Chapter 16
Implementing Sustainable Nano-Bioremediation for Emerging Pollutants:
An Environmentally Friendly Remediation Strategy

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DOI: 10.4018/979-8-3693-1471-5.ch016

ABSTRACT

Bioremediation represents a promising approach for addressing environmental pollution by leveraging natural processes to degrade or convert toxic pollutants into more benign forms. This method utilizes biological agents like algae, fungi, bacteria, and viruses to break down pollutants, ideally to undetectable or non-toxic levels, or even mineralize them to harmless compounds like CO2. By doing so, bioremediation not only cleans up contaminated sites but also restores them and prevents future pollution, all without the need for chemical reagents. Environmental pollution, fueled by rapid industrial growth, continues to pose significant threats to ecosystems and human health. Harmful pollutants like BPA, PAHs, PCBs, and pharmaceutical wastes accumulate in the environment, causing ecological damage and endangering various organisms.

INTRODUCTION

Our actions are harming ecosystems across the globe, making it difficult for native species to survive and putting pressure on dwindling natural resources (Padmavathiamma & Li, 2007; Sverdrup & Warfvinge, 1988). Environmental contamination has become a major concern in recent times, impacting our health and well-being. Rapid industrial growth, unsustainable agricultural practices, and the unchecked dumping of pollutants into water bodies have severely damaged the planet's ecosystems. This has resulted in a rise in barren lands, biodiversity loss, difficulty accessing clean drinking water, economic losses, and more.

The number of man-made chemicals is constantly increasing, and many of these are persistent and harmful to living organisms (Carraro et al., 2016). These wastes often contain polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other hazardous substances that disrupt ecosystems (Contreras-Ramos et al., 2007). These emerging pollutants are pervasive in our daily lives, and their impact varies depending on their composition and source (Agrawal & Rathore, 2014). They are carcinogenic and long-lasting, wreaking havoc on ecosystems and threatening all forms of life (Ghazaryan et al., 2014).

While the mid-20th-century Green Revolution boosted food production, it also led to significant environmental pollution due to the overuse of synthetic fertilizers and pesticides (Martens & Westermann, 2018). These chemicals have accumulated in soil, freshwater, and agricultural ecosystems over time, posing a serious threat (Ghazaryan et al., 2017, 2018).

Microbes play a crucial role in the remediation of pollutants through structural modifications and chemical alterations (Martens & Westermann, 2018). Organic pollutant degradation primarily occurs through microbial proliferation and metabolic activity. These microbes require organic pollutants as essential nutrients for growth, including phosphorus, nitrogen, sulfur, and trace elements, which are vital for their metabolic processes (El-Ramady et al., 2020). During bioremediation, organic chemicals are broken down by microbes, releasing electrons that are utilized by microorganisms to generate bio-energy (El-Zemrany et al., 2016).

Heavy metal contamination, often resulting from industrial activities such as refining, incineration, and waste disposal, poses significant threats to ecosystems and human health (Agrawal & Rathore, 2014; Doran, 2009). Contaminants degrade soil and water integrity, affecting biological health; Bioremediation uses plants, microbes, bacteria, fungi, and algae also nanoparticles to mitigate pollution, offering a sustainable approach to restoring polluted environments (Rajput et al., 2021, 2022; Zainith et al., 2018).