

Contents

Epigraph	<i>xv</i>
Abbreviations	<i>xvii</i>
Glossary	<i>xxiii</i>
Preface	<i>xxvii</i>
Acknowledgment	<i>xxix</i>

1	Introduction	1
1.1	Chemistry and Development	1
1.2	Pollution and Contamination	3
1.3	Chemical pollutants	4
1.4	Pollutants in the Environment	6
1.5	Concept of Emerging Pollutants	7
1.6	Historical Background of Emerging Pollutants	8
1.7	Classification of Emerging Pollutants	9
1.8	Regulations and Normatives	11
	References	13
2	Occurrence and Removal of Environmental Pollutants	19
2.1	Introduction	19
2.2	Pollutants in the Atmosphere	19
2.3	Pollutants in Ground and Surface Waters: Quality Parameters	20
2.4	Pollutants in the Ground and Soil	23
2.5	Sources of Emerging Pollutants or CECs	23
2.5.1	CECs from WWTPs	24
2.5.2	CECs in Wastewater Biosolids	25
2.5.3	CECs from Agriculture and Livestock	25
2.5.4	CECs in Soils	26
2.5.5	CECs in Groundwater	27
2.5.6	CECs in Landfill	28
2.5.7	CECs in Seawater	29
2.6	Treatment of CECs	30
2.6.1	Treatment of CECs in WWTPs	30
2.6.1.1	Physical Methods	30
2.6.1.2	Chemical Methods	31

2.6.1.3	Biological Methods	32
2.6.2	Treatment of CECs in Landfill Leachates	32
2.6.3	Wastewater Reuse	33
2.7	Toxicity of CECs	34
	References	37
3	Detection and Analysis of Chemical Pollutants	43
3.1	Introduction	43
3.2	Sample Preparation	43
3.2.1	Extraction with Organic Solvents	44
3.2.2	Microwave-Assisted Extraction (MAE)	44
3.2.3	Dispersive Liquid–Liquid Microextraction (DLLME)	45
3.2.4	Vortex-Assisted Liquid–Liquid Microextraction (VALLME)	45
3.2.5	Single-Drop Microextraction	45
3.2.6	Solid-Phase Extraction (SPE)	46
3.2.7	Solid-Phase Microextraction (SPME)	47
3.2.8	Dispersive Solid Phase Microextraction (DSPE/DSPME)	47
3.2.9	Matrix Solid-Phase Dispersion (MSPD)	48
3.2.10	Passive Sampling	48
3.2.11	Immunosorbent Extraction	49
3.2.12	Extraction of Volatile Compounds	49
3.2.13	Online Extraction	50
3.2.14	Extraction with Nanomaterials	50
3.2.15	Sampling from Biological Materials	50
3.3	Analytical Methods for Identifying EPs	50
3.3.1	Separation Methods	52
3.3.2	Characterization Methods	52
	References	53
4	Overview of Pharmaceutical Products as Emerging Pollutants	57
4.1	Introduction	57
4.2	Therapeutic Classes of PCs Detected in the Environment	59
4.3	Sources of PCs in the Environment	59
4.4	Detection and Analysis of PCs in the Environment	61
4.5	Occurrence of PCs in the Environment	63
4.5.1	Pharmaceuticals in WWTPs	64
4.5.2	PCs in Hospital Wastewater	64
4.5.3	PCs in Surface Water and Groundwater	66
4.5.4	PCs in Seawater	68
4.5.5	PCs in Drinking Water	68
4.5.6	PCs in Soil	69
4.6	Ecotoxicological Aspects of PCs on Environment	72
4.7	Removal of PCs	75
4.7.1	Conventional Systems for Removing PCs in Water-Treatment Systems	76
4.7.2	Adsorption on Activated Carbon	77

4.7.3	Technologies Based on Advanced Oxidation Processes (AOPs)	77
4.7.3.1	AOPs Based on Ozone	77
4.7.3.2	AOPs Based on UV Radiation	77
4.7.3.3	AOPs Based on γ -Radiation	79
4.7.3.4	Electro-Oxidation with and without Active Chlorine Generation	79
4.8	Conclusions	79
	References	80
5	Therapeutic Classes of PCs in the Environment	103
5.1	Introduction	103
5.2	Antibiotics (ABs)	105
5.2.1	Chemical Classes of Antibiotics	105
5.2.2	The Problem of the Resistance of Antibiotics	114
5.2.3	Antibiotics in the Environment	114
5.2.4	Degradation/Removal of Antibiotics	116
5.2.5	An Example of ABs in the Environment: Sulfonamides	116
5.3	Estrogens and Hormonal Compounds	117
5.3.1	Estrogens in the Environment	117
5.4	Drugs with Endocrine Disruption Properties	120
5.5	Analgesic, Anti-inflammatory, Antiarthritic, and Antirheumatic Compounds	124
5.5.1	Non-Narcotic Analgesics Drugs	124
5.5.2	Narcotic Analgesics Drugs	125
5.5.3	Non-Steroidal Anti-Inflammatory Drugs (NSAIDs)	125
5.5.3.1	Diclofenac	126
5.5.3.2	Ibuprofen	127
5.5.3.3	Naproxen	128
5.5.3.4	Ketoprofen	128
5.5.3.5	Mefenamic Acid	128
5.6	Psychotropic Drugs	128
5.6.1	Environmental Impact of Psychotropic Drugs	129
5.7	Antiepileptic Drugs	131
5.8	β -Blockers/Diuretics	133
5.8.1	β -Blockers in the Environment	133
5.9	Lipid Regulators	135
5.10	β_2 -Sympathomimetic Drugs	136
5.11	Antidiabetic Drugs	138
5.12	X-Ray Contrast Drugs: Diagnostic Agents	139
5.13	Cytostatic PCs: Antineoplastics	140
5.14	Veterinary Drugs: Anthelmintics	141
5.14.1	Classes of Anthelmintics	142
5.14.2	Anthelmintics in the Environment	145
	References	146
6	Illegal Drugs, Occurrence, and Fate in Environment	167
6.1	Introduction	167
6.2	What is an Illicit Drug?	168

6.2.1	Differences Between Licit and Illicit Drugs as Environmental Contaminants	169
6.3	Classes of Illicit Drugs	171
6.3.1	Opiates	171
6.3.1.1	Opiates in the Environment	171
6.3.2	Other Central Nervous System Depressants	172
6.3.3	Central Nervous System Stimulants: Cocaine	173
6.3.3.1	Cocaine in the Environment	173
6.3.4	Central-Nervous-System Stimulants: Amphetamine-Type Substances (ATSs)	173
6.3.4.1	Amphetamine-Type Substances in the Environment	176
6.3.5	Hallucinogens	176
6.3.6	Cannabis	177
6.3.6.1	Cannabis and its Metabolites in the Environment	177
6.4	Analytical Methods for Detecting of Illicit Drugs	177
6.5	Illicit Drugs in the Environmental Compartments	178
6.5.1	Illicit Drugs in Wastewater	179
6.5.2	Illicit Drugs in Surface Water	181
6.5.3	Illicit Drugs in Seawater	182
6.5.4	Illicit Drugs in Drinking Water	182
6.5.5	Illicit Drugs in Soil	183
6.5.6	Illicit Drugs in Ambient Air	184
6.5.7	Illicit Drugs on Currency Notes	184
6.6	Estimation of Drug Consumption in Communities (Sewage-Based Epidemiology)	185
	References	187
7	Pesticides as Pollutants	197
7.1	Introduction	197
7.2	Classification of Pesticides	198
7.2.1	Classification of Pesticides by Activity	199
7.2.2	Classification of Pesticides by Toxicity	199
7.2.3	Classification of Pesticides by Chemical Structure	200
7.3	Organic Pesticides	200
7.3.1	Organochlorine Pesticides	200
7.3.2	Organophosphorus Pesticides	202
7.3.3	Carbamates	203
7.3.4	Thiocarbamates	204
7.3.5	Pyrethrins and Pyrethroids	205
7.3.6	Phenoxy Carboxylic Acids	205
7.3.7	Triazines	206
7.3.8	Uracils and Ureas	207
7.3.9	Azoles and Related Compounds	208
7.3.10	Morpholine Derivatives	209
7.3.11	Bipyridines	210
7.3.12	Amides	211
7.3.13	Neonicotinoids	211

7.3.14	Other Classes of Herbicides	213
7.3.14.1	Pyridazines and Pyridazinones	213
7.3.14.2	Nitrile Herbicides	213
7.3.14.3	Dinitroanilines	213
7.3.14.4	Pyridine Herbicides	214
7.3.14.5	Pyrimidines	214
7.4	Pesticides in the Environment	215
7.4.1	Degradation and Transformation of Pesticides in Environment	217
7.4.2	Pesticide TPs in the Environment	217
7.4.3	Analysis of Pesticides	218
7.4.4	Pesticides in Water	220
7.5	An Example of National Survey: Pesticides in Italy	221
7.6	An Example of Pesticides in the Environment: Neonicotinoid Insecticides	223
	References	224
8	Lifestyle Products as Emerging Pollutants	233
8.1	Introduction	233
8.2	Stimulants	233
8.2.1	Caffeine	234
8.2.1.1	Caffeine in the Environment	234
8.2.2	Nicotine	236
8.2.2.1	Cigarettes in the Environment	237
8.2.2.2	Nicotine in the Environment	237
8.3	Food Additives	238
8.3.1	Toxicology of Food Additives	239
8.3.2	Global Regulation on Food Additives	240
8.4	Classes of Food Additives	241
8.4.1	Substances with Nutritive and Other Dietary Effects	241
8.4.1.1	Vitamins and Provitamins	241
8.4.1.2	Amino Acids	242
8.4.1.3	Minerals and Trace Elements	242
8.4.1.4	Bulking Agents	242
8.4.2	Substances with Stabilizing Effects	242
8.4.2.1	Preservatives	242
8.4.2.2	Antioxidants	242
8.4.2.3	Synergists and Sequestrants	243
8.4.2.4	Packaging Gases	243
8.4.2.5	Stabilizers	244
8.4.3	Substances with Sensory Effects (Organoleptic Substances)	245
8.4.3.1	Coloring Agents	245
8.4.3.2	Color Stabilizers	245
8.4.3.3	Bleaching Agents	246
8.4.3.4	Intense Sweeteners	246
8.4.3.5	Nutritive Sweeteners	246
8.4.3.6	Acidulants	246

8.4.3.7	Substances with a Salty Taste	246
8.4.3.8	Substances with a Bitter Taste	246
8.4.3.9	Substances with an Alkaline Taste	246
8.4.3.10	Flavor Enhancers	246
8.4.3.11	Spices and Flavorings	247
8.4.3.12	Chewing-Gum Bases	247
8.4.4	Substances as Processing Aids	247
8.4.4.1	Extractants	247
8.4.4.2	Clarifying Agents	248
8.4.4.3	Filter Aids	248
8.4.4.4	Propellants	248
8.4.4.5	Cooling Agents and Cryogenics	248
8.4.4.6	Mold-Release Agents	248
8.4.4.7	Antifoaming Agents	248
8.4.4.8	Acidity Regulators	249
8.4.4.9	Emulsifying Salts	249
8.4.4.10	Dough Conditioners and Flour Improvers	249
8.4.4.11	Leavening Agents	249
8.4.4.12	Enzymes	249
8.4.4.13	Microbial Cultures	249
8.4.5	Dietary Supplements	249
8.5	Food Additives as Emerging Organic Contaminants	250
8.6	Antioxidants in the Environment	250
8.7	Artificial Sweeteners in the Environment	251
8.7.1	Metabolism of Artificial Sweeteners	252
8.7.2	Occurrence of the Artificial Sweeteners in the Environment	253
8.7.3	Artificial Sweeteners as Pollution Markers	255
8.7.3.1	Ecotoxicological Studies on Sucralose	256
	References	257
9	Industrial Chemicals as Emerging Pollutant	265
9.1	Introduction	265
9.2	Perfluorinated Alkyl Substances (PFASs)	266
9.2.1	PFASs in the Environment	268
9.2.2	Analysis of PFASs	269
9.2.3	Toxicology and Regulation of PFASs	270
9.3	Plasticizers	271
9.3.1	Bisphenol A (BPA)	271
9.3.1.1	BPA in the environment	272
9.3.1.2	Toxicology and regulation of bisphenol A (BPA)	273
9.3.2	Phthalates	274
9.3.2.1	Phthalates in the environment	276
9.3.2.2	Toxicology and regulation of phthalates	279
9.3.3	<i>N</i> -Butylbenzenesulfonamide (NBBSA)	280
9.3.3.1	NBBSA in the Environment	280
9.4	Flame Retardants	281
9.5	Brominated Flame Retardants (BFRs)	281

9.5.1	Polybrominated Diphenyl Ether (PBDE)	282
9.5.2	Tetrabromobisphenol A (TBBPA)	289
9.5.3	Polybrominated Biphenyls (PBBs)	291
9.5.4	Hexabromobenzene (HBB)	291
9.5.5	Hexabromocyclododecane (HBCD)	292
9.5.6	Decabromodiphenyl Ethane (DBDPE)	292
9.5.7	1,2-Bis(2,4,6-Tribromophenoxy)ethane (BTBPE)	292
9.6	Polychlorinated Alkanes (C ₁₀ –C ₁₃)	292
9.6.1	Use and Consumption of PCAs	293
9.6.2	Properties of PCAs	294
9.6.3	PCAs in the Environment	295
9.6.4	Toxicology and Regulations of PCAs	296
9.7	Organophosphate Flame Retardants (OPFRs)	297
9.7.1	Use and Demand of OPFRs	297
9.7.2	Properties of OPFRs	298
9.7.3	OPFRs in the Environment	299
9.7.4	Toxicology and Regulations of OPFRs	300
9.8	Corrosion Inhibitors: Benzothiazoles and Benzotriazoles	302
9.8.1	Benzotriazoles	302
9.8.2	Benzothiazoles	303
9.9	Polycyclic Aromatic Hydrocarbons (PAHs)	304
9.10	Volatile Organic Compounds (VOCs)	306
9.10.1	Hazardous Compounds Originating from Oil Products	308
9.10.2	Gasoline Additives: MTBE	309
9.11	Other Industrial Chemicals	310
9.11.1	Siloxanes	310
9.11.2	1,4-Dioxane	311
9.11.3	Nitroaromatic Compounds	311
9.11.3.1	2,4-Dinitrophenol	312
9.11.4	Naphthenic Acids	312
9.11.5	Other Chlorinated Compounds	312
9.11.6	Perchlorate	313
	References	314
10	Surfactants in the Environment	341
10.1	Introduction	341
10.2	Structure and Classification	342
10.3	Nonionic Surfactants	343
10.3.1	Fatty Alcohols	344
10.3.2	Alcohol Ethoxylates	344
10.3.3	Ethylene Oxide/Propylene Oxide-Block Polymers	345
10.3.4	Alkylphenol Ethoxylates	345
10.3.5	Ethoxylated Oils and Fats	346
10.3.6	Alkanolamides	346
10.3.7	Esters	347
10.3.8	Nonionic Surfactants Derived from Carbohydrates and Related Compounds	347

10.3.8.1	Alkyl Polyglucosides	348
10.3.8.2	Sorbitan Esters	348
10.3.8.3	Alkyl Carbohydrate Esters	349
10.3.9	Ester/Ether Surfactants	349
10.3.9.1	Ethoxylated Glycol and Glycerol Esters	350
10.3.9.2	Ethoxylated Sorbitan Esters	350
10.3.9.3	Ethoxylated Pentaerythritol Esters	350
10.3.9.4	Polyglycerol Monoester	350
10.3.10	Amine Oxides	351
10.4	Anionic Surfactants	351
10.4.1	Carboxylic Acids Derivatives	351
10.4.1.1	Carboxylic Acid Salts	351
10.4.1.2	Ether Carboxylic Acids	352
10.4.2	Sulfuric and Sulfonic Acid Derivatives	353
10.4.2.1	Alkyl Sulfates	353
10.4.2.2	Alkyl Sulfonates	353
10.4.2.3	Alkylbenzene Sulfonates	354
10.4.2.4	Sulfosuccinates	354
10.4.2.5	Sulfo Fatty Acid Esters	355
10.4.2.6	Fatty Acid Isethionates and Taurides	355
10.4.3	Phosphoric Acid Esters and Salts	356
10.4.4	Acylamino Acids and Salts	356
10.5	Cationic Surfactants	357
10.5.1	Alkyl Amines	357
10.5.2	Alkylimidazolines	358
10.5.3	Quaternary Ammonium Compounds	358
10.5.3.1	Tetraalkyl(-aryl) Ammonium Salts	358
10.5.3.2	Heterocyclic Ammonium Salts	358
10.5.4	Ethoxylated Alkyl Amines	359
10.5.5	Esterified Quaternaries	360
10.6	Amphoteric Surfactants	360
10.6.1	Acyl Ethylenediamines and Derivatives	360
10.6.2	N-Alkyl Amino Acids or Imino Diacids	361
10.6.3	Alkyl Betaines	361
10.7	Alkoxylated Polysiloxanes	362
10.8	Fluorosurfactants	362
10.9	Toxicological Aspects (Environmental Impact) of Surfactants	363
10.9.1	Environmental Impact of Alkylphenol Ethoxylates (APEOs)	364
10.10	Environmental Occurrence of the Surfactants	365
10.10.1	Alkylphenol Ethoxylates (APEOs), and Their Degradation Products in the Environment	366
10.10.2	LASs and Their Degradation Products	368
10.11	Biodegradation of Surfactants	368
10.11.1	Aerobic Biodegradation	371
10.11.2	Anerobic Biodegradation	371
	References	373

11	Personal-Care Products	385
11.1	Introduction	385
11.2	Musks: Fragrances	385
11.3	Biocides	388
11.3.1	Triclosan	389
11.3.2	Chlorophene and Dichlorophene	391
11.3.3	Parabens	392
11.4	Sunscreen Agents: UV Filters	396
11.4.1	Analysis of UV-Filters	397
11.4.2	UV-Filters as Endocrine Disrupters	398
11.4.3	UV Filters in the Environment	399
11.4.3.1	Benzophenone Derivatives in the Environment	401
11.4.3.2	3-Benzylidene- and 4-Methylbenzylidene-Camphor in the Environment	402
11.5	Insect Repellents: <i>N,N</i> -diethyl- <i>m</i> -toluamide (DEET)	403
11.6	Other PCPs	405
	References	407
12	Water Disinfectant By-Products	423
12.1	Introduction	423
12.2	Wastewater Treatments	424
12.2.1	Water Reuse	425
12.2.2	Drinking Water Treatments	425
12.2.3	Water Disinfection	425
12.3	Disinfection Methods	426
12.3.1	Chlorination	426
12.3.2	Chlorine Dioxide	427
12.3.3	Chloramination	428
12.3.4	Sodium Dichloroisocyanurate	428
12.3.5	Ozonization	429
12.3.6	UV Irradiation	429
12.3.7	Other Methods of Disinfection	429
12.4	Water DBPs	430
12.4.1	DBPs from Chlorination	430
12.4.2	Other Halogenated DBPs	432
12.4.3	Nitrogenous DBPs	433
12.4.4	Carbonaceous DBPs from Ozonation	435
12.5	Methods of Analysis of DBPs	435
12.6	Disinfection By-Products (DBPs) in Drinking Water	437
12.7	Disinfection By-Products in Swimming Pools	438
12.8	Changes in Oxidation/Disinfection Strategies	439
12.9	Toxicological Studies on DBPs	441
12.10	Regulations/Guidelines of DBPs in Drinking Water	442
	References	444
13	Other Contaminants of Emerging Concern	453
13.1	Introduction	453

13.2	Nanotechnology as a Pollution Source	453
13.2.1	Detection of NMs	454
13.2.2	NMs in the Environment	456
13.2.3	Toxicity of NMs	457
13.3	Microplastics (MPs)	458
13.4	Toxic Elements and Elemental Species	460
13.4.1	Arsenic (As)	462
13.4.2	Cadmium (Cd)	462
13.4.3	Lead (Pb)	463
13.4.4	Mercury (Hg)	464
13.4.5	Manganese (Mn)	465
13.4.6	Antimony (Sb)	466
13.4.7	Technology-Critical Elements	466
13.4.8	Radionuclides	467
13.5	Biotoxins	467
13.5.1	Mycotoxins	468
13.5.2	Algal Toxins	469
13.5.3	Other Marine Toxins	472
13.5.3.1	Cyclic Imines	472
13.5.3.2	Ciguatoxins	472
13.5.3.3	Azaspiracids (AZAs)	472
13.5.3.4	Tetrodotoxin (TTX)	472
13.5.3.5	Palitoxins	473
13.5.4	Bacterial Toxins	473
13.5.5	Naturally Occurring Toxins in Vegetable Foodstuffs	473
13.6	Microorganisms	473
13.7	Contaminants on the Horizon: Ionic Liquids and Prions	474
	References	475

A	InChI Key for the Most Relevant Compounds in this Book	487
----------	---	------------

Index	493
--------------	------------