 1988, Šourková et al. 2005, Claassens et al. 2006a, Claassens, et al. 2006b) |
| Soil fertility improvement | Biodegradable geotextile material | (Broda et al. 2020, Wu et al. 2020) |
| Normalization of pH, soil fertility improvement | Biochar | (Ahmad et al. 2014, Nurhidayati & Mariati 2014, Rogovska et al. 2014, DeLuca et al. 2015, Ghosh & Maiti 2020) |
| Soil acidity reduction | Liming (sugar beet lime)+ composted biosolids | (Fernández-Caliani et al. 2021) |
| Soil alkalinity reduction | Gypsification (application of gypsum, phosphogypsum, etc.) + acidification (application of sulphur, sodium disulphate, etc.) of soils | (Orlov et al. 1991, Bituh et al. 2021) |
| Heavy metal detoxification | Humic preparations | (Gilmanova & Grekhova 2018, Stepanov et al. 2018, Zhao et al. 2022) |
| Nickel detoxification | Plants (*A. retroflexus* L., *Salix schwerinii* E. L. Wolf) + microorganisms (*Pseudomonas frederiksbergensis*, *Pleurotus ostreatus*). | (Stahl et al. 1988, Šourková et al. 2005, Claassens et al. 2006a, Claassens, et al. 2006b, Wenzel 2009) |
| Arsenic detoxification | *Solanum nigrum* L. + *Klebsiella pneumoniae*. | (Stahl et al. 1988, Šourková et al. 2005, Claassens et al. 2006a, Claassens, et al. 2006b, Wenzel 2009) |
| Cadmium detoxification | Plants (*Brassica juncea* (L.) Coss, *Pinus sylvestris* Lour., *Solanum nigrum* L.) + microorganisms (*Aspergillus fumigates*, *Aspergillus niger*, *Azotobacter chroococcum*, *Cupriavidus taiwanesis*, *Enterobacter hormaechei*, *Klebsiella pneumonia*, *Penicillium rubens*, *Rhizobium leguminosarum bv. trifolii*, *Pseudomonas putida*) | (Stahl et al. 1988, Šourková et al. 2005, Claassens et al. 2006a, Claassens, et al. 2006b, Wenzel 2009) |

pay for environmental damages. Nonetheless, the benefits of restoring disturbed nature outweigh any moral concerns.

Restoration of such technogenically disturbed lands helps to restore the disturbed environment (vegetation, soil, water resources, landscape, fauna). Restored land is returned to agricultural use and/or reforestation, which is especially important in an era of global food security and hunger alleviation. In addition, the reclamation of anthropogenically disturbed land contributes to local quality improvement. Biological remediation is one of the existing technologies that can help restore ecosystems by reconstructing and rehabilitating areas using natural processes and mechanisms. Only limited data on the state of agrochemical characteristics, hygienic indicators, and soil pollutant content do not allow for the immediate organization of effective reclamation stages. Up-to-date data on soil quality is needed to compare "before" and "after" reclamation measures, which, together with modern scientific approaches, will allow the overall reclamation process to be intensified.

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