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AJ NING ILMIY MUAMMOLARI YECHIMIGA
BAG’ISHLANGAN

YASHIL TEXNOLOGIYALARNING SANOATDA INTEGRATSIYASI: ZAMONAVIY TEXNOLOGIYALAR, EKOLOGIK XAVFSIZLIK VA INDUSTRIAL RIVOJLANISH TENDENSIYALARI

mavzusidagi xalqaro ilmiy va ilmiy-texnik anjuman

MATERIALLAR TO‘PLAMI

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PHYTOREMEDIATION OF METALLURGICAL EFFLUENTS USING EICHHORNIA CRASSIPES*:* MECHANISMS, PERFORMANCE, INTEGRATION.

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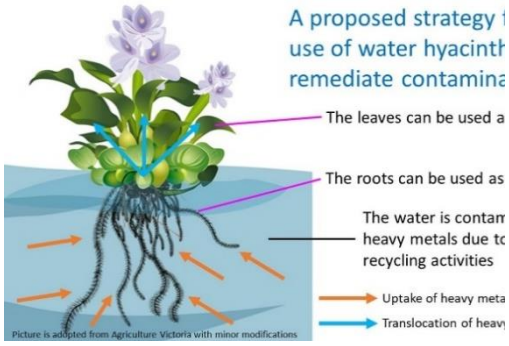
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The rapid expansion of metallurgical and mineral processing industries has intensified the generation of wastewater enriched with toxic metal ions such as Cu^{2+}, Fe^{2+}/Fe^{3+}, Zn^{2+}, Pb^{2+}, Cd^{2+}, and Ni^{2+}. Conventional physicochemical treatment methods—precipitation, ion exchange, and membrane filtration—are often costly and produce secondary sludge. This study explores a low-carbon, nature-based solution employing *Eichhornia crassipes* - *E.C* (water hyacinth) for the sorption and removal of dissolved metal ions from industrial effluents. The plant's extensive root system, high biomass productivity, and strong affinity for metal uptake make it a promising candidate for phytoremediation. Mechanisms of metal removal include biosorption, bioaccumulation, ion exchange, and rhizofiltration. Experimental findings from literature indicate removal efficiencies exceeding 70–95% for several heavy metals under optimized conditions. The integration of hyacinth-based treatment into constructed wetland systems offers a sustainable and economically viable approach for wastewater detoxification in metallurgical operations [1].

Metallurgical and ore beneficiation industries are major contributors to environmental pollution, particularly through the discharge of aqueous effluents containing dissolved heavy metals. In regions with intensive mining and smelting activities, such as Almalyk, wastewater streams from flotation, leaching, and smelting processes often contain elevated concentrations of copper, iron, and trace toxic elements. These contaminants pose significant risks to aquatic ecosystems and human health due to their persistence, toxicity, and bioaccumulation.

Consequently, there is growing interest in sustainable alternatives. Phytoremediation — using plants to remove, stabilize, or degrade pollutants—has emerged as an eco-friendly and cost-effective solution. Among aquatic macrophytes, Water hyacinth has attracted attention due to its exceptional growth rate and metal uptake capacity [2].

The efficiency of water hyacinth in removing metal ions from aqueous solutions is governed by several physicochemical and biological mechanisms:





2.1. Biosorption. The root surfaces of *E.C.* contain functional groups such as hydroxyl (–OH), carboxyl (–COOH), and amino ($–NH_2$) groups. These groups bind metal ions through electrostatic attraction, complexation, and ion exchange. This passive process occurs rapidly and does not require metabolic activity.

2.2. Bioaccumulation. In addition to surface adsorption, metal ions are actively transported into plant tissues. Once inside, metals may be sequestered in vacuoles or bound to proteins such as phytochelatins, reducing their toxicity.

2.3. Rhizofiltration. The dense root network acts as a physical and chemical filter, trapping suspended particles and absorbing dissolved metals. This mechanism is particularly effective for dilute solutions typical of secondary effluents.

2.4. Ion exchange and precipitation. Metal ions in solution can replace naturally occurring ions (e.g., Ca^{2+}, Mg^{2+}) on plant surfaces. In some cases, microenvironmental changes near roots promote precipitation of metals as insoluble hydroxides or carbonates.

Application in metallurgical wastewater treatment

Water hyacinth has been successfully applied in treating effluents from copper smelting, flotation tailings, and acid mine drainage. Removal efficiencies include: Cu^{2+}: 80–95%, Pb^{2+}: 75–90%, Cd^{2+}: 70–85%, Zn^{2+}: 65–80%, Fe^{3+}: up to 90% under controlled pH conditions. The performance depends on parameters such as pH (optimal range 5.5–7.5), temperature, initial metal concentration, and biomass density.

To scale this technology for industrial use, water hyacinth is typically implemented in constructed wetland systems. These engineered ecosystems combine biological, chemical, and physical processes for wastewater treatment. A typical system includes: Primary sedimentation tank, equalization basin, hyacinth pond or wetland cell polishing unit.

Retention time ranges from 5 to 15 days depending on pollutant load. Periodic harvesting of biomass is essential to prevent saturation and release of accumulated metals. This technology provides significant advantages, such as low operational cost and energy requirement, high removal efficiency for multiple metals, carbon sequestration and oxygen generation as well as potential biomass utilization (bioenergy, compost after detoxification).

The use of *E.C.* aligns with global trends toward sustainable and circular industrial practices. In metallurgical regions, integrating phytoremediation into wastewater treatment systems can significantly reduce environmental impact while lowering operational costs. Furthermore, this approach supports low-carbon technologies by minimizing chemical usage and energy consumption [3].

Conclusion. Water hyacinth-based phytoremediation represents a promising strategy for the treatment and detoxification of metallurgical and beneficiation wastewater. Through mechanisms such as biosorption, bioaccumulation, and rhizofiltration, *E.C.* effectively removes heavy metal ions from aqueous solutions. When integrated into engineered wetland systems, this method offers a scalable, eco-friendly alternative to conventional treatment technologies. Future research should focus on optimizing system design, improving biomass management, and enhancing metal recovery from harvested plant material.

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