Environmental Chemistry for a Sustainable World 54

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Water Pollution and Remediation: Organic Pollutants

Springer

Environmental Chemistry for a Sustainable World

Volume 54

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ISSN 2213-7114 ISSN 2213-7122 (electronic)
Environmental Chemistry for a Sustainable World
ISBN 978-3-030-52394-7 ISBN 978-3-030-52395-4 (eBook)
https://doi.org/10.1007/978-3-030-52395-4

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Preface

Water and air, the two essential fluids on which all life depends, have become global garbage cans

Jacques-Yves Cousteau

Earth's surface and ground waters are severely affected by the discharge of contaminants. Organic pollutants originate from industrial effluents, domestic sewage, water treatment plants, urban turn-off, agriculture, aquaculture, pulp and paper making, food processing, tannery, and various industries. Massive point-source pollution such as industrial pollution during fabrication, storage, processing, and transportation is of particular concern because the amount of discharged pollutants is usually high, thus inducing immediately severe health impact on ecosystems. Whereas, diffuse pollution such as low pesticide and drug levels in waters induce diseases in the long run. As a countermeasure, there is a need for efficient methods and techniques to remove organic pollutants from wastewater. This book reviews the occurrence, analysis, toxicity, and remediation technologies of water organic pollutants. Chapters discuss the treatment of pollutants such as hydrocarbons, microplastics and plastics, phthalates, polycyclic aromatic hydrocarbons, pharmaceutical drugs and metabolites, oil spill, petroleum hydrocarbons, personal care products, tannery waste, and dyes and pigments.



Chapter 1 by Godoy et al. includes a summary of techniques for sampling, extraction, purification, and identification of microplastics, a review of publications on the abundance of microplastics in different aquatic ecosystems around the world, and a brief synthesis of researches about sorption of chemicals on microplastics. Chapter 2 by Tahir et al. provides highlights on the nature of plastics, types, sources, consumption, effects, and pollution caused by excessive use of plastics. Techniques used for the identification of plastics present in water and the different remediation techniques such as primary, mechanical, chemical treatment, and recycling are elaborated. Finally, the chapter focuses on the health impact and utilization of degradable plastics. Chapter 3 by Muneer et al. discusses water pollution caused by plastics. Three strategies to tackle water pollution caused by nanoplastics, microplastics, and macroplastics are discussed: scientific methods, community involvement, and government policies. Chapter 4 by Jain et al. narrates how plastics and e-wastes contaminate our water system and their hazardous effect on living beings. All aspects of plastic and e-waste, such as types of plastics and e-waste, effects on marine and freshwater life, solution for prevention, and prospects are discussed.

Chapter 5 by Rachna et al. reviews concentrations, impact, and remediation of polycyclic aromatic hydrocarbons (PAH) in rivers and sediments, with focus on functionalized nanomaterials to degrade PAHs. Chapter 6 by Ghosh and Chakraborty presents aerobic granulation as a rapid, eco-friendly, and cost-effective technology for treatment of recalcitrant, hydrocarbon-rich wastewater. The chapter

gives mechanisms, factors, characteristics, and techniques of aerobic granulation and applications to the oil remediation. Chapter 7 by Denaro et al. reviews the use and synergy of bacteria and algae to degrade petroleum hydrocarbons. Chapter 8 by Samanta and Mitra presents the types of petroleum hydrocarbons polluting waters and their abatement by physical, chemical, and biological methods. Chapter 9 by Mustapha examines aspects of pharmaceuticals such as active metabolites, influxes, distribution, analysis, fate, and transport routes. Chapter 10 by Saggioro reviews advanced oxidation processes (AOP) such as heterogeneous processes using TiO_2; homogeneous processes using ozone, ultraviolet, hydrogen peroxide, and the Fenton reagents; and coupling AOP and other treatment processes for the removal of personal care products, for example, triclosan and triclocarban, and pharmaceuticals compounds: carbamazepine, diclofenac, and ibuprofen. Chapter 11 by Othman et al. reports advanced technologies for the treatment of oily industrial wastewater, such as flotation, coagulation, biological treatment, membrane filtration, and electrochemical treatment.

Chapter 12 by Fatehi et al. details the source of oil contaminants and two types of oil removal technologies: remediation by physical, thermal, and chemical methods and bioremediation. Chapter 13 by Dheenadayalan and Thiruvengadathan reviews sources, health effects, and remediation of organic pollutants in waters. Remediation includes physical, chemical, and biological methods. Chapter 14 by Karim et al. proposes the application of soil as a heterogeneous Fenton catalyst for the abatement of organic pollutants. Performance of clay, laterite, and volcanic soils to decompose hydrogen peroxide in water medium is explained. Chapter 15 by Sun et al. discusses properties, toxicity, contamination levels, analysis, and treatment of waters contaminated by phthalates.

Chapter 16 by Patel et al. discusses adverse effects, treatment technologies, and management processes of tannery waste. Chapter 17 by Ashraf et al. compares methods for the treatments of dyes and pigments, such as physical, chemical, and biological techniques. Chapter 18 by Akram presents the methodologies used for the treatment of textile waste, with focus on nanomaterials such as silica and iron-based magnetic materials such as sorbents and photocatalysts. Synthetic and biomaterials-based composites are also discussed as next-generation materials for wastewater treatment.

Aligarh, India — Inamuddin
Aligarh, India — Mohd Imran Ahamed
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Chapter 9
Fate of Pharmaceutical Drugs and Metabolites in the Environment



Aliru Olajide Mustapha

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Abstract

1. Issues/Problems

In recent years, there have been global concerns about the emerging levels of abused drugs (cocaine, opioid, cannabinoid, amphetamine, lysergic diethylamide and hallucinogen) apart from pharmaceuticals, dyes, solvents, pesticides, heavy metals and chemicals from industrial wastes and direct dumping of other contaminants to the aquatic environment. The escalating levels of these pollutants have prompted the need for proper monitoring of their prevalence in order to stem its

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Inamuddin et al. (eds.), *Water Pollution and Remediation: Organic Pollutants*, Environmental Chemistry for a Sustainable World 54,
https://doi.org/10.1007/978-3-030-52395-4_9

social and environmental impacts. New drugs are daily being introduced as the number of patents keeps increasing, and the pharmaceutical products for numerous therapeutic and commercial purposes keep escalating accordingly, reaching already the increasingly polluted environment. The inadvertent and purposeful discharges of pharmacologically active compounds via excreta remain underappreciated, yet their toxicological potency on the ecosystem has become a global issue. Environmental monitoring and risk assessments have shown the sewage treatment works as one of the potential routes through which the levels of consumption by a local population can be estimated. The exposure data of trends in their distribution, biodegradability, fate, toxicity and environmental assessment can safeguard aquatic and human environment by letting the appropriate authorities involved in fighting and controlling drug menace develop the desired approaches in controlling and effective monitoring of emerging pollution challenges.

2. Major Advances

We reviewed the occurrence of bioactive metabolites, metabolism, measurement, transport routes in the aquatic environment and treatment processes with the available analytical methodologies in the literature.

The major points are:

1. The literature showed the distribution of the plethora of trace drugs include abused drugs, which were as follows: cocaine, opioid, cannabinoid, amphetamine, lysergic diethylamide, hallucinogen and pharmaceuticals of many therapeutic classes of drugs: antibiotics, anti-inflammatory, anti-epileptics, antineoplastics, antidepressants, beta-blockers, β_2-sympathomimetics, contraceptives, diagnostic contrast media, lipid regulators, preservatives, sunscreen agents and tranquilizers in the environment. They occurred in varying concentration and range from 10 to 8700 ng L^{-1} in sewage treatment works and 10–410 ng L^{-1} and stream at different locations.
2. The environmental analyses have shown that significant routes which the pharmaceutical drugs enter the aquatic environment are some domestic sewage systems from Italy, Belgium, Spain, Germany, the United States and the United Kingdom with 15 compounds detected from biweekly samplings from Nottingham sewage treatment work effluents, including ibuprofen, caffeine, lidocaine, cocaine, codeine, amphetamine, ecgonine methyl ester, benzoylecgonine, ephedrine, methadone, nicotine, 6-acetylmorphine, diacetylmorphine, diazepam and procaine. The mean concentrations, 19.2 $\pm$ 5.8, 15.2 $\pm$ 4.3, 13.6 $\pm$ 5.7, 9.1 $\pm$ 3.5, 8.2 $\pm$ 3.1, 5.1 $\pm$ 2.8, 4.7 $\pm$ 1.7 and 4.2 $\pm$ 1.7 ng L^{-1}, were found, respectively. In Spain, 225 and 2307 ng L^{-1} of cocaine and benzoylecgonine in 5 sewage treatment work influents were higher compared to 47 ng L^{-1} of cocaine concentrations in effluent. The toxicity and extent of persistence may have potential effects on the environment after the sewage-sludge disposal to surface waters or landfills.
3. The reported hydrophilicity/lipophilicity properties of compounds allowed the chemical partitioning onto suspension in solution and biosolids with microbial degradation. The degradation possibilities of compounds include partial/complete

degradation, mineralization or sorption to sludge, which is a repository of microorganism during sewage treatment work degradation processes.

4. The reported multistep extraction protocols reduced the matrix influences and improved recovery under stability of pH. The delivered extracts were very clean using several solid-phase extraction adsorbents as recent advances. The effluent concentrations ranged from 0.3 to 30.2 ng L^{-1} with percentage recoveries from 78.6 to 97.8%, using solid-phase extraction-gas chromatography-mass spectrometry in many studies.
5. The observed degree of removal of drugs from the influent and its relative concentrations were higher when compared to the effluent drug concentrations where about 10 times higher in the influent compared to the effluent were found. However, improved sampling strategies and recovery, new detection methodologies and reduction of matrix influences employed at the determination of most effluents have added new trends that will further improve the treatment capability and assessments of sewage treatment plants.

Keywords Drugs · Pharmaceuticals · Wastewater · Analysis · Environment

9.1 Introduction

Human activities impact the environment through occurrence of pollutants and the interconnectedness of their metabolites in a myriad of ways. Chemical pollution is caused by the presence of dyes, solvents, pesticides, heavy metals and chemicals from industrial wastes and direct dumping to the aquatic environment. Disrupting chemicals such as natural hormones from humans and animals and phytoestrogen as well as agricultural herbicides and fertilizers are in the environment. Other sources such as mining, deforestation and release of semi-volatile organics have worldwide significant consequences. For example, nitrates are found from fertilizers; industrial effluents have bisphenol A, nonylphenol, polycyclic aromatic hydrocarbons and phthalates (Rogers 1996).

Pharmaceutical substances are ever-increasing at the risks to our lives as a result of high consumption and deposition of many of these therapeutic classes of drugs harbouring potential consequences for the environment. Despite the continuous discharge and rapid rise of some of these chemicals that are mutagenic, reproductive, toxic and carcinogenic in the environment, the assessment of occurrence and metabolism of pharmaceuticaldrugs and associated metabolites would continue to generate concerns due to the underappreciated levels of inadvertent and purposeful discharges of these toxicological substances (Mustapha 2013).

In recent years, there have been global concerns about the emerging levels of abused pharmaceuticals (illicit drugs) apart from drugs used for therapeutic purposes. The escalating levels of these drugs have prompted the need for proper monitoring of their prevalence in order to stem its social and environmental impacts.

Table 9.1 Contaminants in wastewaters

Pollutants	Sources/usages	Analytes
Acrylamide monomer	Coagulants	Polyacrylamide
Alkylphenols	Detergents, surfactants	4-Alkylphenol; polyethoxylates; 4-nonylphenol; monoethoxylates
Chlorophenols and chlorophenoxy acids	Herbicides	4-Chlorophenol, 2-chlorophenol
Lipids	Petroleum hydrocarbon	Phosphatidylserine, Phosphatidylethanolamine, Phosphatidylcholine
Mineral oils	Engine oils, paints	Paraffin, alkylbenzene cycloparaffin
Nitrosamines and nitroaromatics	Control nematodes	Dimethylnitrosamine
Organochlorine pesticides	Agricultural control of pests, transformer fluids, plasticizers and artificial rubbers	Aldrin, endrin, dieldrin
Organophosphorus compounds	Pesticides	Residues
Organotin compounds	Stabilizers in biocides, foams	Tributyltin oxide
Phthalates esters	Plasticizers	Bis(2-ethylhexyl)phthalate
Polychlorinated dibenzodioxins	Pulp bleaching	Congener group
Polycyclic aromatic hydrocarbons	Pyrolysis of organic materials	Naphthalenes
Surfactants and related residues	Detergents	Linear alkylbenzene
Chlorobenzenes	Paint removers	Chlorobenzenes

Environmental monitoring and risk assessments have shown the sewage treatment works as one of the potential routes through which the levels of consumption by a local population can be estimated. Studies revealed a plethora of illicit drugs and their common classes include cocaine, opioid, cannabinoid, amphetamine, lysergic diethylamide and hallucinogen (Baker and Kasprzyk-Hordern 2011; Harman et al. 2011; Karolak et al. 2010).

The biodegradability and non-biodegradability or resistance to degradation has increased the environmental risk factors of the ecosystem due to the hydrophobicity/lipophobicity properties of these drugs. In Table 9.1, the myriads of chemicals are shown coupled with the menace of use and abuse of illicit drugs having necessitated the establishment of many international agencies saddled with the responsibilities to monitor the production, transport, unlawful possession and usage of the 'controlled' substances. The substances considered risky for human health and social well-being of the society have different legislation in many countries with the hope to curb the menace, but the concerted efforts have not been fully achieved for their purpose.

Regardless, the nefarious activities of the consumers are on the increase, and the hidden natures of the business have helped its purported widespread and escalating consumption.

Until the idea of Daughton and Ternes (1999) and Daughton (2004), using intrusive approach to provide information on the community consumption of illicit drugs of whose idea was later demonstrated by Zuccato et al. (2005), nearly nothing was in the public domain about the estimation and levels of abused drugs in the environment. Today, the abused drugs are similarly surviving like other pharmaceuticals and medicinal drugs as reported by several studies, but the extent and spread differ from one location to another. The levels of abused drugs and abused pharmaceuticals in the effluents to receiving waters can generate exposure data to indicate potential threats; it constitutes to the environment as well to the appropriate authorities involved in fighting and controlling drug menace.

Therefore, we must provide updates on the fate and removal of these pharmacologically active contaminants from effluents to safeguard aquatic and human environment. The highlight of pharmaceutical occurrence, metabolism, transport routes, stability, analysis and current development in monitoring their fate is of great interest to humans and the environment.

9.2 Pharmaceutical Occurrence in Aqueous Environment

Pharmaceutical products produce active ingredients from parent drugs after metabolism; the biotransformation of these drugs generates associated metabolites that are excreted after intended use by dose users and pass on to the sewage system. In the sewage system, there exist increased possibilities of risks of environmental effects as more polar degradation products are produced in complex biochemical pathways that are very complicated to follow. The concerns for environmental sustainability and safety have led increasing attention to the large production of pharmaceuticals and their corresponding metabolites including those that are normally procured illegally (without approval/prescription) for illicit purposes. Yet, new pharmaceuticaldrugs of varying chemical classes enter the aquatic environment through sewage system and run-off.

The drug residue (unmetabolized) from excreta and urine and associated active metabolites are flushed in the toilets, and unwanted drugs are directly dumped to the surface river or disposed via drains; this constitutes a major source of pollution. The distributions of therapeutic classes of drugs in the environment are antibiotics, anti-inflammatory, anti-epileptics, antineoplastics, antidepressants, beta-blockers, β_2-sympathomimetics, contraceptives, diagnostic contrast media, lipid regulators, preservatives, sunscreen agents and tranquilizers (Hedgespeth et al. 2012). Selected different classes of pharmaceuticals are in Tables 9.2, 9.3 and 9.4.

Detectable levels of different classes of pharmaceuticals ranging from ng L^{-1} to μg L^{-1} were found in rivers, seas, lakes and surface and underground waters due to incomplete removal from the sewage system.

Table 9.2 Classes of pharmaceuticals in wastewaters

Groups of pharmaceuticals	Drugs
Acidic pharmaceuticals Antiphlogistics, analgesics and phenolic antiseptics	Salicylic acid, bezafibrate (lipid regulator, antiseptic biphenylol, antiphlogistic ibuprofen, ibuprofen, diclofenac, clofibric acid, naproxen, bezafibrate, fenoprofen, mefenamic acid, paracetamol)
Antibiotics	Penicillin, tetracyclines, sulphonamides and macrolides
Beta-blocker and β_2-sympathomimetics	Atenolol, sotalol, metoprolol and β_2-sympathomimetics (salbutamol)
Oestrogens	Oestrone, oestradiol, ethinyloestradiol
Iodinated contrast media	Iopamidol, iomeprol, iopromide, iohexol, diatrizoate, ioxitalamic acid, adsorbable organic iodine
Neutral pharmaceuticals	Antiphlogistics, anti-epileptic agents, lipid regulators, vasodilators
Nitrosamines	Morpholine, N-nitrosodimethylamine, diethylamine, di-n-propylamine, di-n-butylamine, diphenylamine, methylethylamine, pyrrolidine, piperidine
Other micro-pollutants	Benzotriazole, 4-tolyltriazole, 5-tolyltriazole, bisphenol A

Table 9.3 Psychoactive drugs and beta-blockers from wastewaters

	Influent [ng L^{-1}]			Effluent [ng L^{-1}]		
Substances	LOQ	No of samples	Max	LOQ	No of samples	Max
Anti-epileptics						
Carbamazepine	200	9	1000	100	9	1200
Primidone	200	9	420	10	9	250
Antidepressants						
Doxepin	200	9	100	10	9	190
Opioids						
Codeine	200	9	160	10	9	30
Dihydrocodeine	200	9	140	10	9	70
Methadone	100	9	130	5	9	120
Morphine	200	9	440	10	9	29
Oxycodon	200	0	–	10	0	–
Tramadol	200	6	470	10	6	370
Tranquilizers						
Diazepam	200	0	–	10	0	–
Nordiazepam	200	0	–	10	0	–
Oxazepam	200	6	190	10	6	180
Beta-blockers						
Atenolol	100	9	910	5	9	370
Sotalol	100	9	1300	5	9	1200
Metoprolol	100	9	1200	5	9	1100
Propranolol	5	9	70	3	9	60
Bisoprolol	100	9	380	5	9	270
Celiprolol	100	9	160	5	9	160
Betaxolol	5	4	10	3	1	–

Note: LOQ = limit of quantification; Max = maximum

Table 9.4 Pharmaceuticals in effluents, rivers and streams

	STWs (ng L^{-1})			Rivers/streams (ng L^{-1})	
Analyte	LOQ	Number STWs	Maximum	LOQ	Maximum
Lipid regulator					
Bezafibrate	250	49	4600	25	3100
Gemfibrozil	50	49	1500	10	510
Clofibric acid	50	49	1600	10	550
Fenofibric acid	50	49	1200	10	280
Antiphlogistics					
Acetylsalicylic acid	100	49	1500	20	340
Diclofenac	50	49	2100	10	1200
Ibuprofen	50	49	3400	10	530
Indomethacin	50	49	600	10	200
Ketoprofen	50	49	380	10	120
Naproxen	50	10	520	10	390
Phenazon	100	30	410	20	950
Salicylic acid	50	36	140	10	4100
Beta-blocker					
Betaxolol	25	29	190	10	30
Bisoprolol	25	29	370	10	2900
Metoprolol	25	29	2200	10	2200
Propranolol	25	29	290	10	590
β_2-Sympathomimetics					
Salbutamol	50	29	170	10	35
Terbutaline	50	29	120	10	<LOQ
Psychiatric drug					
Diazepam	30	20	40	30	<LOQ
Anti-epileptic					
Carbamazepine	50	30	6300	30	1100
Antibiotics					
Clarithromycin	20	8	260	20	260
Roxithromycin	20	10	1000	20	560
Chloramphenicol	20	10	560	20	60
Sulphamethoxazole	20	10	2000	20	480
Trimethoprim	20	10	660	20	200
Dehydrato-erythromycin	20	10	6000	20	1700
X-ray contrast media					
Diatrizoate	10	25	8700	10	ca.100
Iomeprol	10	12	3800	10	890
Iopamidol	10	25	15,000	10	2800
Iopromide	10	24	11,000	10	910
Oestrogens					
Oestrone	1	38	70	0.5	1.6
17β-oestradiol	1	38	3	0.5	<LOQ
17β-oestradiol-17-valerate	4	38	<LOQ	2	<LOQ
17α-Ethinyloestradiol	1	38	15	0.5	<LOQ
16α-Hydroxyestrone	1	15	5	0.5	<LOQ

Note: LOQ = limit of quantification

9.3 Abused Pharmaceuticals (Illicit Drugs) in Aqueous Environment

Cocaine, amphetamine, opioid, lysergic acid diethylamide, hallucinogen and cannabinoid are common classes of abused drugs. They are often referred to as 'hidden drug', and the users' hidden activities have given rise to their purported widespread and escalation. Until recently, limited information in the literature was known about illicit drugs and whether they similarly exist as pharmaceuticals in the environment. The emerging trends in the spread and usage of these drugs have prompted many international agencies to conduct risks assessment to ascertain the levels of impacts to the environment. The sewage treatment plants were identified as routes through which the drugs enter the environment, while direct dumping of expired drugs by end-users and drug manufacturing companies is another source.

Some drug users do divert prescription drugs for medical purposes in many ways to supplement their personal nefarious activities. The continuing practice has affected people, environment and societies in many ways as their active bioactive metabolites are continuously being discharged through the sewage disposal (e.g. to landfills, grassland, incineration and land reclamation) to the environment in complex mixtures of reactions that are very difficult to understand.

Table 9.5 therefore illustrates and compares the drug levels from different sewage treatment locations so as to appreciate the distribution and potential threats as reported in the literature. The observed degree of removal of drugs from the influent and its relative concentrations were higher when compared to the effluent drug concentrations. For example, 225 and 2307 ng L^{-1} cocaine and benzoylecgonine in 5 sewage treatment work influents in Spain were higher compared to 47 ng L^{-1} of cocaine concentrations in effluent**.** The benzoylecgonine relative concentration is about 10 times higher in the influent compared to the effluent.

The urination and faeces are products of metabolism through which unmetabolized drugs and associated metabolites get to the sewage systems. The fluctuation pattern in the use of lavatory, periods of work and resident population vary from individuals and locations which invariably would similarly affect the illicit load pattern. Active researches are ongoing on the detection of abused drugs; their fate through human metabolism and environmental degradation processes are needed to fully understand their myriad of pathways and behaviour.

Human metabolism of drugs in the body is associated with the biotransformation of drugs into metabolites with the unchanged parent drug being eliminated in the body. A degree of metabolism has been associated with a number of parameters such as ethnicity, gender, age, patient and the drug administration time.

The conjugation reaction occurs when polar molecules transfer metabolites such as the glucuronic acid transfer to hydroxyls, phenols, thiols, carboxyls, hydroxyl amino and amines groups (Mustapha 2013). The interests are the metabolites that may pass to the sewage, retain in the STWs and pass on to the environment through effluents or biosolids. The following are the metabolisms of major illicit drugs detected in wastewaters.

Table 9.5 Abused pharmaceuticals in wastewaters

Analytes	Matrix	Influent (ng L^{-1})	Effluent (ng L^{-1})	Surface water (ng L^{-1})
Cocaine	5 STPs, Spain	225.0	47	10
	5 STPs, Belgium	22–678	–	1.2–26
	37 STPs, Belgium	32–753	–	–
	3 rivers, Italy	–	–	0.3–44
	5 STPs, Ireland	489 ± 117	25–248 ± 20	0–33 ± 11
	Eastern Spain	370–1000.24	30–560	–
	30 STPs, Belgium	09–683	–	–
	2 STPs, Italy	218.4–421.4	0.9–10.7 ± 3.2	–
	4 STPs; River Po	42–120	–	–
	42 STPs, NE Spain	04–4700	01–100	–
	Barcelona, Spain	2.40	–	–
Benzoylecgonine	5 STPs, Spain	2307.0	–	111
	5 STPs, Belgium	82–1898	928	44–191
	37 STPs, Belgium	46–2258	–	–
	3 rivers, Italy	2.2–183	–	–
	5 STPs, Ireland, UK	290 ± 11	22	–
	Eastern Spain	150–1000.5	22 ± 4–31 ± 18	–
	30 STPs, Belgium	37–1550	6.0–7.9	–
	2 STPs, Italy	547.4–197.2	–	–
	4 STPs; River Po	420–750	0.92–100.3 ± 28.6	–
	42 STPs, NE Spain	09–7500	–	–
	Barcelona, Spain	5.24	01–1500	–
	12 STPs, Germany	65 ± 5	77 ± 9	71

Note: STPs = sewage treatment plants

9.3.1 Cocaine Metabolism

Cocaine is a powerful stimulant and addictive drug that has smoking, intranasal and intravenous routes of administration. The addicts usually mix street cocaine with diluents which sometimes cause poisoning. The cocaine is metabolized spontaneously in the presence of hepatic esterase and pseudocholinesterase to produce ecgonine methyl ester. Cocaine under non-enzymatic hydrolysis at pH 6 demethylates and converts to its main metabolite, benzoylecgonine (and this is detected in urine). The most toxic norcaine is produced through N-demethylation;

Analytes	Matrix	Influent	Effluent	SW
Nor- BE	3 rivers, Italy	–	–	0.2–8.4
	Eastern Spain	150–430	30–170	–
	2 STPs, Italy	18.8 ± 5.6–36.6 ± 7.8	<LOQ – 7.5 ± 2.9	–
Cocaethylene	2 STPs, Italy	5.9 ± 2.6–11.5 ± 5.1	0.2 ± 0.5	–
	Barcelona, Spain	77.5–78.5 ± 33.2	1.71–4.2 ± 1.2	4.63
	3 rivers, Italy	–	–	0.07–0.2
Norcocaine	3 rivers, Italy	–	–	0.15–3.6
	Eastern Spain	0.15–0.43	0.03–0.17	–
	2 STPs, Italy	4.3 ± 0.9–13.7 ± 5.3	0.7 ± 0.5	–
Amphetamines	3 rivers, Italy	–	–	<0.65
	Eastern Spain	1400	110–210	–
	2 STPs, Italy	5.4–14.7 ± 10.6	2.8	–
	42 STPs, Spain	Mar-80	Apr-00	–
	Barcelona, Spain	20.8–41.1 ± 9.1	0.45–2.2 ± 0.1	2.84
	5 STPs, Spain	15	<1.0	<0.8
Methamphetamines	5 STPs, Nebraska	1.3 ± 0.1–1.4	35.0 ± 7.3	–
	3 rivers, Italy	0.1–62.6 ± 13	–	<0.41–1.7
	Eastern Spain	–	<100–540	–
	2 STPs, Italy	<500	<1.11–3.5 ± 2	–
	42 STPs, Spain	3–277	Mar-90	–
	3 STPs, America	15 ± 2–66 ± 14	0.8–1.3	–
	Barcelona, Spain	4.8–18.2 ± 5.8	2.1–6.3 ± 0.6	2.87
	Murray, America	6.0–34	03-Jul	–

(continued)

Analytes	Matrix	Influent	Effluent	SW
MDA	42 STPs, Spain	03–266	01–200	–
	3 Rivers, Italy	–	–	3 ± 0.3–4
	Eastern Spain	500–1400	41.0–68.0	–
	2 STPs, Italy	4.6 ± 7.3–8.7	0.9 ± 1.9–1.1 ± 1.5	–
	5 STPs, Spain	03–266	1–200	–

Note: STPs = sewage treatment plants; Nor-BE = Nor-benzoylecgonine; MDA = methylenedioxyamphetamine

Analytes	Matrix	Influent	Effluent	SW
MDMA	3 rivers, Italy	–	–	1.1–4.0
	Eastern Spain	326–2700.5	100–210.2	–
	2 STPs, Italy	13.6–14.2	4.4 ± 3.7–5.1 ± 3	–
	5 STPs, Spain	91	67	3.5
	STP, Italy	2–598	2–267	–
	Barcelona, Spain	133–135.13 ± 29.8	8.2–14.8 ± 2.2	129
	Murray, America	<1.0–10.0	–	–
	42 STPs, Spain	2–598	2–267	–
MDEA	5 STPs, Spain	27	<2.1	–
	2 STPs, Italy	4.19–1.5 ± 3.8	<1.64	–
	STP, Italy	6–114	12	–
	STP, Spain	<500	<100	–
	42 STPs, NE Spain	06–114	12	–
Opiates				
Heroin	Barcelona Spain	2.4	1.2	–
	STP, Italy	20	<20.0	<1.5
Morphine	5 STPs, Spain	25.9–96.7	20.9–81.1	–
	3 rivers, Italy	–	–	3.5–38
	5 STPs, Ireland	874 ± 86	452	–
	2 STPs, Italy	83.3–204.4	5.5 ± 11.1	1-2 L
	Barcelona, Spain	68.1–162.9 ± 20.0	21.8 ± 3.0	3.25
	12 STPs, Germany	123 ± 6	9.0 ± 1.2	83
	STP, Italy	7.1–96.7	0.1–8.1.	4.8–6.3
Nor-morphine	5 STPs, Spain	30.7	–	–
	1 STP, Italy	<25	<2.5–3.7	<12.0.5
6 ACM	3 rivers, Italy	–	–	0.93
	2 STPs, Italy	10.4 ± 4.8–11.8 ± 8.5	–	–
	Barcelona, Spain	8.4–12.8 ± 3.1	2.5–3.6 ± 0.5	–

MDMA = methylenedioxymethamphetamine; MDEA = methylenedioxyethyamphetamine; 6 ACM = 6-monoacetylmorphine; STPs = sewage treatment plants

Analytes	Matrix	Influent	Effluent	SW
	12 STPs, Germany	8.4–12.8 ± 3.1	0.9 ± 1.2	83
	STP, Italy	102 ± 14	<3.1	<0.9–3.4
M3G	2 STPs, Italy	2.5 ± 7.1–18.1 ± 30	<0.48	–
Methadone	5 STPs, Spain	4.0–239	4.0–24.7	–
	3 rivers, Italy	–	–	4.9–10.1
	2 STPs, Italy	11.6 ± 1.7–49.7 ± 9.6	9.1 ± 0.5–36.2 ± 2.8	–
	12 STPs, Germany	123 ± 6	9.0 ± 12	83
	STP, Italy	4–23.9	2–2.7	4.9–10.1
Codeine	5 STPs, Spain	18.1–119.7	3.1–397	–
	3 rivers, Italy	–	–	1.0–51
	12 STPs, Germany	80 ± 5	7.7 ± 8	90
Norcodeine	5 STPs, Spain	5–68.0	15.5–22.9	–
6 Acetyl codeine	3 rivers, Italy	–	–	<0.31
EDDP	3 rivers, Italy	–	–	9.9–18.0
	5 STPs, Ireland	9.0–206 ± 10	–	–
	2 ST1 STP, Italy	19.8 ± 3.1–91.3 ± 19.2	22.6 ± 0.6–72.1 ± 8.7	–
	STP, Italy	4.5–41.3	4.9–56.7	9.61–17.5
THC	5 STPs, Spain	11.3–31.5	–	–
	2 STP, Italy	62.7 ± 5–91.2 ± 24.7	<0.94–7.2 ± 3.7	–
	Barcelona, Spain	4.3–21.03 ± 7.8	8.4 ± 3.8–11. 23	2.65
	STP, Italy	8.3–31.5	<8.3	<7.0–13.6
THC-COOH	3 rivers, Italy	–	–	0.48–3.7
	STP, Italy	12.5–96.2	12.5	16.4–34.1
	5 STPs, Spain	37.8–96.2	14.8–48.1	–
OH- THC	Barcelona, Spain	8.4–46.3	4.8–15.3	10.7

STPs = sewage treatment plants; M3G = morphine-3-glucuronide; **THC =** tetrahydrocannabinol; THC-COOH = 11-nor-9-carboxy-Δ^9-tetrahydrocannabinol; OH-THC = 11-hydroxy-Δ^9-tetrahydrocannabinol; EDDP = 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine

other metabolites are anhydroecgonine, cocaethylene, ecgonidine, *p*-hydroxyl-benzoylecgonine, *m*-hydroxyl-benzoylecgonine and norecgonidine methyl ester.

9.3.2 Amphetamine Metabolism

Amphetamine classifications are amphetamines, methamphetamines ('speed') and methylenedioxymethamphetamine ('ecstasy or Adam'). The addictive drugs can be

taken orally or by snorting, smoking or injecting. Among other risks, the stimulant drugs give risks of abuse and dependence that cause harm to the central nervous system.

9.3.3 Opiate Metabolism

Opium poppy (*Papaver somniferum*) is an ingredient in morphine, thebaine and codeine. Most popular illegal drugs from opium poppy are morphine and heroin, while morphine and 6-monoacetylmorphine are related metabolites. The positions 3 and 6 of phenolic hydroxyl and alcoholic hydroxyl with the nitrogen atom typifies morphine metabolism. The degradation of heroin (diacetylmorphine) pathways produces main metabolites with different morphine conjugates; different enzyme actions emphasize the morphine metabolism complexity. Approximately 90% of an administered dose of morphine is excreted in the urine; only about 10% is excreted as unchanged parent morphine. The major metabolite is morphine-3-glucuronide, while minor metabolite is morphine-6-glucuronide. Others are codeine (3-O-methylmorphine), normorphine-6-glucuronide and morphine-N-oxide found in human urine and in wastewaters.

9.3.4 Lysergic Acid Diethylamide Metabolism

The drug is quickly dispersed in the body after metabolism, with smaller dose of the original eliminated in the human urine. The lysergic acid diethylamide metabolites in human biological fluids include 2-oxo-lysergic acid diethylamide, 2-oxo-3-hydroxy-lysergic acid diethylamide, N-demethyl-lysergic acid diethylamide, 14-hydroxy-lysergic acid diethylamide and 13-hydroxy-lysergic acid diethylamide. The 13- and 14- hydroxyl-lysergic acid diethylamide and 2-oxo-3-hydroxy-lysergic acid diethylamide are found in urine as glucuronide conjugates.

9.3.5 Cannabinoid Metabolism

One of the important cannabinoids is tetrahydrocannabinol, and C*annabis sativa L* is the active chemical, and cannabinol and cannabidiol are other constituents. On ingestion, the cannabinoids are metabolized by cytochrome P45 oxidase in the liver. The Δ^9-tetrahydrocannabinol metabolism leads to 11-hydro-Δ^9-tetrahydrocannabinol, which turned to 9-carboxy-tetrahydrocannabinol. The tetrahydrocannabinol metabolism is yet to be properly understood.

9.4 Sewage Treatment Works as Transport Routes of Pollutants

The significant routes which the pharmaceuticaldrugs enter the aquatic environment are domestic sewage systems. The faeces and urine are excreted along with its ingested chemicals and metabolites. Other major sources are discharges from commercial, domestic, drug manufacturers and run-off areas. The residues were found in varying concentrations in wastewaters reported in Italy, Belgium, Spain, Germany, the United State and the United Kingdom (Ai Jia et al. 2012; Ashfaq et al. 2016, 2017; Baena-Nogueras et al. 2017; Kasprzyk-Hordern and Baker 2012a; Kasprzyk-Hordern and Baker 2012b). Apart from the percolating filters, active sludge processes, nitrification and denitrification facilities, ozonation and membrane bioreactors as biological removal methods of trace pollutants from wastewaters, microbial degradation is the most effective removal process in sewage works. Studies of transformation of organics in mammals and humans, persistence of chemicals and microbial biodegradations involve complex interplay of biochemical, physical and transformational reactions of pollutants, and their nature determines the quality of effluent.

Apart from biodegradation, volatilization and hydrolysis, adsorption onto the biosolid surfaces through physico-chemical interactions also occurs. The removal extent due to the interaction of polar compounds is most times determined by the adsorption coefficient, with low adsorption coefficient compounds easily released to the receiving waters as effluents. The incomplete removal of these organic compounds from municipal sewage treatment works often leads to soil leaching and damaged ecosystem. This practice constitutes primary routes for chemicals to enter the aquatic environment.

Apart from the chemical degradation, sorption processes and biodegradation, typical sewage treatment work details of complex mixtures in the removal processes are not understood during the wastewater treatment. The toxicity and extent of persistence have potential effects on the environment after the sewage-sludge disposal to seas or agricultural landfills.

9.5 Microbial Degradation of Compounds in the Environment

The hydrophilicity/lipophilicity properties of compounds allow the chemical partitioning onto suspension in solution and biosolids. Understanding the degradation possibilities of compounds includes partial/complete degradation, mineralization or sorption to sludge which is a repository of microorganism during sewage treatment work degradation processes. Organic contaminants are located with the fraction of biomass determining the degree of contamination. Sewage contains mixtures of human excreta in complex association of fats, protein, sugars, cellulose,

lignin, fatty acids, humid materials and amino acids. The drugs and their metabolites found in both aquatic environments and human fluids are given in Tables 9.6 and 9.7.

The metabolites of cocaine are norecgonidine methyl ester, ecgonidine, *m*-hydroxyl-benzoylecgonine and *p*-hydroxyl-benzoylecgonine, and methamphetamine conjugates. Degradation studies have been carried out on the degradation of

Table 9.6 Human drug metabolites found in the aquatic environment

Compound	Human metabolites identified
Amphetamine	Amphetamine
	3, 4-Methylenedioxyamphetamine
	Methylenedioxymethamphetamine
	Methylenedioxyethylamphetamine
	Methylbenzodioxolylbutanamine
	Methamphetamine
	p-Hydroxy-methamphetamine
Cannabinoids	Δ^9-Tetrahydrocannabinol
	Hydroxyl-tetrahydrocannabinol – conjugate
	Nor-9-carboxy-Δ9-tetrahydrocannabinol – glucuronide
	Δ^9-Tetrahydrocannabinol-9-carboxylic acid
Cocaine	Benzoylecgonine
	Cocaethylene
	Cocaine
	Ecgonidine
	Ecgonidine methyl ester
	Ecgonine
	Ecgonine methyl ester
	m-OH-benzoylecgonine
	Norecgonine methyl ester
	Norcocaine
	Norecgonidine
LSD	2-Oxo-3-hydroxy-lysergic diethylamide
	Hydroxyl lysergic diethylamide
	Iso-lysergic diethylamide
	Lysergic diethylamide
	Nor-lysergic diethylamide
Opiates	6-Monoacetylmorphine
	Heroin
	Morphine
	Normorphine
	Morphine-3-glucuronide
	Methadone
	2-Ethylene-1,5-dimethyl-1-3,3-diphenylpyrrolidine
	Ethyl morphine

Table 9.7 Biodegradability test of some pharmaceuticals

Compound tests		
Non-biodegradable	Biodegradable	Readily biodegradable
Chlorhexidine	Ampicillin	Aspirin
Clofibrate	Ibuprofen	Caffeine
Codeine phosphate		Ephedrine
Dextropropoxyphene		Menthol
Amitriptyline		Paracetamol
Erythromycin		Phenylpropanolamine
Meprobamate		Theobromine
Methyldopa		Theophylline
Metronidazole		
Naproxen		
Sulphamethoxazole		
Sulphasalazine		
Tetracycline		
Tolbutamide		

16α-hydoxyestrone, antitumor cisplatin, diatrizoate, trimethoprim, cyclophosphamide, X-ray contrast agents, cytarabine and iopromide, but details of metabolites were not identified or reported (Azaria et al. 2017; Mustapha 2013;)

9.6 Analytical Methodologies for Pharmaceuticals Residues in Wastewaters

Important advances in the detection and quantitative measurement of pharmaceuticaldrugs and their metabolites using various chromatographic and mass spectrometric methods have been developed. In gas chromatography-mass spectrometry and liquid chromatography-mass spectrometry techniques, liquid chromatography-mass spectrometry is most popular due to its measurement ability of chemicals at low concentration. Several alternative methods such as immunochemical techniques are good and inexpensive for pharmaceuticalanalyses (Mustapha 2013).The literatures have reported multistep extraction protocols, to reduce the matrix influences (Boruszko 2017; Gómez-Acata et al. 2017; Kasprzyk-Hordern et al. 2007; Ledjeri et al. 2016; Lepik and Tenn 2017; Madikizela et al. 2017; Martín et al. 2012; Mendoza et al. 2015; Olajire et al. 2005). Improved recovery after matrix effect under stability of pH delivers extracts that are very clean using several SPE adsorbent. Suitable parameters depend on application needs, the reason why several SPE adsorbents have been used with GC-MS^2 or LC-MS^2 for the determination of drugs and metabolites at low concentrations (ng L^{-1} levels) in aquatic media (Patrolecco et al. 2015; Paz et al. 2016; Song et al. 2016; Tang et al.

Table 9.8 Types of cartridges and adsorbent materials

Types	Sorbent materials
Isolute, pH® (1000 mg/6 mL)	Silica treated with phenyl groups in which silanol group is end-capped
Bond Elut Certify® (300 mg/6 mL)	Lipophilic and strongly cationic properties
Oasis, MCX® (500 mg/6 mL)	Polymeric sorbent with strong cation-exchange sulphonic group located on surface of polydivinyl. High selectivity for basic compounds. Benzene-co-N-vinyl pyrrolidone) copolymer
Phenomenex Strata-X™ (200 mg/6 mL)	–
Chrolut, ENV® (500 mg/6 mL)	Hyper-cross-linked polystyrene-divinylbenzene polymer based
Chromabond, Easy (500 mg/6 mL)	Bifunctional polystyrene-divinylbenzene copolymer
Isolute,C_{18} (EC)® (500 mg/6 mL)	Strongly apolar and lipophilic based on octadecyl silica with end capping of free silanol group
Isolute, ENV® (500 mg/6 mL)	Hydrophobic sorbent with hydroxylated polystyrene-divinylbenzene copolymer
Oasis, HLB® (500 mg/6 mL)	Divinylbenzene/N-vinyl pyrrolidone copolymer with hydrophilic/lipophilic properties. Application: all compounds and polar metabolites
Oasis, MAX (60 mg)	Strong anion-exchange mixed mode polymeric sorbent built upon HLB copolymer. Application: acidic compounds
Chromabond, C_{18} (200 mg).	Silica-based, end-capped sorbent. Application: non-polar compounds
Isolute, HCX (200 mg)	Weak anion-exchange mixed mode. Application: non-polar and basic analyte
Oasis, WAX (60 mg)	Weak anion-exchange mixed mode polymeric sorbent built upon HLB copolymer. Application: strong acids (e.g. sulphonates)
Oasis, WCX (60 mg)	Weak cation-exchange mixed mode polymeric sorbent built upon HLB copolymer. Application: strong bases e.g. quaternary amines)

2017; Tiwari et al. 2016; Xiang et al. 2017; Xu et al. 2016; Zhong et al. 2017). The different types of cartridges and adsorbent materials in multistep extraction procedures reported in the literature are shown in Table 9.8.

9.7 Pharmaceuticals and Metabolites Detected in Nottingham Sewage Treatment Work Effluent

The Nottingham sewage treatment work is located at Stoke Bardolph in the East Midlands; it treats the sewage of about 170 million litres per day using activated sludge. It serves over 500,000 people. A total of 16 h is used for wastewater

treatment stages from influent wastewater to effluent including recycling before discharging it to River Trent. The sewage treatment work further removes 330 tonnes of plastics and paper as well as 2000 tonnes of grit per year (Mustapha 2013).

Systematic samplings for the biweekly collections of samples were adopted to obtain representative samples. To avoid effluent dilution due to distance from the discharge point to the receiving waters, efforts were made to ensure that collections were made at the same distance close to the effluent discharge points to minimize uncertainties in analyte concentrations. The varying amounts of analytes at the receiving waters further confirmed the major routes of sewage treatment plants by which pharmaceutical compounds enter the aquatic environment. The new challenges are introduction of abused pharmaceuticals making treatability at sewage treatment plants very difficult due to dearth of information of removal techniques.

In Table 9.9, there are 15 compounds that were detected from biweekly samplings from Nottingham sewage treatment work effluents including ibuprofen, caffeine, lidocaine, cocaine, codeine, amphetamine, ecgonine methyl ester, benzoylecgonine, ephedrine, methadone, nicotine, 6-acetylmorphine, diacetylmorphine, diazepam and procaine with their corresponding concentrations as presented. This study confirms necessary analytical capabilities for the determination of drugs in wastewaters using solid-phase extraction-gas chromatography-mass spectrometry. The presence of 15 different compounds, ibuprofen, caffeine, lidocaine, cocaine, codeine, amphetamine, ecgonine methyl ester, benzoylecgonine, ephedrine, methadone, nicotine, 6-acetylmorphine, diacetylmorphine, diazepam and procaine, was found. The compounds detected in effluents ranged from 0.3 to 30.2 ng L^{-1} with percentage recoveries from 78.6 to 97.8%, using solid-phase extraction-gas chromatography-mass spectrometry. The instrumental limits of detection ranged from 0.1 to 1.5 ng L^{-1} and standard deviation values of 1.1–21.4%. The most abundant compounds found in the final effluents were nicotine, ibuprofen, codeine, ephedrine, procaine, benzoylecgonine, lidocaine and caffeine, with mean concentrations of 19.2 ± 5.8, 15.2 ± 4.3, 13.6 ± 5.7, 9.1 ± 3.5, 8.2 ± 3.1, 5.1 ± 2.8, 4.7 ± 1.7 and 4.2 ± 1.7 ngL^{-1}, respectively.

However, improved sampling strategies employed at the determination of effluents at Stoke Bardolph Sewage Treatment Plant in Nottingham have added new trends that will further improve the treatment capability and assessments of the sewage treatment plant (Mustapha 2013).

9.8 Conclusions

With the different aspects of drug's occurrence, fate, treatability and transformations in the aquatic environment in the literature, the pharmaceutical markets for numerous therapeutic and commercial purposes will keep escalating. The desired approaches at safeguarding the environment in controlling and effective monitoring of chemical discharges into the environment are the new pollution challenges. This work examines aspects of some pharmaceuticals' fate, transport routes,

Table 9.9 Concentration of compounds from Nottingham sewage treatment work effluents

Compound	Biweekly sampling periods of Nottingham effluents (ng L^{-1})								Mean ± STD	LOD (ng/L)	Major ions for substance identification (m/z)		
	1ST SMP	2ND SMP	3RD SMP	4TH SMP	5TH SMP	6TH SMP	7TH SMP	8TH SMP			Molecular ions	Precursor ions	Product ions
6-Acetylmorphine	1.4	2.1	3.6	8.2	3.9	1.0	1.2	–	3.3 ± 2.5	0.8	341	282	229
Amphetamine	3.9	4.6	4.8	6.6	2.5	3.0	3.5	5.6	4.3 ± 1.4	0.3	206	116	73
Benzoylecgonine	4.9	4.9	4.7	3.5	2.4	11.0	4.1	–	5.1 ± 2.8	1.4	290	168	150
Caffeine	7.7	4.9	6.5	3.9	4.1	5.0	3.4	2.2	4.7 ± 1.7	0.5	194	109	67
Cocaine	1.7	1.4	1.1	1.4	1.4	–	–	–	1.4 ± 1.3	0.7	303	182	82
Codeine	10.1	11.0	10.8	14.2	11.3	13.0	10.9	27.2	13.6 ± 5.7	0.4	299	178	73
Diacetylmorphine	–	–	3.4	2.6	1.1	–	–	1.4	2.1 ± 1.1	0.8	369	310	268
Diazepam	3.5	8.9	1.2	4.2	5.3	4.7	1.4	2.6	4.0 ± 2.5	1.2	285	256	221
Ecgonine ME	0.6	–	1.7	1.4	0.8	0.8	–	0.3	0.9 ± 1.3	0.3	199	99	82
Ephedrine	3.7	13.8	14.2	8.0	6.9	9.1	10.0	7.3	9.1 ± 3.5	0.1	230	179	58
Ibuprofen	14.3	13.4	8.0	16.7	15.2	13.5	17.3	23.3	15.2 ± 4.3	0.8	278	160	73
Lidocaine	15.7	5.8	1.4	2.4	2.0	5.2	2.3	3.2	4.7 ± 1.7	1.4	234	86	58
Methadone	3.8	3.2	4.1	2.3	4.1	1.3	–	–	3.1 ± 1.2	1.2	283	197	180
Nicotine	20.4	16.8	17.0	11.4	14.5	30.2	20.4	23.0	19.2 ± 5.8	1.5	162	133	84
Procaine	15.2	6.5	8.4	7.1	7.4	4.7	8.3	8.3	8.2 ± 3.1	1.1	235	99	88

Note: SMP = sampling period; n = triplicate determinations; STD = standard deviation; STW = sewage treatment work; - (<LOD = limit of detection); Ecgonine ME = ecgonine methyl ester; m/z = mass/ions ratio

environmental distribution and bioactive metabolites. The inadvertent and purposeful discharges of pharmacologically active compounds via excreta remain underappreciated, yet their toxicological potency on the ecosystem has become a global issue. The persistent influxes of these pollutants with new and emerging contaminants have shown potential effects based on several studies reported on the plethora of compounds in the aquatic realms.

Highlights of current developments in drug monitoring, measurements of distribution and the extent at which sewage treatment plants allow the transport of chemicals (through different environment media) into the environment are reviewed. Preferred removal methods and measurements of trace drugs depend largely on sludge types, influents, effluents and sediments from sewage treatment plants. The capability to furthering the understanding of overall issues of pharmaceuticals' fate and other contaminants is now made available with exposure data on pollutant trend in the aquatic environment.

References

Ai Jia, Wan Y, Yang X, Hu J (2012) Occurrence and fate of quinolone and fluoroquinolone antibiotics in a municipal sewage treatment plant. Water Res 46:387–394. https://doi.org/10.1016/j.watres.2011.10.055

Ashfaq M, Khan KN, Rasool S, Mustafa G, Saif-Ur-Rehman M, Nazar MF (2016) Occurrence and ecological risk assessment of fluoroquinolone antibiotics in hospital waste of Lahore, Pakistan. Environ Toxicol Pharmacol 42:16–22. https://doi.org/10.1016/j.etap.2015.12.015

Ashfaq M, Nawaz KK, Saif Ur Rehman M, Mustafa G, Faizan Nazar M, Sun Q (2017) Ecological risk assessment of pharmaceuticals in the receiving environment of pharmaceutical wastewater in Pakistan. Ecotoxicol Environ Saf 136:31–39. https://doi.org/10.1016/j.ecoenv.2016.10.029

Azaria S, Nir S, van Rijn J (2017) Combined adsorption and degradation of the off-flavor compound 2-methylisoborneol in sludge derived from a recirculating aquaculture system. Chemosphere 169:69–71. https://doi.org/10.1016/j.chemosphere.2016.11.051

Baena-Nogueras RM, González-Mazo E, Lara-Martín PA (2017) Degradation kinetics of pharmaceuticals and personal care products in surface waters: photolysis vs biodegradation. Sci Total Environ 590–591:643–654. https://doi.org/10.1016/j.scitotenv.2017.03.015

Baker DR, Kasprzyk-Hordern B (2011) Multi-residue analysis of drugs of abuse in wastewater and surface water by solid-phase extraction and liquid chromatography–positive electrospray ionisation tandem mass spectrometry. J Chromatogr A 1218(12):1620–1631. https://doi.org/10.1016/j.chroma.2011.01.060

Boruszko D (2017) Research on the influence of anaerobic stabilization of various dairy sewage sludge on biodegradation of polycyclic aromatic hydrocarbons PAHs with the use of effective microorganisms. Environ Res 155:344–352. https://doi.org/10.1016/j.envres.2017.02.019

Daughton CG (2004) Non-regulated water contaminants: emerging research. Environ Impact Assess Rev 24(7–8):711–732. https://doi.org/10.1016/j.eiar.2004.06.003

Daughton CG, Ternes TA (1999) Pharmaceuticals and personal care products in the environment: agents of subtle change? Environ Health Perspect 107(Suppl 6):907–938. https://doi.org/10.1289/ehp.99107s6907

Gómez-Acata S, Esquivel-Ríos I, Pérez-Sandoval MV, Navarro-Noya Y, Rojas-Valdez A, Thalasso F (2017) Bacterial community structure within an activated sludge reactor added with phenolic compounds. Appl Microbiol Biotechnol 101(8):3405–3414. https://doi.org/10.1007/s00253-016-8000-z

Harman C, Reid M, Thomas KV (2011) In situ calibration of a passive sampling device for selected illicit drugs and their metabolites in wastewater, and subsequent year-long assessment of community drug usage. Environ Sci Technol 45(13):5676–5682. https://doi.org/10.1021/es201124j

Hedgespeth ML, Sapozhnikova Y, Pennington P, Clum A, Fairey A, Wirth E (2012) Pharmaceuticals and personal care products (PPCPs) in treated wastewater discharges into Charleston Harbor, South Carolina. Sci Total Environ 437(0):1–9. https://doi.org/10.1016/j.scitotenv.2012.07.076

Karolak S, Nefau T, Bailly E, Solgadi A, Levi Y (2010) Estimation of illicit drugs consumption by wastewater analysis in Paris area (France). Forensic Sci Int 200(1–3):153–160. https://doi.org/10.1016/j.forsciint.2010.04.007

Kasprzyk-Hordern B, Baker DR (2012a) Estimation of community-wide drugs use via stereoselective profiling of sewage. Sci Total Environ 423(0):142–150. https://doi.org/10.1016/j.scitotenv.2012.02.019

Kasprzyk-Hordern B, Baker DR (2012b) Enantiomeric profiling of chiral drugs in wastewater and receiving waters. Environ Sci Technol 46(3):1681–1691. https://doi.org/10.1021/es203113y

Kasprzyk-Hordern B, Dinsdale RM, Guwy AJ (2007) Multi-residue method for the determination of basic/neutral pharmaceuticals and illicit drugs in surface water by solid-phase extraction and ultra-performance liquid chromatography–positive electrospray ionisation tandem mass spectrometry. J Chromatogr A 1161(1–2):132–145. https://doi.org/10.1016/j.chroma.2007.05.074

Ledjeri A, Yahiaoui I, Aissani-Benissad F (2016) The electro/Fe3+/peroxydisulfate (PDS) process coupled to activated sludge culture for the degradation of tetracycline. J Environ Manag 184(Pt 2):249–254. https://doi.org/10.1016/j.jenvman.2016.09.086

Lepik R, Tenn T (2017) Determination of biodegradability of phenolic compounds, characteristic to wastewater of the oil-shale chemical industry, on activated sludge by oxygen uptake measurement. Environ Technol 33(1–3):329–339. https://doi.org/10.1080/09593330.2011.572923

Madikizela LM, Tavengwa NT, Chimuka L (2017) Status of pharmaceuticals in African water bodies: occurrence, removal and analytical methods. J Environ Manag 193:211. https://doi.org/10.1016/j.jenvman.2017.02.022

Martín J, Camacho-Muñoz D, Santos JL, Aparicio I, Alonso E (2012) Occurrence of pharmaceutical compounds in wastewater and sludge from wastewater treatment plants: removal and ecotoxicological impact of wastewater discharges and sludge disposal. J Hazard Mater 239–240:40–47. https://doi.org/10.1016/j.jhazmat.2012.04.068

Mendoza A, Aceña J, Pérez S, López de Alda M, Barceló D, Gil A (2015) Pharmaceuticals and iodinated contrast media in a hospital wastewater: a case study to analyse their presence and characterise their environmental risk and hazard. Environ Res 140:225–241. https://doi.org/10.1016/j.envres.2015.04.003

Mustapha AO (2013) Fate and behavior of drugs in the environment; PhD Thesis. Nottingham Trent University, UK. P

Olajire AA, Altenburger R, Kuester E (2005) Chemical and ecotoxicological assessment of polycyclic aromatic hydrocarbon-contaminated sediments of the Niger Delta. Sci Total Environ 340:123–136. https://doi.org/10.1016/j.scitotenv.2004.08.014

Patrolecco L, Capri S, Ademollo N (2015) Occurrence of selected pharmaceuticals in the principal sewage treatment plants in Rome (Italy) and in the receiving surface waters. Environ Sci Pollut Res Int 22(8):5864–5876. https://doi.org/10.1007/s11356-014-3765-z

Paz A, Tadmor G, Malchi T, Blotevogel J, Borch T, Polubesova T (2016) Fate of carbamazepine, its metabolites, and lamotrigine in soils irrigated with reclaimed wastewater: Sorption, leaching and plant uptake. Chemosphere 160:22–29. https://doi.org/10.1016/j.chemosphere.2016.06.048

Rogers HR (1996) Sources, behaviour and fate of organic contaminants during sewage treatment and in sewage sludges. Sci Total Environ 185(1–3):3–26. https://doi.org/10.1016/0048-9697(96)05039-5

Song X, McDonald J, Price WE, Khan SJ, Hai FI, Ngo HH (2016) Effects of salinity build-up on the performance of an anaerobic membrane bioreactor regarding basic water quality parameters and

removal of trace organic contaminants. Bioresour Technol 216:399–405. https://doi.org/10.1016/j.biortech.2016.05.075

Tang K, Escola Casas M, Ooi GT, Kaarsholm KM, Bester K, Andersen HR (2017) Influence of humic acid addition on the degradation of pharmaceuticals by biofilms in effluent wastewater. Int J Hyg Environ Health pii: S1438-4639(16):30250–30254. https://doi.org/10.1016/j.ijheh.2017.01.003

Tiwari M, Sahu SK, Pandit GG (2016) Distribution and ecotoxicological concerns of persistent organic pollutants in sediment from creek ecosystem. J Environ Sci Health B 51(9):616–621. https://doi.org/10.1080/03601234.2016.1181907

Xiang X, Chen X, Dai R, Luo Y, Ma P, Ni S (2017) Anaerobic digestion of recalcitrant textile dyeing sludge with alternative pretreatment strategies. Bioresour Technol 222:252. https://doi.org/10.1016/j.biortech.2016.09.098

Xu J, He W, Wang Z, Zhang D, Sun J, Zhou J (2016) Comparison of molecular biology mechanism of Shewanella putrefaciens between fresh and terrestrial sewage wastewater. Front Bioeng Biotechnol 4:86. https://doi.org/10.3389/fbioe.2016.00086

Zhong HY, Wang H, Liu X, Liu C, Liu GY, Tian Y (2017) Degradation and characteristic changes of organic matter in sewage sludge using Vermi-biofilter system. Chemosphere 180:57–64. https://doi.org/10.1016/j.chemosphere.2017.03.121

Zuccato E, Chiabrando C, Castiglioni S, Calamari D, Bagnati R, Schiarea S, Fanelli R (2005) Cocaine in surface waters: a new evidence-based tool to monitor community drug abuse. Environ Health: Glob Access Sci Sour 4:14. https://doi.org/10.1186/1476-069X-4-14