Why does India need bioremediation? | Explained

What are the two different types of bioremediation? How is traditional microbiology combined with cutting-edge biotechnology? Has the government initiated schemes to further bioremediation programmes? What are some of the challenges the country faces with respect to adoption of such technologies?

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Garbage, collected from different wards in Bengaluru, being dumped in the Mittanaganahalli landfill in 2024. | Photo Credit: File Photo

Human waste is leading to a decaying world where access to clean air, water or soil is becoming increasingly difficult. The solution is two-pronged - stop making more waste and clean up the waste already made.

What is bioremediation?

Bioremediation literally means “restoring life through biology.” It harnesses microorganisms such as bacteria, fungi, algae and plants to sequester or transform toxic substances such as oil, pesticides, plastics, or heavy metals.

These organisms metabolise these pollutants as food, breaking them down into harmless by-products such as water, carbon dioxide, or organic acids. In some cases, they can convert toxic metals into less dangerous forms that no longer leach into the soil or groundwater.

There are two broad types:

In situ bioremediation, where treatment happens directly at the contaminated site — think oil-eating bacteria sprayed on an ocean spill.

Ex situ bioremediation, where contaminated soil or water is removed, treated in a controlled facility, and returned once cleaned.

Modern bioremediation combines traditional microbiology with cutting-edge biotechnology. First, new biotechnologies are enabling humans to gain unprecedented insight into biology, allowing them to identify biomolecules with useful characteristics. Second, these technologies allow humans to replicate these biomolecules under desired conditions of use, such as sewage plants or agricultural lands.

For example, genetically modified (GM) microbes are designed to degrade tough chemicals like plastics or oil residues that natural species struggle with. Synthetic biology also allows for “biosensing”, organisms that change colour or fluorescence when they detect toxins, providing early warnings of contamination.

Why does India need bioremediation?

India’s rapid industrialisation has come at a heavy environmental cost. Although pollution has been reducing, rivers such as the Ganga and Yamuna receive untreated sewage and industrial effluents daily. Oil leaks, pesticide residues, and heavy-metal contamination threaten both ecosystems and public health.

Traditional clean-up technologies are expensive, energy-intensive, and often create secondary pollution. Bioremediation offers a cheaper, scalable, and sustainable alternative, especially in a country where vast stretches of land and water are affected but resources for remediation are limited.

Moreover, India's diverse biodiversity is a huge advantage. Indigenous microbes adapted to local conditions, such as high temperatures, salinity, or acidity, can outperform imported strains in environmental recovery.

Where does India stand today?

Bioremediation is gaining traction in India, though still largely in pilot phases. The Department of Biotechnology (DBT) has supported several projects through its Clean Technology Programme, encouraging partnerships between universities, public research institutions, and industries.

CSIR-National Environmental Engineering Research Institute has a mandate to propose and implement programmes related to bioremediation. Researchers at the Indian Institute of Technology have experimented with a nanocomposite material synthesised from cotton that can be used to mop up oil spills and others have identified bacteria that can consume toxic pollutants in soils.

Startups are entering the space too. Firms like Biotech Consortium India Limited (BCIL) and Econirmal Biotech offer microbial formulations for soil and wastewater treatment.

However, widespread adoption faces challenges - technical ones such as a lack of site-specific knowledge and the complex nature of pollutants, and regulatory ones such as a lack of unified bioremediation standards.

What are other countries doing?

In many advanced economies, bioremediation is a part of mainstream environmental management. For example, Japan integrates microbial and plant-based cleanup systems into its urban waste strategy. The European Union funds cross-country projects that use microbes to tackle oil spills and restore mining sites. China has made bioremediation a priority under its soil pollution control framework, using genetically improved bacteria to restore industrial wastelands.

Opportunities and risks

The opportunities for India are immense. Bioremediation can help restore rivers, reclaim land, and clean industrial sites, while creating jobs in biotechnology, environmental consulting, and waste management. It can also integrate with the government's Swachh Bharat Mission, Namami Gange, and other green technology initiatives.

But risks remain. The introduction of genetically modified organisms into open environments need to be strictly monitored to prevent unintended ecological effects. Inadequate testing or poor containment or monitoring can create fresh problems while solving old ones. Public engagement will be necessary to allow the smooth adoption of new technologies, and their further monitoring.

India will need new biosafety guidelines, certification systems, and trained personnel to scale this technology responsibly.

The way forward

To realise the full potential of bioremediation, India needs to strengthen a few area. First, there is a need to develop national standards for bioremediation protocols and microbial applications. Second, building regional bioremediation hubs linking universities, industries, and local governments would enable better understanding of local issues and identifying appropriate technologies for their resolution. This can be implemented through support for local startups and community projects through the DBT–BIRAC ecosystem. Finally, public engagement would raise awareness that microbes can be allies, not threats, in environmental restoration.

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