

Contents

Preface *xi*

Acknowledgments *xiii*

1 Microplastics Formation *1*

Xinxing Zhang, Qinke Cui, and Zhuo Huang

1.1 Definition of Microplastics *1*

1.2 Types of Microplastics *2*

1.2.1 Polyethylene *3*

1.2.2 Polypropylene *3*

1.2.3 Polystyrene *4*

1.2.4 Polyvinyl Chloride *4*

1.2.5 Polyester *5*

1.3 Generation of Microplastics *5*

1.3.1 Primary Microplastics *6*

1.3.1.1 Industrial *7*

1.3.1.2 Consumer *9*

1.3.2 Secondary Microplastics *15*

1.3.2.1 Plastics-Derived Microplastics *19*

1.3.2.2 Rubbers-Derived Microplastics *37*

1.3.2.3 Fibers-Derived Microplastics *56*

1.3.2.4 Foam-Derived Microplastics *60*

References *71*

2 Migration and Transformation of Microplastics *85*

Xue Yu, Xiaorong Luo, Yuhang Ye, Mengke Zhang, Mengyao Xu, Chenglong Han, and Xueqiang Lu

2.1 Migration and Transformation of Microplastics in Water *85*

2.1.1 Microplastics in the Freshwater Environment *85*

2.1.1.1 Distribution of Microplastics in the Freshwater Environment *85*

2.1.1.2 Migration and Transformation Processes of Microplastics in the Freshwater Environment *86*

2.1.2	Microplastics in the Marine Environment	88
2.1.2.1	Distribution of Microplastics in the Marine Environment	88
2.1.2.2	Migration and Transformation Processes of Microplastics in the Marine Environment	88
2.1.3	Influencing Factors of Migration and Transformation of Microplastics in the Water Environment	96
2.1.3.1	Shape of Microplastics	96
2.1.3.2	Size of Microplastics	97
2.1.3.3	Salinity Gradient	97
2.1.3.4	Water Quality and Hydrodynamic Characteristics	98
2.1.3.5	Windage	98
2.1.3.6	Interaction Between Biofilms and Microplastics	99
2.2	Migration and Transformation of Microplastics in Soil	100
2.2.1	Source and Distribution of Microplastics in Soil	100
2.2.1.1	Source of Microplastics in Soil	100
2.2.1.2	Distribution of Microplastics in Soil	102
2.2.2	Migration Pathways of Microplastics in Soil	104
2.2.3	Influencing Factors of Microplastic Migration in Soil	105
2.2.3.1	Characteristics of Microplastics	105
2.2.3.2	Characteristics of Soil	106
2.2.3.3	Bioturbation and Mechanical Disturbance in Soil	107
2.2.3.4	External Environment	108
2.2.4	Transformation of Microplastics in Soil	109
2.2.4.1	Physical Transformation	110
2.2.4.2	Chemical Transformation	110
2.2.4.3	Biodegradation	111
2.2.5	Transfer of Microplastics in the Terrestrial Food Chain	112
2.3	Migration and Transformation of Microplastics in Atmosphere	112
2.3.1	Sources	112
2.3.1.1	Daily Life use Process	113
2.3.1.2	Industrial and Agricultural Production Processes	113
2.3.1.3	Sea- or Soil-mediated Inputs	113
2.3.1.4	Other Sources	114
2.3.2	Flux and Abundance	114
2.3.2.1	Calculation Method of Settling Flux and Influencing Factors	114
2.3.3	Migration Pathways of Microplastics in the Atmosphere	115
2.3.4	Influencing Factors on the Transport of Microplastics in the Atmosphere	115
2.3.4.1	Physicochemical Characteristics of Microplastics	115
2.3.4.2	Meteorological Factors	116
2.3.4.3	Human Factors	117
2.3.4.4	Geographical Location	117
2.3.5	Human Health and Ecological Risks of Atmospheric Microplastics	118
2.3.5.1	Adsorption of Contaminants	118
2.3.5.2	Human Health Risk	119

- 2.3.5.3 Ecological Risk 120
- 2.3.6 Atmospheric Microplastic Transport Simulation 120
- References 121

- 3 Toxicity and Health Effects of Microplastics 137**
Hanyun Zheng, Quanwei Li, Xiongjie Gu, Yaru Qian, Yunxu Shang, Hong Yu, Lihui An, and Feifei Wang
- 3.1 Estuarine and Marine Organisms 137
 - 3.1.1 Plankton 137
 - 3.1.1.1 Enrichment of Microplastics in Plankton 137
 - 3.1.1.2 Toxic Effects of Microplastics on Plankton 138
 - 3.1.2 Benthic Fauna 140
 - 3.1.2.1 Enrichment of Microplastics in Benthic Fauna 140
 - 3.1.2.2 Toxic Effects of Microplastics on Benthic Fauna 141
 - 3.1.3 Marine Fishes 144
 - 3.1.3.1 Enrichment of Microplastics in Marine Fishes 144
 - 3.1.3.2 Toxic Effects of Microplastics on Marine Fishes 144
 - 3.1.4 Marine Mammals 149
 - 3.1.4.1 Enrichment of Microplastics in Marine Mammals 149
 - 3.1.4.2 Toxic Effects of Microplastics on Marine Mammals 150
 - 3.1.5 Seabirds 151
 - 3.1.5.1 Enrichment of Microplastics in Seabirds 151
 - 3.1.5.2 Toxic Effects of Microplastics on Seabirds 152
- 3.2 Freshwater Organisms 153
 - 3.2.1 Plankton 153
 - 3.2.1.1 Phytoplankton 153
 - 3.2.1.2 Zooplankton 157
 - 3.2.2 Freshwater Fishes 161
 - 3.2.2.1 Occurrence of Microplastics in Freshwater Fish 161
 - 3.2.2.2 Ingestion and Excretion of Microplastics 164
 - 3.2.2.3 Toxic Effects of Microplastics on Fish 165
 - 3.2.3 Benthic Organisms 168
 - 3.2.3.1 Occurrence of Microplastics in Benthic Organisms 168
 - 3.2.3.2 Toxic Effects of Microplastics on Benthic Organisms 170
- 3.3 Soil Organisms 172
 - 3.3.1 Effect of Microplastics on Soil Microorganisms 172
 - 3.3.2 Effects of Microplastics on Soil Fauna 174
 - 3.3.3 Effect of Microplastics on Plants 177
- 3.4 Human Health 182
 - 3.4.1 Detection of Microplastics in Human Tissues 182
 - 3.4.1.1 The Detection of Microplastics in Digestive System 182
 - 3.4.1.2 The Detection of Microplastics in Respiratory System 185
 - 3.4.1.3 The Detection of Microplastics in Circulatory System 186
 - 3.4.1.4 The Detection of Microplastics in Reproductive System 186

- 3.4.2 Health Effects and Toxicity Mechanisms Due to Gastrointestinal Exposures 187
 - 3.4.2.1 The Main Sources of Microplastics Exposure to the Digestive Tract 187
 - 3.4.2.2 Gastrointestinal Exposures and Human Health 191
 - 3.4.2.3 Toxic Mechanisms of Health Damage Caused by Microplastic Gastrointestinal Exposure 192
- 3.4.3 Health Effects and Toxicity Mechanisms Due to Respiratory Exposures 204
 - 3.4.3.1 Microplastics Accumulation in the Respiratory System 204
 - 3.4.3.2 Respiratory Exposure and Human Health 209
 - 3.4.3.3 Toxic Mechanisms of Health Damage Caused by Microplastic Respiratory Exposure 211
- 3.4.4 Health Effects and Toxicity in Other Tissues and Cells 219
 - 3.4.4.1 Cell Uptake and Phagocytosis of Microplastics 219
 - 3.4.4.2 Neurotoxicity 221
 - 3.4.4.3 Cytotoxicity and Immune Response 221
 - 3.4.4.4 Germ Cell Toxicity 222
 - 3.4.4.5 Cytotoxicity of Other Tissues 223
- 3.4.5 Combined Toxicity of Microplastics and Other Pollutants 223
- References 225

- 4 Solutions to Microplastics Pollution 245**
Li Li, Xuan Wang, Nan Wang, Wu Guo, Quanquan Guo, and Xinkai Li
 - 4.1 Reduction 246
 - 4.1.1 Legislation and Public Policy 246
 - 4.1.1.1 Restricting Certain Types of Single-use Plastics 247
 - 4.1.1.2 Extending the Producer Responsibility 252
 - 4.1.1.3 Active Use of Post-consumer Recycled Plastic 254
 - 4.1.2 Design 257
 - 4.1.2.1 Design for Reduction 257
 - 4.1.2.2 Design for Reuse 258
 - 4.1.2.3 Design for Recycle 259
 - 4.1.3 Technical Support 260
 - 4.1.3.1 Technologies for High Performance 260
 - 4.1.3.2 Technologies for Optimizing the Apparent Structure 263
 - 4.1.4 Brief Summary 265
 - 4.2 Substitution 265
 - 4.2.1 Biobased Plastics 266
 - 4.2.1.1 Biobased Plastics Derived from Natural Polymers 267
 - 4.2.1.2 Biobased Plastics Polymerized from Natural Monomers 275
 - 4.2.1.3 Plastics Derived from Biosynthesis 278
 - 4.2.1.4 Market Prospects for Biobased Plastics 282
 - 4.2.2 Biodegradable Plastics 282
 - 4.2.2.1 Degradation Mechanisms of Basic Polymers 283
 - 4.2.2.2 Biobased Biodegradable Plastics 284

- 4.2.2.3 Petrochemical Biodegradable Plastics 287
- 4.2.2.4 State-of-the-art in Improving Biodegradability of Polymers 291
- 4.2.2.5 Research Progress in Production of MPs from Biodegradable Plastics 292
- 4.2.3 Recyclable and Long-life Plastics 292
 - 4.2.3.1 Long-life Polymers 293
 - 4.2.3.2 Closed-loop Recyclable Polymers 296
- 4.2.4 Brief Summary 297
- 4.3 Recycling 299
 - 4.3.1 Recyclability Improvement of Plastics 299
 - 4.3.1.1 Strengthening Policy Control 300
 - 4.3.1.2 Design for Recycling 302
 - 4.3.2 Recycling Technologies 304
 - 4.3.2.1 Mechanical Recycling 307
 - 4.3.2.2 Chemical Recycling 321
 - 4.3.2.3 Biocatalytic Recycling 332
 - 4.3.2.4 Energy Recycling 333
 - 4.3.3 Brief Summary 335
- 4.4 Control in the Environment 336
 - 4.4.1 Strategies and Technologies for Microplastics Remediation 337
 - 4.4.1.1 Physical Methods 337
 - 4.4.1.2 Chemical Methods 347
 - 4.4.1.3 Biological Methods 362
 - 4.4.1.4 Combined Methods 370
 - 4.4.2 Brief Summary 371
- 4.5 Conclusion 372
- References 373

- Index 405**