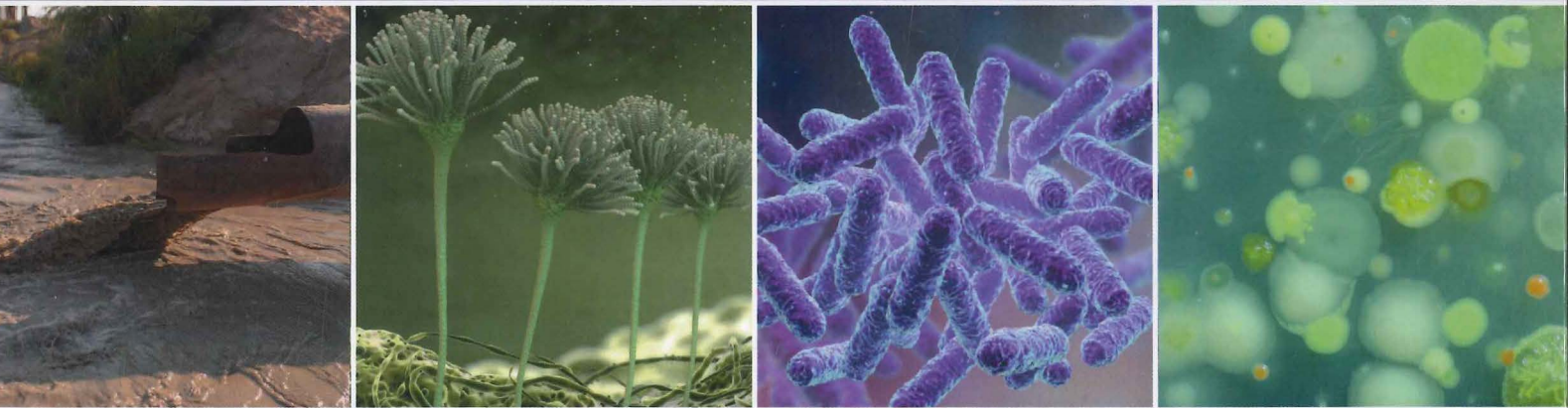


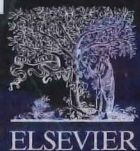
MICROBIAL BIODEGRADATION AND BIOREMEDIATION

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	xiii	2.4 Human exposure to pollutants	42
Preface	xvii	2.5 Metabolic response of pollutants in the human body	44
Part I		2.6 Toxic effects of pollutants on human health	45
Toxicity of various pollutants and introduction to bioremediation	1	2.7 Conclusion	49
		References	49
1. Prospects and scope of microbial bioremediation for the restoration of the contaminated sites	3	3. The use of molecular tools to characterize functional microbial communities in contaminated areas	55
<i>Shreosi Chatterjee, Swetambari Kumari, Sonalin Rath and Surajit Das</i>		<i>Punyasloke Bhadury and Anwesha Ghosh</i>	
1.1 Introduction	3	3.1 Introduction	55
1.2 Recent advances in conventional remediation technologies	4	3.2 Elucidating structure of microbial communities	56
1.3 Biological treatment of pollutants: bioremediation	8	3.3 Functional analysis of microbial communities	61
1.4 Selection criteria of microorganisms for the bioremediation	9	3.4 Determination of "in situ" abundance of microorganisms	64
1.5 Applications of microorganisms for environmental restoration	10	3.5 Conclusion	65
1.6 Factors influencing the efficiency of bioremediation	16	References	65
1.7 Microbial bioremediation strategies	18		
1.8 Future perspectives and challenges	23	4. Fate and consequences of microplastics in the environment and their impact on biological organisms	69
Acknowledgments	24	<i>Arijit Reeves, Punarbasu Chaudhuri and Sukalyan Chakraborty</i>	
References	24	4.1 Introduction	69
2. Mechanism of toxicity and adverse health effects of environmental pollutants	33	4.2 Residence time of microplastics in the environment	74
<i>Vandana, Monika Priyadarshane, Uma Mahto and Surajit Das</i>		4.3 Impact on terrestrial organisms	74
2.1 Introduction	33	4.4 Impact on aquatic organisms	75
2.2 Types of pollutants	33	4.5 Impact on human beings	76
2.3 Sources and fate of pollutants in the environment	36	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
<i>Jaya Chakraborty, Krishna Palit and Surajit Das</i>		
5.1	Introduction	81
5.2	Metagenomics-based methodology for microbial diversity analysis	82
5.3	Bacterial diversity of natural versus polluted coastal ecosystem	85
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
<i>Kristofer G. Paso</i>		
6.1	Introduction	109
6.2	Single species isotherms	111
6.3	Multisorption	120
6.4	Site-specific interactions	127
6.5	Electrical potential correction	133
6.6	Continuum approaches	139
	References	142
7.	Biodegradation of organophosphates: biology and biotechnology	145
<i>Sunil Parthasarathy, Annapoorni Lakshman Sagar and Dayananda Siddavattam</i>		
7.1	Introduction	145
	Acknowledgments	155
	References	155
	Further reading	159
8.	Pollutants in the coral environment and strategies to lower their impact on the functioning of reef ecosystem	161
<i>Neha P. Patel and Soumya Haldar</i>		
8.1	Introduction	161
8.2	Pollutants and their impact on the reef ecosystem	162
8.3	Current and advance strategies for protecting reef ecosystem from pollution	167
8.5	Conclusion	173
	Acknowledgements	173
	References	173
Part II		
Role of diverse microorganisms in bioremediation		179
9.	Biology, genetic aspects and oxidative stress response of actinobacteria and strategies for bioremediation of toxic metals	181
<i>Himadri Tanaya Behera, Abhik Mojumdar and Lopamudra Ray</i>		
9.1	Introduction	181
9.2	Actinobacteria: biology and genetic systems	182
9.3	Regulation of oxidative stress in actinobacteria	184
9.4	Metal detoxification and bioremediation	187
9.5	Bioremediation strategies using actinobacteria	188
9.6	Conclusion	190
	References	190
10.	Bacterial and fungal bioremediation strategies	193
<i>N. Magan, S. Gouma, S. Fragoeiro, M.E. Shuaib and A.C. Bastos</i>		
10.1	Introduction	193
10.2	Bioremediation considerations	194
10.3	Advantages and disadvantages of bioremediation	194
10.4	Microbial mechanisms of transformation of xenobiotic compounds	196
10.5	Screening of bacteria and white rot fungi for bioremediation applications for pesticides and crude oil	199
10.6	Degradation of pesticide mixtures and crude oil by bacteria and fungi	201
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

11. Current trends in algal biotechnology for the generation of sustainable biobased products	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	14. Recent advancements in microbial bioremediation of industrial effluents: challenges and future outlook	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
12. A review on microbial potential of toxic azo dyes bioremediation in aquatic system	241	14.5 Conclusion	299
<i>Raya Majumdar, Wasim Akram Shaikh, Sukalyan Chakraborty and Santanu Chowdhury</i>		References	300
12.1 Introduction	241	15. Potential of anaerobic bacteria in bioremediation of metal-contaminated marine and estuarine environment	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
13. Role of rhizosphere microbiome during phytoremediation of heavy metals	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-Sanchez</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

16. Plant growth-promoting rhizobacteria-assisted bioremediation of toxic contaminant: recent advancements and applications	327	18.2 Aromatic compounds: properties and sources	366
<i>Rupa Rani, Vipin Kumar and Pratishtha Gupta</i>		18.3 Impact of aromatic pollutants on planetary health	368
16.1 Introduction	327	18.4 Microbes involved in aromatic compound degradation	369
16.2 Pesticides	327	18.5 Bacterial metabolism of aromatic compounds	369
16.3 Environmental fate of pesticides	333	18.6 Bioremediation: strategies to remove pollutants	381
16.4 Plant growth-promoting rhizobacteria	333	18.7 Roadblocks/factors affecting bioremediation	384
16.5 Bioremediation of pesticides by plant growth-promoting rhizobacteria	338	18.8 Future directions	385
16.6 Conclusion and future prospects	338	Acknowledgments	385
Acknowledgment	338	References	386
References	338		
17. Cyanobacterial and microalgal bioremediation: an efficient and eco-friendly approach toward industrial wastewater treatment and value-addition	343	19. Microbial bioremediation of Cr(VI)-contaminated soil for sustainable agriculture	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	20. Microbial bioremediation of aquaculture effluents	409
17.10 Case studies	356	<i>Luis Rafael Martínez-Córdova, Glen Ricardo Robles-Porchas, Francisco Vargas-Albores, Marco Antonio Porchas-Cornejo and Marcel Martínez-Porchas</i>	
17.11 Future prospective and conclusions	356	20.1 Introduction	409
References	357	20.2 Microbes as bioremediators	410
		20.3 Limitations of microbial bioremediation	414
Part III		20.4 Multitrophic bioremediation systems: a sustainable alternative	414
Various pollutants and their bioremediation strategies	363	20.5 Conclusion	415
18. Microbial degradation of aromatic pollutants: metabolic routes, pathway diversity, and strategies for bioremediation	365	References	415
<i>Balaram Mohapatra, Tushar Dhamale, Braja Kishor Saha and Prashant S. Phale</i>			
18.1 Introduction	365		

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

26. Electrochemical biosensors for monitoring of bioorganic and inorganic chemical pollutants in biological and environmental matrices	509	27.6 Bioelectrochemical system for treatment of solid waste and semisolid waste	542
<i>Uday Pratap Azad, Supratim Mahapatra, Divya, Ananya Srivastava, Nagaraj P. Shetti and Pranjal Chandra</i>		27.7 BES for carbon capture and flue gas treatment	542
26.1 Introduction	509	27.8 Conclusion	543
26.2 Types of inorganic pollutants and their source	510	References	543
26.3 Electrochemical biosensor for ammonia detection	513	28. Biofilm-mediated bioremediation of polycyclic aromatic hydrocarbons: current status and future perspectives	547
26.4 Electrochemical biosensors for SO ₂ , HSO ₃ ⁻ , and SO ₃ ⁻	516	<i>Neelam Kungwani, Sudhir K. Shukla, T. Subba Rao and Surajit Das</i>	
26.5 Electrochemical biosensors for hydrogen sulfide detection	517	28.1 Introduction	547
26.6 Electrochemical biosensors for chloride and fluoride ion determination	517	28.2 Polycyclic aromatic hydrocarbons: sources and toxicity	548
26.7 Organic pollutants and electrochemical biosensors for their quantification	519	28.3 Polycyclic aromatic hydrocarbons biodegradation: metabolic and genomic aspect	550
26.8 Electrochemical biosensors for azo dyes	519	28.4 Bacterial biofilms	553
26.9 Electrochemical biosensors for aromatics nitro compounds	520	28.5 Fidelity of biofilms in polycyclic aromatic hydrocarbons bioremediation	557
26.10 Electrochemical biosensors for phenolic compounds	521	28.6 Biofilm omics insights into polycyclic aromatic hydrocarbons bioremediation	561
26.11 Electrochemical biosensors for pesticide detection	522	28.7 Conclusion	564
26.12 Conclusion	523	References	565
Acknowledgments	524	29. Extremophilic nature of microbial ligninolytic enzymes and their role in biodegradation	571
Declaration of competing interest	524	<i>Adarsh Kumar and Ram Chandra</i>	
References	524	29.1 Introduction	571
27. Bioelectrochemical system for environmental remediation of toxicants	533	29.2 Extremophilic ligninolytic enzymes	572
<i>Ankur Singh and Vipin Kumar</i>		29.3 Role of extremophilic ligninolytic enzymes in bioremediation	577
27.1 Bioelectrochemical system for bioremediation	533	29.4 Conclusion and future prospects	583
27.2 Configurations of bioelectrochemical system for environmental remediation	535	Acknowledgments	584
27.3 Microbial community and biocompatible electrodes for bioelectrochemical system	536	References	584
27.4 Principle of remediation by bioelectrochemical system	538	30. Marine hydrocarbon-degrading bacteria: their role and application in oil-spill response and enhanced oil recovery	591
27.5 Bioelectrochemical system for treatment of wastewater	540	<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
31. Nanoremediation of toxic contaminants from the environment: challenges and scopes	601		
<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		