Optimizing biological consortia for mining wastewater treatment

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Abstract Industrial processes, such as the mineral extraction of raw materials, have been in crucial focus because of the current drive towards greener and more sustainable energy sources. Hence, the production workflow of critical elements, such as rare earth elements (REEs), is reassessed to identify less toxic and degradable reagents, while also identifying the challenges associated with the emissions of not yet regulated elements (i.e. Li, B, Tb). Innovative biological wastewater (WW) treatment options are studied to effectively remove contaminants and recycle industrial water in a low-cost and lowered carbon-equivalent emissions manner. This work aims to use aquatic plants and phytoplankton to remove regulated and unregulated contaminants (i.e. flotation chemicals, heavy metals, REEs) from mining WW outlets. A thorough screening of different species has been done to identify the potential to decontaminate the water effluent by promising biological entities in batch experiments. The study assessed removal potential of toxic elements, including the REEs, and greener flotation agents by the species selected. Preliminary results show promising element-specific removal by some species, allowing us to suggest potential synergetic biological treatments that will provide low-cost and sustainable WW treatment alternatives.

Keywords: Phytoremediation; Mining wastewater; Biological process

1. Introduction

Rising demand for non-fossil energy has boosted the extraction of critical elements like REEs, essential for batteries, magnets, and electronics. The extraction process consumes large amounts of water, often a scarce resource, and produces toxic, contaminated WW. Some of these elements are already regulated by the European Water directive framework (i.e. As, Pb, U); however, others (i.e. Li, Tb) remain unregulated as their natural occurrence in water is not expected. The increasing mining and mineral beneficiation-activity in Europe, likely leads to a mobilization of these elements in nature posing environmental and health risks (Gajendra et al., 2025). Therefore, more emphasis on WW management is required to face such a challenge. So far, there is a lack of methods to eliminate most of these non-regulated pollutants from water. Unlike conventional WW treatment methods, such as ion exchange, electrochemical exchange and osmosis biological water treatments enable environmental sustainability, lower costs, and by-products with value creation (Chugh et al., 2022). Many biological treatments have been proven to be efficient for both organic and inorganic pollutants; more recently nature-based solutions are being used worldwide to solve large-scale pollution issues (i.e. wetlands).

Phytoremediation is an eco-friendly and cost-effective technique for WW treatment (Chugh et al., 2022). The treatment efficiency can be influenced by exposure time, concentration of pollutants, environmental factors (pH, temperature), and biomass (plant/phytoplankton) (Mustafa et al., 2021). During WW treatment, the used plants/ microorganisms must be able to tolerate and remove various elements. Simultaneous exposures to diverse elements can result in limitations and competition between nutrients (K, Ca, Na, Mg), essential (Cu, Zn), and toxic (Cd, As, Pb, Hg, U, etc.) elements uptake. Aquatic species such as *Salvinia natans* are ideal for phytoremediation due to their ability to uptake, tolerate, and bioaccumulate toxic inorganic pollutants (Polechońska et al., 2019). Microalgae also offer bioaccumulation and biosorption mechanisms. Biosorption occurs regardless of whether the algal cell is living or dead. Species like *Chlorella vulgaris* and *Chlamydomonas reinhardtii* have successfully removed metals (Chugh et al., 2022) and organic contaminants (Jain et al., 2022). Consortia of microalgae and cyanobacteria such as *Anabaena sp*. have good removal and economic efficiency (Cuellar-Bermudez et al., 2017). After phytoremediation, polluted biowaste can undergo thermal decomposition to generate bioenergy through pyrolysis, while potentially toxic elements are stabilized in solid products (char/biochar) (Voglar et al., 2024). Furthermore, microalgal biomass may be valorized for biofuel, organic fertilizers and pharmaceuticals.

This study aims to compare aquatic plants and phytoplankton's ability to remove elements and organic reagents from WW. The most effective organisms will then be integrated into greener remediation strategies and potentially leverage novel and functional consortia of aquatic plants, algae and bacteria.

2. Methods

We used a range of aquatic plants, microalgae and cyanobacteria (Tab. 1) and screened their removal performance against major alkali and essential elements, heavy metals, REEs and organic reagents. Removal experiments are performed with mine discharge water and synthetically spiked water samples (ppb to ppm range of spikes). Factors such as exposure time, pH, pollutant composition, and initial concentrations will be taken into consideration and optimized. Photosynthetic pigment concentrations will be measured to investigate the induced stress effect on aquatic plants and phytoplankton species. The removal efficiency of different elements was assessed by ICP-OES and ICP-MS and of organic flotation agents by LC-MS/MS. Based on the synergetic and/or antagonistic relative uptake across the different organisms we aim to formulate task-specific biological consortia for water treatment.

Table 1. Screened organisms for bioremediation

Organism species	Type
Lemna gibba	Aquatic plant
Salvinia natans	Aquatic plant
Botryococcus braunii	Algae
C. reinhardtii	Algae
Chlorella vulgaris	Algae
Klebsormidium sp.	Algae
N. oculata	Algae
Spirogyra sp.	Algae
Anabaena torulosa	Cyanobacteria
Scytonema	Cyanobacteria
Spirulina major	Cyanobacteria
S. elongatus	Cyanobacteria

3. Preliminary Results and Outlook

Remediation potential over the mine water discharged (pH = 3.2) from Apolo mine (Baita, Maramures County, Romania) was studied. Hereby, the aquatic plant *Salvina natans* shows high Cr, Fe, Ga, As, Ag, Pb, removal potential and adequate for Al, Mn, Zn and Rb (Fig. 1). The plant biomass showed significantly higher levels of elements after WW treatment, particularly Fe, Al, Pb, Rb, Li, Zn, Ga, As and Cd. There are no significant differences among the treatments in terms of chlorophyll a and b concentration. This indicates that the treatments do not adversely affect the photosynthetic capacity of *Salvinia natans*. However, the significantly lower total carotenoid contents obtained after treatment (30%-50%), indicate the presence of oxidative stress. We expect further results from *Chlorella vulgaris* regarding metal removal. In the following steps, the variety of phytoremediation organisms (Tab. 1) will be screened for regulated elements (e.g. U, Th, As), unregulated metals (e.g. REE, Li, B) and organic flotation reagents.

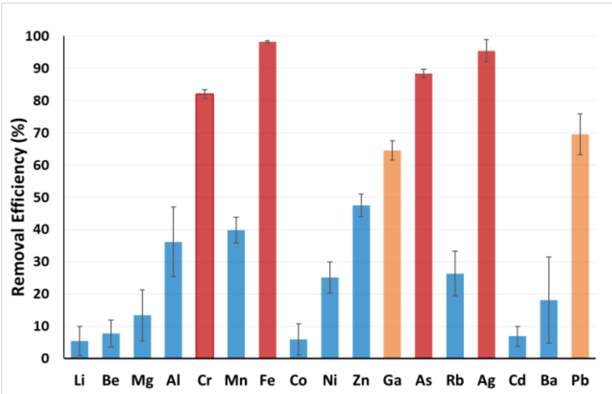

Figure 1. Removal efficiencies of *Salvinia natans*

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