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ENVIRONMENTAL RECTIFICATION THROUGH MICROBIAL BIOREMEDIATION: PRINCIPLES AND STRATEGIES

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INTRODUCTION & AIM

Environmental pollution arising from industrialization, urbanization, agricultural activities, and improper waste disposal has resulted in the accumulation of hazardous contaminants in soil, water, and air. Conventional remediation methods are often costly, energy-intensive, and may generate secondary pollutants. Microbial bioremediation offers an eco-friendly and sustainable alternative by utilizing naturally occurring or engineered microorganisms to transform, detoxify, or remove contaminants from the environment. Bacteria, fungi, algae, and microbial consortia play crucial roles in degrading hydrocarbons, pesticides, heavy metals, dyes, and emerging pollutants. Recent advances in molecular biology, metagenomics, and synthetic biology have further enhanced the efficiency and applicability of microbial remediation technologies.

Aim

To review the principles, mechanisms, and contemporary strategies of microbial bioremediation for environmental restoration and sustainable pollution management

METHOD

Review Design

Scoping Review following **PRISMA Extension for Scoping Reviews (PRISMA-ScR 2.0)** guidelines.

Information Sources

Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar

Search Keywords

Microbial bioremediation, Environmental remediation, Biodegradation, Bioaugmentation, Biostimulation, Heavy metal remediation, Hydrocarbon degradation

Eligibility Criteria

Inclusion:

•Peer-reviewed articles (2015–2026)
•English language
•Studies involving microbial remediation of pollutants

Exclusion:

•Non-peer-reviewed literature
•Conference abstracts only
•Studies lacking experimental evidence

PRISMA Flow Summary

Stage	Number of Records
Records identified	850
After duplicate removal	720
Screened	720
Full-text assessed	180
Included in review	95

RESULTS & DISCUSSION

1. Major Microbial Remediation Mechanisms

Mechanism	Function	Target Pollutants
Biodegradation	Breakdown of contaminants	Petroleum hydrocarbons, pesticides
Biosorption	Adsorption onto microbial biomass	Heavy metals
Bioaccumulation	Intracellular uptake	Toxic metals
Biotransformation	Conversion to less toxic forms	Organic pollutants
Mineralization	Complete degradation to CO_2 and H_2O	Complex organics

2. Key Microorganisms Used in Bioremediation

Microorganism	Environmental Application
Pseudomonas spp.	Hydrocarbon degradation
Bacillus spp.	Heavy metal removal
Rhodococcus spp.	Oil spill remediation
Aspergillus spp.	Dye degradation
Phanerochaete chrysosporium	Lignin and xenobiotic degradation
Chlorella spp.	Wastewater treatment

KEY FINDINGS

✓ Microbial bioremediation is cost-effective and environmentally sustainable.
✓ Bioaugmentation and biostimulation significantly enhance pollutant degradation.
✓ Microbial consortia generally outperform single-species applications.
✓ Omics technologies have improved understanding of microbial metabolic pathways.
✓ Genetically engineered microbes show promising future applications but require biosafety evaluation.

CONCLUSION

Microbial bioremediation represents a powerful and sustainable strategy for environmental rectification. Diverse microorganisms possess remarkable capacities to degrade, transform, or immobilize environmental contaminants. Emerging approaches such as microbial consortia engineering, metagenomics-guided remediation, and synthetic biology are expanding the effectiveness of bioremediation technologies. Continued integration of advanced molecular tools and field-scale validation studies will further strengthen the role of microbial remediation in achieving long-term environmental sustainability.

FUTURE WORK / REFERENCES

1. Ghosh S., et al. (2024). Advances in microbial bioremediation technologies. Environmental Research, 245, 117982.
2. Sharma B., et al. (2023). Microbial strategies for sustainable remediation. Journal of Environmental Management, 337, 117698.
3. Azubuike C.C., Chikere C.B., Okpokwasili G.C. (2016). Bioremediation techniques. World Journal of Microbiology and Biotechnology, 32, 180.
4. Singh A., Ward O.P. (2022). Biodegradation and bioremediation. Springer Nature.
5. PRISMA-ScR Checklist and Explanation (Updated Guidelines).