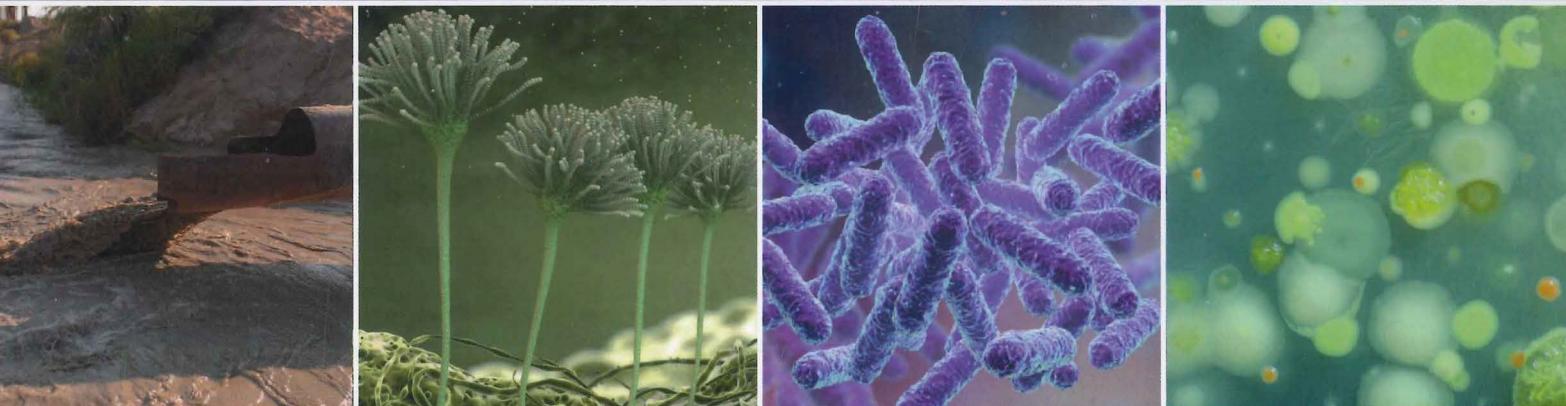


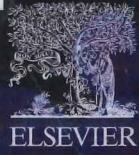
# MICROBIAL BIODEGRADATION AND BIOREMEDIATION

TECHNIQUES AND CASE STUDIES FOR ENVIRONMENTAL POLLUTION



Second Edition

Surajit Das | Hirak Ranjan Dash



# Microbial Biodegradation and Bioremediation

Techniques and Case Studies for Environmental  
Pollution

Second Edition

Edited by

**Surajit Das**

Laboratory of Environmental Microbiology and Ecology (LEnME),  
Department of Life Science, National Institute of Technology, Rourkela, India

**Hirak Ranjan Dash**

DNA Fingerprinting Unit, Forensic Science Laboratory, Bhopal, India



# Contents

List of contributors  
Preface

## Part I Toxicity of various pollutants and introduction to bioremediation

### 1. Prospects and scope of microbial bioremediation for the restoration of the contaminated sites

*Shreosi Chatterjee, Swetambari Kumari,  
Sonalin Rath and Surajit Das*

1.1	Introduction	3
1.2	Recent advances in conventional remediation technologies	4
1.3	Biological treatment of pollutants: bioremediation	8
1.4	Selection criteria of microorganisms for the bioremediation	9
1.5	Applications of microorganisms for environmental restoration	10
1.6	Factors influencing the efficiency of bioremediation	16
1.7	Microbial bioremediation strategies	18
1.8	Future perspectives and challenges	23
	Acknowledgments	
	References	

### 2. Mechanism of toxicity and adverse health effects of environmental pollutants

*Vandana, Monika Priyadarshanee,  
Uma Mahto and Surajit Das*

2.1	Introduction	33
2.2	Types of pollutants	33
2.3	Sources and fate of pollutants in the environment	36

xiii	2.4 Human exposure to pollutants	42
xvii	2.5 Metabolic response of pollutants in the human body	44
1	2.6 Toxic effects of pollutants on human health	45
	2.7 Conclusion	49
	References	49
3	3. The use of molecular tools to characterize functional microbial communities in contaminated areas	55
	<i>Punyasloke Bhadury and Anwesha Ghosh</i>	
3	3.1 Introduction	55
	3.2 Elucidating structure of microbial communities	56
	3.3 Functional analysis of microbial communities	61
	3.4 Determination of "in situ" abundance of microorganisms	64
	3.5 Conclusion	65
	References	65
4	4. Fate and consequences of microplastics in the environment and their impact on biological organisms	69
	<i>Arijit Reeves, Punarbasu Chaudhuri and Sukalyan Chakraborty</i>	
4	4.1 Introduction	69
	4.2 Residence time of microplastics in the environment	74
	4.3 Impact on terrestrial organisms	74
	4.4 Impact on aquatic organisms	75
	4.5 Impact on human beings	76
	4.6 Conclusion	76
	References	77

5. Metagenomic approaches to study the culture-independent bacterial diversity of a polluted environment—a case study on north-eastern coast of Bay of Bengal, India	81	8.2 Pollutants and their impact on the reef ecosystem	162
<i>Jaya Chakraborty, Krishna Palit and Surajit Das</i>		8.3 Current and advance strategies for protecting reef ecosystem from pollution	167
5.1 Introduction	81	8.5 Conclusion	173
5.2 Metagenomics-based methodology for microbial diversity analysis	82	Acknowledgements	173
5.3 Bacterial diversity of natural versus polluted coastal ecosystem	85	References	173
5.4 Bacterial community composition in north-eastern coast of Bay of Bengal: the case study	86		
5.5 Scope of metagenomic tools in the diversity analysis	99		
5.6 Conclusion	101		
References	101		
6. Constructing thermodynamic models of toxic metal biosorption	109	Part II	
<i>Kristofer G. Paso</i>		Role of diverse microorganisms in bioremediation	179
6.1 Introduction	109	9. Biology, genetic aspects and oxidative stress response of actinobacteria and strategies for bioremediation of toxic metals	181
6.2 Single species isotherms	111	<i>Himadri Tanaya Behera, Abhik Mojumdar and Lopamudra Ray</i>	
6.3 Multisorption	120	9.1 Introduction	181
6.4 Site-specific interactions	127	9.2 Actinobacteria: biology and genetic systems	182
6.5 Electrical potential correction	133	9.3 Regulation of oxidative stress in actinobacteria	184
6.6 Continuum approaches	139	9.4 Metal detoxification and bioremediation	187
References	142	9.5 Bioremediation strategies using actinobacteria	188
		9.6 Conclusion	190
		References	190
7. Biodegradation of organophosphates: biology and biotechnology	145	10. Bacterial and fungal bioremediation strategies	193
<i>Sunil Parthasarathy, Annapoorni Lakshman Sagar and Dayananda Siddavattam</i>		<i>N. Magan, S. Gouma, S. Fragoeiro, M.E. Shuaib and A.C. Bastos</i>	
7.1 Introduction	145	10.1 Introduction	193
Acknowledgments	155	10.2 Bioremediation considerations	194
References	155	10.3 Advantages and disadvantages of bioremediation	194
Further reading	159	10.4 Microbial mechanisms of transformation of xenobiotic compounds	196
8. Pollutants in the coral environment and strategies to lower their impact on the functioning of reef ecosystem	161	10.5 Screening of bacteria and white rot fungi for bioremediation applications for pesticides and crude oil	199
<i>Neha P. Patel and Soumya Haldar</i>		10.6 Degradation of pesticide mixtures and crude oil by bacteria and fungi	201
8.1 Introduction	161	10.7 Inoculant production for soil incorporation of bioremedial fungi	204
		10.8 Use of spent mushroom composts	206
		10.9 Conclusions and future strategies	207
		References	208

<b>11. Current trends in algal biotechnology for the generation of sustainable biobased products</b>	213	13.6 Biotechnological contribution	271
<i>Bobby Edwards III, Rajneesh Jaswal, Ashish Pathak and Ashvini Chauhan</i>		13.7 Omics tools to understand plant–microorganism association during phytoremediation	272
11.1 Introduction	213	13.8 Functional and taxonomic diversity of root-associated bacteria in heavy metal hyperaccumulating plants: a case study	273
11.2 What is bioprospecting?	225	References	280
11.3 Phycoremediation, microalgae, and bioprospecting	227	<b>14. Recent advancements in microbial bioremediation of industrial effluents: challenges and future outlook</b>	293
11.4 Isolation methods	228	<i>Khushboo Choudhary, Vivekanand Vivekanand and Nidhi Pareek</i>	
11.5 Culturing the target strain(s)	231	14.1 Introduction	293
11.6 Information garnered from the whole genome sequencing of lipid-producing microalgae	231	14.2 Industrial effluents and toxicity	294
11.7 Bioinformatics resources to study lipid metabolic pathways in microalgae	232	14.3 Remediation: a microbial perspective	295
References	234	14.4 Emerging strategies for bioremediation of industrial effluents	296
<b>12. A review on microbial potential of toxic azo dyes bioremediation in aquatic system</b>	241	14.5 Conclusion	299
<i>Raya Majumdar, Wasim Akram Shaikh, Sukalyan Chakraborty and Santanu Chowdhury</i>		References	300
12.1 Introduction	241	<b>15. Potential of anaerobic bacteria in bioremediation of metal-contaminated marine and estuarine environment</b>	305
12.2 Bioremediation of azo dyes	245	<i>M.B. Binish, P. Binu, V.G. Gopikrishna and Mahesh Mohan</i>	
12.3 Cyanobacterial remediation of azo dyes	248	15.1 Introduction	305
12.4 Application of cyanobacteria derived nanoparticles to remove azo dye from aquatic phase	255	15.2 Principle and biochemistry of bioremediation	306
12.5 Limitations	256	15.3 Mechanisms of metal remediation by microorganism	307
12.6 Conclusion	256	15.4 Metal degradation by bacteria	308
References	256	15.5 Genetically modified bacteria in metal bioremediation	309
<b>13. Role of rhizosphere microbiome during phytoremediation of heavy metals</b>	263	15.6 Bioremediation of metals in marine and estuarine environments	310
<i>L. Breton-Deval, A. Guevara-García, K. Juarez, P. Lara, D. Rubio-Noguez and E. Tovar-Sánchez</i>		15.7 Bioremediation of mercury—a case study	311
13.1 Introduction	263	15.8 Significance of anaerobic bacteria in mercury bioremediation	311
13.2 Coping mechanism of microorganism to high concentrations of metals	264	15.9 Biosorption by mercury-resistant anaerobic bacteria—case study from a tropical estuary	312
13.3 The physiological effect of heavy metals in plants	267	15.10 Discussion	319
13.4 Plant mechanisms to withstand with high concentrations of heavy metals	268	15.11 Conclusion	320
13.5 Plants with the ability to tolerate high concentrations of heavy metals: natural cases	270	Acknowledgments	320
		References	321

<b>16. Plant growth-promoting rhizobacteria-assisted bioremediation of toxic contaminant: recent advancements and applications</b>	327	<b>18.2 Aromatic compounds: properties and sources</b>	366
<i>Rupa Rani, Vipin Kumar and Pratishtha Gupta</i>		<b>18.3 Impact of aromatic pollutants on planetary health</b>	368
16.1 Introduction	327	<b>18.4 Microbes involved in aromatic compound degradation</b>	369
16.2 Pesticides	327	<b>18.5 Bacterial metabolism of aromatic compounds</b>	369
16.3 Environmental fate of pesticides	333	<b>18.6 Bioremediation: strategies to remove pollutants</b>	381
16.4 Plant growth-promoting rhizobacteria	333	<b>18.7 Roadblocks/factors affecting bioremediation</b>	384
16.5 Bioremediation of pesticides by plant growth-promoting rhizobacteria	338	<b>18.8 Future directions</b>	385
16.6 Conclusion and future prospects	338	<b>Acknowledgments</b>	385
Acknowledgment	338	<b>References</b>	386
References	338		
<b>17. Cyanobacterial and microalgal bioremediation: an efficient and eco-friendly approach toward industrial wastewater treatment and value-addition</b>	343	<b>19. Microbial bioremediation of Cr(VI)-contaminated soil for sustainable agriculture</b>	395
<i>Priyanka Gehlot, Vivekanand Vivekanand and Nidhi Pareek</i>		<i>Swati Pattnaik, Swati Mohapatra, Swayamsidha Pati, Debashis Dash, Deepika Devadarshini, Ksheerabdi Tanaya, Bibhuti Bhusan Mishra and Deviprasad Samantaray</i>	
17.1 Introduction	343	19.1 Introduction	395
17.2 General characteristics	344	19.2 Chromium production and toxicity	396
17.3 Cyanobacteria in bioremediation	345	19.3 Microbial bioremediation of Cr(VI) toxicity	397
17.4 Microalgae in bioremediation	345	19.4 Impact of Cr(VI)-contaminated soil in agriculture	398
17.5 Cyanobacterial bioremediation of various industrial wastewaters	346	19.5 Case study	400
17.6 Phycoremediation of industrial wastewater	348	19.6 Conclusion	405
17.7 Cyanobacteria: value-added products	349	References	405
17.8 Microalgae: value-added products	351		
17.9 Merits and demerits of algal bioremediation technology	355		
17.10 Case studies	356		
17.11 Future prospective and conclusions	356		
References	357		
<b>Part III</b>		<b>20. Microbial bioremediation of aquaculture effluents</b>	409
<b>Various pollutants and their bioremediation strategies</b>	363	<i>Luis Rafael Martínez-Córdoba, Glen Ricardo Robles-Porchas, Francisco Vargas-Albores, Marco Antonio Porchas-Cornejo and Marcel Martínez-Porchas</i>	
<b>18. Microbial degradation of aromatic pollutants: metabolic routes, pathway diversity, and strategies for bioremediation</b>	365	20.1 Introduction	409
<i>Balaram Mohapatra, Tushar Dhamale, Braja Kishor Saha and Prashant S. Phale</i>		20.2 Microbes as bioremediators	410
18.1 Introduction	365	20.3 Limitations of microbial bioremediation	414
		20.4 Multitrophic bioremediation systems: a sustainable alternative	414
		20.5 Conclusion	415
		References	415

<b>21. Transport and disposal of radioactive wastes in nuclear industry</b>	<b>419</b>	
<i>T. Subba Rao, S. Panigrahi and P. Velraj</i>		
21.1 Introduction	419	
21.2 The nuclear fuel cycle	420	
21.3 Classification of radioactive wastes	422	
21.4 Radioactive waste management or treatment of radioactive waste	425	
21.5 Transport of radioactive wastes in the environment	426	
21.6 Decontamination of radioactive waste	427	
21.7 Biological decontamination of radioactive waste	429	
21.8 Conclusion	436	
References	436	
<b>22. Biofilm-mediated biodegradation of hydrophobic organic compounds in the presence of metals as co-contaminants</b>	<b>441</b>	
<i>Prerna J. Yesankar, Asifa Qureshi and Hemant J. Purohit</i>		
22.1 Introduction	441	
22.2 Hydrophobic organic compounds: a class of persistent organic pollutants	441	
22.3 Metals: as coexisting contaminant	443	
22.4 Microbial interactions with HOCs and metal contaminants	443	
22.5 Biofilms for the rescue	445	
22.6 Remedial mechanism for combined pollutants	451	
22.7 Engineered biofilms and genomic approaches	453	
22.8 Factors affecting biofilm-mediated remediation for mixed pollutants	454	
22.9 Conclusion	455	
22.10 Challenges and future perspectives	455	
Acknowledgments	456	
References	456	
<b>23. Factors affecting the bioremediation of industrial and domestic wastewaters</b>	<b>461</b>	
<i>J.K. Bwapwa</i>		
23.1 Introduction	461	
23.2 Factors affecting bioremediation of domestic/industrial wastewater: analysis	462	
23.3 Main aspects influencing the bioremediation of domestic and industrial wastewater	463	
23.4 Effectiveness of contaminants removal mechanisms	466	
23.5 Type of microorganisms	468	
23.6 Conclusion	470	
References	470	
<b>24. Organophosphate pesticide: usage, environmental exposure, health effects, and microbial bioremediation</b>	<b>473</b>	
<i>Rishi Mahajan, Shalini Verma, Shalini Chandel and Subhankar Chatterjee</i>		
24.1 Introduction	473	
24.2 Usages and associated health risks	474	
24.3 Human population's exposure to organophosphorus pesticide	475	
24.4 Pharmacology and toxicology	476	
24.5 Clinical effects: toxicological analyses and biomedical investigations	476	
24.6 Removal of organophosphorus pesticides from the environment	480	
24.7 Microbial mediated organophosphorus pesticide biodegradation	481	
24.8 Evaluating the significance of organophosphorus pesticide degrading enzymes	485	
24.9 Conclusion	486	
References	486	
<b>Part IV</b>		
<b>Advanced bioremediation strategies</b>	<b>491</b>	
<b>25. Feasibility of using bioelectrochemical systems for bioremediation</b>	<b>493</b>	
<i>Song Jin and Paul H. Fallgren</i>		
25.1 Introduction	493	
25.2 Bioelectrochemical system configurations, microbial processes, and remediation	494	
25.3 Anodic remediation	498	
25.4 Cathodic remediation	498	
25.5 Current state and challenges	500	
References	503	

<b>26. Electrochemical biosensors for monitoring of bioorganic and inorganic chemical pollutants in biological and environmental matrices</b>	<b>509</b>	<b>27.6</b> Bioelectrochemical system for treatment of solid waste and semisolid waste	<b>542</b>
<i>Uday Pratap Azad, Supratim Mahapatra, Divya, Ananya Srivastava, Nagaraj P. Shetti and Pranjal Chandra</i>		<b>27.7</b> BES for carbon capture and flue gas treatment	<b>542</b>
26.1 Introduction	509	<b>27.8</b> Conclusion	<b>543</b>
26.2 Types of inorganic pollutants and their source	510	References	<b>543</b>
26.3 Electrochemical biosensor for ammonia detection	513		
26.4 Electrochemical biosensors for $\text{SO}_2$ , $\text{HSO}_3^-$ , and $\text{SO}_3^-$	516		
26.5 Electrochemical biosensors for hydrogen sulfide detection	517		
26.6 Electrochemical biosensors for chloride and fluoride ion determination	517		
26.7 Organic pollutants and electrochemical biosensors for their quantification	519		
26.8 Electrochemical biosensors for azo dyes	519		
26.9 Electrochemical biosensors for aromatics nitro compounds	520		
26.10 Electrochemical biosensors for phenolic compounds	521		
26.11 Electrochemical biosensors for pesticide detection	522		
26.12 Conclusion	523		
Acknowledgments	524		
Declaration of competing interest	524		
References	524		
<b>27. Bioelectrochemical system for environmental remediation of toxicants</b>	<b>533</b>	<b>28. Biofilm-mediated bioremediation of polycyclic aromatic hydrocarbons: current status and future perspectives</b>	<b>547</b>
<i>Ankur Singh and Vipin Kumar</i>		<i>Neelam Kungwani, Sudhir K. Shukla, T. Subba Rao and Surajit Das</i>	
27.1 Bioelectrochemical system for bioremediation	533	28.1 Introduction	<b>547</b>
27.2 Configurations of bioelectrochemical system for environmental remediation	535	28.2 Polycyclic aromatic hydrocarbons: sources and toxicity	<b>548</b>
27.3 Microbial community and biocompatible electrodes for bioelectrochemical system	536	28.3 Polycyclic aromatic hydrocarbons biodegradation: metabolic and genomic aspect	<b>550</b>
27.4 Principle of remediation by bioelectrochemical system	538	28.4 Bacterial biofilms	<b>553</b>
27.5 Bioelectrochemical system for treatment of wastewater	540	28.5 Fidelity of biofilms in polycyclic aromatic hydrocarbons bioremediation	<b>557</b>
		28.6 Biofilm omics insights into polycyclic aromatic hydrocarbons bioremediation	<b>561</b>
		28.7 Conclusion	<b>564</b>
		References	<b>565</b>
<b>29. Extremophilic nature of microbial ligninolytic enzymes and their role in biodegradation</b>	<b>571</b>		
<i>Adarsh Kumar and Ram Chandra</i>			
29.1 Introduction	571		
29.2 Extremophilic ligninolytic enzymes	572		
29.3 Role of extremophilic ligninolytic enzymes in bioremediation	577		
29.4 Conclusion and future prospects	583		
Acknowledgments	584		
References	584		
<b>30. Marine hydrocarbon-degrading bacteria: their role and application in oil-spill response and enhanced oil recovery</b>	<b>591</b>		
<i>Christina Nikolova and Tony Gutierrez</i>			
30.1 Introduction	591		

30.2	Diversity of marine hydrocarbon-degrading bacteria	591	31.3	Limitations of traditional remediation methods	607
30.3	Use of marine hydrocarbon-degrading bacteria in oil spill cleanup	594	31.4	Nanoremediation: an alternative for traditional remediation processes	608
30.4	Use of marine hydrocarbon-degrading bacteria in enhanced oil recovery	595	31.5	Nanotoxicity and fate of nanomaterials in the environment	610
30.5	Research needs	596	31.6	Conclusion	612
	References	597		References	612
			Index		617
<b>31.</b>	<b>Nanoremediation of toxic contaminants from the environment: challenges and scopes</b>	<b>601</b>			
	<i>Avinash Ingle, Amedea B. Seabra, Nelson Duran, Indarchand Gupta, Aniket Gade and Mahendra Rai</i>				
31.1	Introduction	601			
31.2	Different kinds of remediation	602			