

Contents

Foreword xv

Preface xvii

1	Science and Technology of Nanomaterials: Introduction	1
	<i>Merin Sara Thomas, Sabu Thomas, and Laly A. Pothen</i>	
1.1	Introduction	1
1.2	Classification of Nanomaterials	2
1.3	Classes of Nanomaterials	2
1.3.1	Organic Nanoparticles	3
1.3.2	Inorganic Nanoparticles	3
1.3.3	Carbon-Based Nanoparticles	3
1.4	Properties of Nanomaterials	3
1.4.1	Size and Surface Area	3
1.4.2	Mechanical Properties	4
1.4.3	Optical and Electrical Properties	6
1.4.4	Magnetic Properties	6
1.5	Characterization of Nanomaterials	6
1.5.1	Surface Morphology, Surface Area, Size, and Shape of Nanoparticles	7
1.5.2	Elemental and Mineral Composition	7
1.5.3	Structures and Bonds in Nanoparticles	8
1.6	Current State of Nanotechnology	8
1.7	Safety Issues of Nanotechnology	8
1.8	Conclusion	9
	References	10
2	Nanoremediation: A Brief Introduction	17
	<i>Renjitha P. Rajan, Merin Sara Thomas, Sabu Thomas, and Laly A. Pothen</i>	
2.1	Introduction	17
2.2	Mechanism of Nanoremediation	18
2.3	Nanotechnology for Disinfection	18
2.4	Nanotechnology for Removal of Heavy Metals and Ions	20
2.5	Nanotechnology for Removal of Organic Contaminants	20

2.6	Nanotechnology for Oil/Water Separation	21
2.7	Challenges in Nanoremediation	22
2.8	Conclusion	23
	References	23
3	Nanotechnology in Soil Remediation	27
	<i>Alice Alex, Sithara Raj, Sunish K. Sugunan, and Gigi George</i>	
3.1	Impact of ENMs on the Environment and Microorganisms	27
3.2	Engineered Nanomaterials in Soil Remediation	29
3.2.1	Iron-Based Nanomaterials	30
3.2.2	TiO ₂ -Based Nanomaterials	31
3.2.3	Carbon-Based Nanomaterials	31
3.2.4	Silica-Based Nanomaterials	32
3.3	Nanotechnology in Soil Remediation	32
3.3.1	TiO ₂ Nanoparticles	33
3.3.2	Iron Nanoparticles	34
3.3.3	Silica Nanoparticles	36
3.3.4	Carbon-Based Nanoparticles	36
3.3.5	Silver Nanoparticles	37
3.4	Conclusion	38
	References	38
4	Nanotechnology for Water Treatment: Recent Advancement in the Remediation of Organic and Inorganic Compounds	45
	<i>Charulata Sivodia and Alok Sinha</i>	
4.1	Introduction	45
4.1.1	Classification and Synthesis Routes of Nanomaterials	45
4.2	Application of Nanotechnology	46
4.2.1	Heavy Metal Removal	46
4.2.2	Dye Removal	47
4.2.3	Organochlorine Compounds (OCCs) Removal	48
4.2.4	Inorganic Anions	49
4.3	Conclusions	52
	References	52
5	Nanotechnology in Air Pollution Remediation	59
	<i>Haleema Saleem, Syed J. Zaidi, Ahmad F. Ismail, and Pei S. Goh</i>	
5.1	Introduction	59
5.2	Recent Developments in Nanotechnology for Air Pollution Remediation	60
5.2.1	Nanoadsorbents	61
5.2.2	Nanofilters and Nanostructured Membranes	62
5.2.3	Nanocatalysts	65
5.2.4	Nanosensors	66
5.2.4.1	Detection of NO ₂	66

5.2.4.2	Detection of H_2S	67
5.2.4.3	Detection of SO_2	68
5.3	Adverse Impact of the Nanomaterials in the Environment	69
5.4	Future Directions	70
	Acknowledgment	71
	References	71
6	Nanomaterials in Filtration	77
	<i>Ahmed Ibrahim Abd-Elhamid and AbdElAziz Ahmed Nayl</i>	
6.1	Introduction	77
6.2	Nanofiber in Air Filtration	79
6.2.1	Pure Nanofiber in Air Filtration	79
6.2.2	Polymer–Nanofiber Composite in Air Filtration	80
6.2.3	MOF–Nanofiber Composite in Air Filtration	81
6.2.4	Nanomaterial–Nanofiber Hybrid in Air Filtration	82
6.2.5	Window Screening	84
6.3	Nanofiber in Wastewater Filtration	85
6.3.1	Oil–Water Separation	85
6.3.2	Antifouling	87
6.3.3	Organic and Inorganic Pollutant Removal	88
6.3.4	Microorganism Removal	92
6.4	Conclusion	94
	References	94
7	Nanoadsorbents for Environmental Remediation	103
	<i>Adnan Khan, Sumeet Malik, Sumaira Shah, Nisar Ali, Farman Ali, Suresh Ghotekar, Harshal Dabhane, and Muhammad Bilal</i>	
7.1	Introduction	103
7.2	Properties and Synthesis of Nanomaterials	105
7.3	Different Classes of Nanoadsorbents for Removal of Contaminants from Wastewater	106
7.3.1	Carbon-Based Nanoadsorbents	106
7.3.2	Silica-Based Nanoadsorbents	107
7.3.3	Metal-Based Nanoadsorbents	109
7.3.4	Polymer-Based Nanoadsorbents	112
7.4	Conclusion	114
	References	114
8	Visible-Light Photocatalytic Degradation of Heavy Metal Ion Hexavalent Chromium $[Cr(VI)]$	121
	<i>Priya Rawat, Harshita Chawla, and Seema Garg</i>	
8.1	Introduction	121
8.2	Modifications in TiO_2 for Visible-Light Activity	126
8.2.1	Coupling of Transition Metal Oxide	126
8.2.1.1	Simple Metal Oxides	126

8.2.1.2	Spinel-Type Mixed Metal Oxides	127
8.2.2	Coupling of Metal Sulfides	128
8.2.3	Coupling of Noble Metals	129
8.2.4	Synergetic Conversion and Capacitive Deionization	130
8.3	Stability of the Photocatalyst	131
8.4	Conclusion	132
8.4.1	Current Scenario	132
8.4.2	Challenges	133
8.4.3	Future Perspectives	133
	References	133

9 **Phytonanotechnology for Remediation of Heavy Metals and Dyes** 139

Lakhan Kumar, Pragya Kamal, Kaniska Soni, and Navneeta Bharadvaja

9.1	Introduction	139
9.2	Environmental Pollution and Health Impacts	141
9.2.1	Heavy Metals and Associated Environmental and Public Health Issues	141
9.2.2	Dyes and Associated Environmental and Public Health Issues	142
9.3	Environmental Pollution and Remediation Strategies	143
9.3.1	Mycoremediation	143
9.3.2	Phytoremediation	144
9.3.3	Phycoremediation	144
9.3.4	Biostimulation	144
9.3.5	Rhizofiltration	144
9.4	Phyto-nanotechnological Approach for Remediation of Environmental Pollutants	145
9.4.1	Heavy Metals Remediation Potential of Plant-Based Nanomaterials	146
9.4.2	Dyes Remediation Potential of Plant-Based Nanomaterials	147
9.5	Prospect and Challenges to Phytonanoremediation	147
9.6	Concluding Remarks	154
	References	155

10 **Surface-Functionalized Gold Nanoparticles for Environmental Remediation** 163

Daniel T. Thangadurai, Nandhakumar Manjubaashini, and Devaraj Nataraj

10.1	Introduction	163
10.2	Fundamentals of Gold Nanoparticles	164
10.3	Significance of Gold Nanoparticles	164
10.4	Importance of Surface-Functionalized Gold Nanoparticles	166
10.5	Applications of Gold Nanoparticles	166
10.6	Synthesis and Characterization of Rhodamine 6G-Functionalized Gold Nanoparticles (Rh6G-AuNPs)	167
10.6.1	Synthesis of Rh6G-AuNPs by Reduction Method	167

10.6.2	Characterization of Rh6G-AuNPs	168
10.6.2.1	X-ray Diffraction Studies	168
10.6.2.2	Morphological Analysis	168
10.6.2.3	XPS studies	170
10.6.2.4	Raman Spectroscopy Analysis	170
10.6.2.5	Thermal Studies	172
10.7	Interaction of Rhodamine 6G-Functionalized AuNPs with Heavy Metal Ion	174
10.7.1	Selectivity and Sensitivity Studies	174
10.7.1.1	Time-Resolved Fluorescence Measurements	174
10.7.1.2	Stability Measurements	176
10.8	Application of Rh6G-AuNPs	178
10.8.1	Real Water Sample Analysis	178
10.8.2	Cytotoxicity Test	178
10.9	Conclusion	180
	Acknowledgments	180
	References	180

11 Metal Oxide Nanoparticles for Environmental Remediation 183

Abhilash Venkateshaiah, Miroslav Černík, and Vinod V.T. Padil

11.1	Introduction	183
11.2	Synthesis of Metal Oxide Nanoparticles	185
11.2.1	Physical Methods	185
11.2.1.1	Chemical Vapor Synthesis	185
11.2.1.2	Laser Ablation Method	186
11.2.1.3	Mechanical Milling Technique	186
11.2.2	Chemical Methods	187
11.2.2.1	Co-precipitation Method	187
11.2.2.2	Sol-Gel Method	188
11.2.2.3	Solvothermal Method	188
11.2.3	Biological Methods	188
11.2.3.1	Plant Mediated Synthesis	189
11.2.3.2	Microbial Mediated Synthesis	189
11.3	Environmental Remediation Using MeO NPs	190
11.3.1	Adsorption	190
11.3.2	Catalysis	191
11.3.3	Antimicrobial Activity	192
11.4	Different MeO NPs in Remediation	193
11.4.1	Titanium Oxide Nanoparticles	193
11.4.2	Zinc Oxide Nanoparticles	195
11.4.3	Iron-Based Oxides	197
11.4.4	Copper Oxide	199
11.4.5	Tin Oxide Nanoparticles	200
11.4.6	Tungsten Oxide Nanoparticles	201

11.4.7	Other Metal Oxide Nanoparticles	201
11.5	Conclusion and Prospects	202
	Acknowledgments	203
	References	204
12	Functionalized Nanoparticles for Environmental Remediation	215
	<i>Beatriz Jurado-Sánchez</i>	
12.1	Introduction	215
12.2	Nanoparticles for Environmental Remediation and Functionalization	216
12.2.1	Metallic and Metal Oxide NPs	216
12.2.1.1	Silver and Gold NPs	216
12.2.1.2	Titanium Dioxide NPs	217
12.2.1.3	Magnetic Iron Oxide NPs	218
12.2.2	Silica and Polymeric NPs	218
12.2.3	Carbon NMs	219
12.2.4	2D NMs	219
12.2.5	Micromotors	220
12.3	Nanofiltration with Functionalized NPs	220
12.4	Nanophotocatalytic Degradation with Functionalized NPs	224
12.5	Chemical Degradation of Pollutants Assisted with Functionalized NPs	230
	Acknowledgments	232
	References	232
13	Dendrimers for Environmental Remediation	243
	<i>Uyiosa O. Aigbe, Kingsley E. Ukhurebor, Robert B. Onyancha, Onoyivwe M. Ama, Otolarin A. Osibote, Heri S. Kusuma, Philomina N. Okanigbuan, Samuel O. Azi, and Peter O. Osifo</i>	
13.1	Introduction	243
13.2	Synthesis Methods	246
13.2.1	Divergent Approach	247
13.2.2	Convergent Method	247
13.3	Physicochemical Properties of Dendrimers	247
13.4	Environmental Application of Dendrimers	248
13.4.1	Water Purification Process Using Functionalized Dendrimers	249
13.4.2	Dendrimers Application in Photocatalysis	252
13.4.3	Dendrimers Application in Soil Remediation	254
13.4.4	Dendrimers Application in Air Remediation	255
13.5	Conclusion	258
	Acknowledgment	259
	References	259

14	Nanocrystals for Environmental Remediation	265
	<i>Muhammad N. Ashiq, Sumaira Manzoor, Abdul G. Abid, and Muhammad Najam-Ul-Haq</i>	
14.1	Introduction	265
14.1.1	Environmental Remediation Techniques	266
14.1.1.1	Photocatalysis	266
14.1.2	Different Types of Nanomaterial Used for Environmental Remediation	268
14.1.2.1	Metal Oxides-Based Nanostructure	268
14.1.2.2	Nanocomposite-Based Photocatalyst	269
14.1.2.3	Magnetic Nanomaterial	271
14.1.3	Nanostructured Material as Efficient Antibacterial Agents	273
	References	276
15	Enzyme Nanoparticles for Environmental Remediation	283
	<i>Neha Tiwari and Deenan Santhiya</i>	
15.1	Introduction	283
15.2	Sources of Various Enzymes Used for Environmental Remediation	285
15.3	Various Enzyme-Immobilized Nanoparticles for Environmental Remediation	285
15.3.1	Magnetic Nanoparticles	285
15.3.2	Mesoporous Nanoparticles	287
15.3.3	Carbon-Based Nanoparticles	287
15.3.4	Carbon Nanotubes	287
15.3.5	Role of Nanoparticles in Environmental Remediation	288
15.4	Importance of Enzyme Nanoparticles in Remediation	288
15.4.1	Advantages of Enzyme Nanoparticles	290
15.5	Challenges in the Bioremediation Through Enzyme Nanoparticles	290
15.6	Conclusion	292
	References	292
16	Nanofibers for Environmental Remediation	301
	<i>Daniel Pasquini, Luís C. de Moraes, and Pedro E. Costa</i>	
16.1	Introduction	301
16.2	Cellulose	301
16.2.1	Chemical Structure and Reactivity	301
16.2.2	The Origin of Cellulose Nanofibers	302
16.2.3	Surface Modification of Cellulose Nanofibers	305
16.2.4	Treatments to Modify Cellulose Nanofiber Surface	306
16.3	Use of Nanofibers in Contaminant Removal Processes	309
16.3.1	Nanoremediation for Dyes	309
16.3.2	Nanoremediation for Lead(II)	312

16.4	Conclusion	316
	References	316
17	Bio-inspired Nanocomposites for Remediation of Pharmaceutical Pollutants	323
	<i>Pavan K. Gautam, Saurabh Shivalkar, Anirudh Singh, M. Shivapriya Pingali, Shrutika Chaudhary, Sushmita Banerjee, Pritish K. Varadwaj, and Sintu K. Samanta</i>	
17.1	Introduction	323
17.2	Environmental Hazards from Pharmaceuticals	324
17.3	Mechanism for Synthesis of NMs	326
17.3.1	Bioreduction of Metallic Salt and Capping of Synthesized NMs	326
17.3.1.1	Protein-Assisted Reduction of Metallic Salts	326
17.3.1.2	Polysaccharides-Assisted Reduction of Metallic Salts	326
17.3.2	Different Parameters Affecting the Synthesis of NMs	327
17.3.3	Living Organisms Applied for Fabrication of NMs	328
17.3.3.1	Bacterial-Oriented Synthesis	328
17.3.3.2	Fungus-Assisted Synthesis	329
17.3.3.3	Algae-Assisted Synthesis	329
17.3.3.4	Plants-Assisted Synthesis	329
17.4	Different Biofabricated NMs Used for Removal of Pharmaceutical Pollutants	330
17.4.1	Biogenic Palladium Nanoparticles	330
17.4.2	Biogenic Manganese Nanoparticles	330
17.4.3	Other Metallic/Bimetallic Nanocomposites	332
17.5	Basic Degradation Mechanism of Pharmaceuticals	333
17.6	Concluding Remarks	333
	References	334
18	Nanomaterials and Their Thin Films for Photocatalytic Air Purification	341
	<i>Juliane Z. Marinho and Antonio Otavio T. Patrocínio</i>	
18.1	Indoor and Outdoor Air Purification Technologies	341
18.2	Mechanisms of Photocatalytic Degradation for Air Purification	342
18.3	Photocatalysts Used for Air Purification	345
18.3.1	Metal Oxides	345
18.3.2	Ternary Oxides	348
18.3.3	Metal Sulfides	348
18.3.4	Metal-Free Materials	349
18.4	Building Strategies for More Efficient Photocatalysts for Air Purification	349
18.4.1	Chemical Modification of Photocatalysts by Doping	350
18.4.2	Modification with Surface Heterostructures	351
18.4.3	Large Scale Applications of Photocatalytic Materials for Air Pollution	352

18.5	Conclusion and Perspectives	353
	References	353
19	Aerogel for Environmental Remediation	361
	<i>Abdul S. Jatoi, Zubair Hashmi, Nabisab Mujawar Mubarak, Faisal A. Tanjung, Muhammad Ahmed, Shaukat A. Mazari, Faheem Akhter, and Shoaib Ahmed</i>	
19.1	Introduction	361
19.2	Aerogel Applications in Air Cleaning	363
19.2.1	Aerogels in CO ₂ Capture	363
19.2.2	Aerogels in Removal of Volatile Organic Compounds (VOC)	364
19.3	Aerogel Applications for Water Treatment	365
19.3.1	Aerogels in Oil and Toxic Organic Compounds Cleanup	365
19.3.2	Aerogels in Removal of Heavy Metal Ions	366
19.4	Conclusion and Outlook	370
	Acknowledgment	371
	References	371
20	Environmental Toxicology of Nanomaterials: Advances and Challenges	379
	<i>Wells Utembe</i>	
20.1	Environmental Toxicology and Nanotechnology	379
20.2	Environmental Toxicity of Nanomaterials – An Overview	380
20.3	Nanotoxicology: Current Approaches, Issues, and Challenges	382
20.3.1	Characterization of Nanomaterials in Environmental Toxicology	382
20.3.2	Approaches and Techniques in <i>In Vivo</i> Toxicological Assessment of Nanomaterials	383
20.3.2.1	Dosimetry in <i>In Vivo</i> Toxicity Testing of Nanomaterials	384
20.3.3	Methods and Techniques in <i>In Vitro</i> Toxicological Assessment of Nanomaterials	385
20.3.3.1	Dosimetry in <i>In Vitro</i> Toxicity Testing of Nanomaterials: Advances and Challenges	387
20.3.4	<i>In Silico</i> Toxicity of Nanomaterials: Quantitative Structure–Activity Relationships (QSAR)	388
20.3.5	Dose–Response in Nanotoxicology	389
20.3.5.1	The Role and Application of Physiologically Based Pharmacokinetic (PBPK) Models	390
20.4	Conclusion	391
	Disclaimer	392
	References	392
21	Societal Impact of Nanomaterials	401
	<i>Paolo Di Sia</i>	
21.1	Introduction	401
21.2	Societal and Environmental Impact of Nanomaterials	402
21.3	Health and Safety Associated with Nanomaterials	404

21.4	The Food Sector	406
21.5	On Intellectual Property	406
21.6	Nanotechnology and Developing Countries	407
21.7	On Social Justice and Civil Liberties	408
21.8	Conclusions	408
	References	409
22	LCA of Nanomaterials for Bioremediation	413
	<i>Garima Pandey, Reeta Chauhan, Ajay S. Yadav, and Sangeeta Bajpai</i>	
22.1	Introduction	413
22.2	Nanobioremediation	415
22.3	Effects of Nanobioremediation	415
22.4	Biosynthesis of Nanoparticles	416
22.5	What Is LCA	417
22.5.1	Life-Cycle Assessment Applied to Nanobioremediation	419
22.5.2	Phases of LCA Studies of Nanobioremediation	421
22.5.2.1	Inventory	421
22.5.2.2	Impact Assessment	421
22.5.2.3	Normalization and Interpretation	422
22.5.3	Challenges and Future Prospects	422
22.6	Conclusion	423
	References	423
	Index	433