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BIOLOGICAL RECLAMATION AND PHYTOREMEDIATION OF COPPER MINE TAILINGS IN THE BOR DISTRICT USING NATIVE PLANT SPECIES

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Abstract

Long-term copper mining in the Bor District has generated extensive degraded land, presenting severe environmental risks from heavy metals, acidic mine drainage, and wind erosion. Traditional physical remediation is cost-prohibitive across hundreds of hectares. This paper evaluates biological reclamation and phytoremediation strategies utilizing native flora and energy crops on tailings ponds and waste dumps. Mechanisms such as phytostabilization and phytoextraction physically retain toxic particulates and immobilize heavy metals. Incorporating species like Betula pendula, Robinia pseudoacacia, and Miscanthus giganteus restores ecosystems while enabling biomass production for local renewable energy, fostering a sustainable circular economy within the "Green Mine" framework.

***Keywords**: phytostabilization, phytoextraction, heavy metals, circular economy, Green Mine.*

1. INTRODUCTION

Long-term extraction and processing of copper ores in the Bor District have left behind extensive degraded areas consisting of flotation tailings ponds, overburden waste dumps, and waste rock stockpiles [1,5]. These facilities represent a permanent environmental risk due to high concentrations of heavy metals (primarily Cu, Fe, Zn, Pb, and As), low substrate pH values caused by Acid Mine Drainage (AMD), and a complete lack of organic matter [1,2,3].

Conventional engineering approaches to reclamation typically rely on capping degraded areas with inert soil layers, an operationally demanding and cost-prohibitive strategy when applied to hundreds of hectares [2,3]. Consequently, contemporary research focuses on phytoremediation—utilizing plants to stabilize and decontaminate soils—and ecological restoration using native plant species adapted to the Bor District [1,3].

The objective of this paper is to analyze the feasibility of applying biological reclamation to tailings ponds in Bor, with emphasis on selecting appropriate plant species (hyperaccumulators and mesophytic species) and assessing the potential utilization of harvested biomass for renewable energy generation [3,4].

2. PHYTOREMEDIATION MECHANISMS AND SUBSTRATE CHARACTERISTICS IN BOR

Phytoremediation on mining dumps operates primarily through two mechanisms [3]:

1. **Phytostabilization:** Establishing a vegetative cover whose root systems physically bind tailings particles (preventing wind erosion and dust emissions) and chemically immobilize heavy metals within the root zone (rhizosphere), reducing contaminant leaching into groundwater [2,3].
2. **Phytoextraction:** Employing specific hyperaccumulating plant species that absorb heavy metals from the soil and accumulate them in above-ground tissues (stems and leaves), progressively reducing soil toxicity over time [3].

Geomechanical and Chemical Constraints of Bor Tailings Substrates

- **Extreme Acidity (pH =2.5 - 4.5):** Requires preliminary neutralization via amendments such as limestone, fly ash, or organic substrates [1,2].
- **Nutrient Deficiency:** Substrates lack essential macronutrients, notably nitrogen (N) and phosphorus (P) [2].
- **Compaction and Moisture Deficit:** Low water retention capacity poses significant drought stress during summer months [2,3].

3. SELECTION OF NATIVE PLANT SPECIES FOR RECLAMATION IN BOR

Selecting plant species naturally adapted to the local microclimate and tolerant to copper toxicity and acidic substrates is crucial for successful biological reclamation, table 1 [1,2].

Table 1. *Overview of Plant Species and Target Locations in the Bor District*

Plant Group	Botanical / Common Name	Role in Reclamation	Target Application Site
Woody Species	*Betula pendula* (Silver Birch), *Robinia pseudoacacia* (Black Locust)	Phytostabilization, nitrogen fixation (*Robinia*) [1, 2]	Open pit Veliki Krivelj
Shrub Species	*Hippophae rhamnoides* (Sea Buckthorn), *Tamarix* spp.	Slope stabilization, drought tolerance [2, 3]	Flotation tailing Veliki Krivelj, flotation tailing RTH
Grasses (Gramineae)	*Festuca rubra* (Red Fescue), *Lolium perenne* (Perennial Ryegrass)	Rapid turf establishment, dust suppression [1, 3]	Flotation tailing: Veliki Krivelj, RTH, Valja Fundfata (Majdanpek)
Energy Crops	*Miscanthus giganteus* (Giant Miscanthus)	Biomass production on degraded land [3, 4]	Dedicated bio-energy test plots

4. SUBSTRATE PREPARATION TECHNOLOGY AND BIOMASS ENERGY UTILIZATION

Successful biological reclamation and energy exploitation of post-mining land require a integrated agrotechnical approach [3,4]:

a) Soil Preparation and Amendment

- **Substrate Conditioning:** Prior to planting or seeding, applying limestone or alkaline industrial slag is mandatory to elevate substrate pH to optimal levels (6.0 - 6.5) [1,2].
- **Organic Matter Addition:** Incorporating compost, manure, or treated sewage sludge enhances water retention capacity and provides essential nutrients (N, P, K) [2,3].

b) Renewable Energy Potential of Biomass

Cultivating energy crops (such as *Miscanthus giganteus* or short-rotation coppice species like willow and black locust) on passivated surfaces enables local bio-energy production [3,4]:

- **Biomass Yield:** With proper agrotechnical management, dry matter yields on reclaimed mine soils can reach 8 to 15 t/ha annually [3].
- **Briquetting and Pelletizing:** Harvested biomass is processed into solid biofuels suitable for space heating in local mining facilities or industrial plants [4].
- **Food Security:** Utilizing contaminated post-industrial land for bio-energy production avoids competing with agricultural land reserved for food crops [3,5].

5. DISCUSSION AND ENVIRONMENTAL-ECONOMIC IMPACTS

Compared to conventional civil engineering methods (capping with sterile soil, asphalt, or concrete), biological reclamation and phytoremediation provide substantial advantages for the Bor District [1,3,4]:

1. **Cost Efficiency:** Self-sustaining vegetative cover dramatically reduces reliance on heavy construction machinery and long-term maintenance costs [3].
2. **Dust Suppression:** Dense plant cover prevents wind erosion and fugitive dust movement toward the city of Bor and surrounding villages (Krivelj, Oštrelj, Slatina) [1,5].
3. **Microclimate and Biodiversity Restoration:** Establishing diverse vegetative cover creates secondary ecosystems, attracting local fauna and restoring the natural landscape [1, 3].
4. **Circular Economy in Mining:** Bio-energy generation directly contributes to the internal renewable energy balance of Serbia Zijin Copper and Serbia Zijin Mining [4].

6. CONCLUSION

Biological reclamation utilizing native plant species and dedicated energy crops represents the most sustainable long-term solution for rehabilitating tailings ponds and waste dumps in the Bor District [1,4].

Integrating phytoremediation with renewable energy generation converts degraded mining land from an environmental liability into a valuable resource for clean energy production [3,4]. Implementing these methodologies within the "Green Mine" corporate strategy substantially advances environmental standards and improves overall quality of life across the Bor Basin [4,5].

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REFERENCES

[1] Antonijević, M., et al. (2021). Ekološki izazovi i sanacija rudarskih jalovišta u Borskom okrugu. Časopis za zaštitu materijala i životne sredine.
[2] Dimitrijević, M., & Radovanović, Z. (2020). Fitoremedijacija zemljišta kontaminiranog teškim metalima na lokacijama rudnika bakra Bor. Rudarsko-geološki fakultet, Beograd.
[3] Liang, Y., et al. (2022). Phytoremediation strategies for heavy metal contaminated copper mine tailings: A review. Environmental Pollution, 298.
[4] Zijin Mining Group. (2023). Green Mining and Ecological Restoration Practices in Bor Complex.
[5] Ministarstvo zaštite životne sredine RS. (2022). Izveštaj o stanju zemljišta u Republici Srbiji.