Chapter 10
Synergistic Role of Artificial Intelligence and Machine Learning in Enhancing Hydrophyte-Based Heavy Metal Stress Management

Pushkar Singh Rawat
https://orcid.org/0000-0002-8679-5603
University of Lucknow, India

Shalini Singh
https://orcid.org/0000-0003-3351-5732
Shri Ramswaroop Memorial University, India

ABSTRACT

Heavy metal pollution threatens ecosystems and human health. Hydrophytes, with their natural ability to absorb and detoxify metals, are valuable for phytoremediation. However, their efficiency varies due to species differences and environmental factors. Integrating Artificial Intelligence (AI) and Machine Learning (ML) enhances this process by enabling predictive modeling, stress detection, and real-time monitoring. AI-driven tools optimize plant selection, growth conditions, and risk assessment while improving scalability and sustainability. Despite challenges like data quality, costs, and ethical concerns, the synergy of hydrophytes with AI/ML offers a promising, eco-friendly solution for restoring aquatic ecosystems.

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1. INTRODUCTION

Heavy metal pollution in aquatic ecosystems is a major global concern, primarily driven by industrialization, urbanization, and climate change. The primary sources are mining wastes, landfill leachates, municipal and industrial effluents, urban run-offs and natural processes such as volcanic eruptions and the erosion of rocks. Toxic metals include cadmium (Cd), lead (Pb), mercury (Hg), copper (Cu), zinc (Zn), nickel (Ni), manganese (Mn), arsenic (As) and chromium (Cr) not only toxic but also highly persistent and non-biodegradable. This implies that they will accumulate with time in our waters, sediments, aquatic plants and animals. Such heavy metals may pile up in aquatic organisms and multiply via the food chain posing serious threats to the well-being of the aquatic ecosystems as well as the health of humans who consume the aquatic organisms (Hama Aziz et al., 2023).

The heavy metals interfere with the normal physiological and biochemical processes of the aquatic organisms, damaging DNA, disrupting growth, affecting reproduction, respiratory disturbance, and death of fish, invertebrates, and other living beings (Jeong et al., 2023). These effects decrease biodiversity, impair the water quality, and destabilize food webs. Even low doses of contaminated water or seafood can cause organ damage, neurological disorders and risks of cancer. In addition, their toxicity can be modified depending on exposure to pollutants such as microplastic or persistent organic compounds (Abubakar et al., 2024). Using such monitoring tools as the Heavy Metal Pollution Index and Degree of Contamination can be considered essential information on the state of pollution. Remediation measures can include traditional processes such as chemical precipitation and adsorption or other modern techniques such as bioremediation, phytoremediation and oxidation processes. Nevertheless, there are still the problems of cost and efficiency (M. Sharma et al., 2025). To combat this problem, governments, industries, and communities should collaborate to minimize discharges, enhance the level of wastewater management, and safeguard aquatic ecosystems to be sustainable.

1.1. Overview of Hydrophytes and Their Role in Phytoremediation

Aquatic plants or hydrophytes are macrophytes which adapt to thrive in water-logged habitats and are classified into floating, submerged and emergent species. They play an important role in aquatic ecosystems as they stabilize the sediments, provide habitats, and control nutrient cycles. In the recent times, they have attracted much interest towards their prospects in phytoremediation of water, sediments and soils using plants to remediate the pollutants (Thakur et al., 2023). Their direct contact with water, high production of biomass and rapid growth allow them to