Chapter

Classification, Potential Routes and Risk of Emerging Pollutants/ Contaminant

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Abstract

Emerging contaminants (ECs), encompass both natural and synthetic chemicals that are present or transformed to new chemical compounds in water bodies across the globe. They are presently not checked in the environment but poses a serious health threat to human and ecosystem as well as environmental damage. ECs are released into environment during the anthropogenic activities such as water treatments, fumigation, farming etc. More than 1036 ECs and their biotransformation have been identified by the NORMAN project, established in 2005 by the European Commission. They were further classified into different categorizes/classes including disinfection by-products, pesticides, pharmaceuticals and personal care products, nanomaterials, benzotriazoles, benzothiazoles among others. The potential sources, path route and their health implication on human were also discussed. The presence of ECs in our environments is global issue that requires urgent attention.

Keywords: emerging pollutants, contaminants, pharmaceuticals, personal care products cosmetics, disinfectant

1. Introduction

Emerging pollutants (EPs) are natural and synthetic chemicals as well as microbes that are of less concern to the researchers, national and international regulatory bodies [1, 2]. They have not been explicitly studied and there is limited information about their environmental effects, health implications and method of analysis. These pollutants are not new in our environments but they can stay for a longtime in the environment because of their biotransformation, formation of metabolites and by-products [2, 3].

EPs are recently recognized as re-emerging factory-made or naturally formed materials that are detrimental to human health after a long-term exposure and lacking regulatory health standard [4, 5]. They are classified as agricultural (pesticides), industrial and consumer waste products, pharmaceutical and illicit drug as well as personal care products [6–8]. More than 121 various types of unregulated chemicals and microbes are present in an untreated water and at least 25 were found in water

treatment plants (WTP) [9]. Furthermore, unregulated chemicals such as nitrosamines (NAs), dioxane, nanomaterials, pharmaceuticals and personal care products (cosmetics, disinfectant, antiseptic, deodorant stick, soap, fragrances, insect repellent, sunscreen, surfactants and toothpaste) as well as perfluorinated alkyl acids (PFAA) are EPs [8, 10, 11]. For instance, N-Nitroso-dimethylamine (NDMA) an emerging contaminant produced as byproducts of chloramines in drinking water treatment plants [12]. Nanomaterials (NMs) are substances produced with a dimension in nanoscale range from 1 to 100 nanometer as to improve the chemical strength and reactivity [10]. However, some NMs introduced contaminants when used for water treatment. Polybrominated biphenyl ethers (PBDEs) PBDEs are brominated hydrocarbons used as flame retardants in the production of furniture, plastics, upholstery, electrical equipment, electronic devices and many other household products [10]. Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) fluorinated organic compounds with many industrial applications; such as surfactants in fluoropolymers and as grease, soil and water resistant in fluorinated polymer [13, 14].

2. Classification of emerging pollutants

Emerging pollutants are classified and categorized as follows [15–17]:

1. Pharmaceuticals (illicit and prescribed drugs).

2. Personal care products (cosmetic, surfactants, disinfectants, domestic biocides, food additives).

3. Industrial chemicals (food additives, pesticides, polychlorinated biphenyl, flame retardant, antimicrobial substances)

4. Disinfection by products (from water treatment plant: Nitrosamine, halonitromethanes, haloacetonitriles, trihalomethanes, halo acetic acids).

5. Algal toxins (toxic released from some algae: Cyanotoxins, microcystin)

6. Biocides and their metabolites (plants and agricultural preventive agents [pesticides])

7. Bioterrorism and disruption devices (Biological and Chemical weapons).

The personal care products and pharmaceuticals as ECs contain active substances in illicit, prescribed and non-prescribed drugs for human and animal consumption. Active ingredients are also found in disinfectants, biocides, preservatives and personal hygiene and beautification products [18]. PPCPs are classified (**Table 1**) base on the consumer product and their uses [19].

Personal care products	Pharmaceuticals
Fragrances, cosmetics, repellents, food supplements and their metabolites, and transformation products personal hygiene products, sunscreen agents, domestic insect,	Drugs such as cocaine and amphetamines, antiseptics, hormones, illicit analgesics, antibiotics, lipid regulators, steroids, anti-inflammatory drugs, diuretics, non-steroid stimulant drugs, antimicrobials, beta blockers,

Table 1.
Classification of pharmaceuticals and personal care products [16].

Category I: Personal care products compound	
ATII (traseolide)	Boisvelone/Iso-E super
Bayrepel	Butyl methoxydibenzoylmethane
Benzaldehyde, (phenylmethylene)	Cineole
hydrazone (Eusolex)	Damascone
Benzophenone	Decamethylcyclopentasiloxane (D5)
AHDI (phantolide)	Boisvelone/Iso-E super
alpha-Terpineol	Decamethyltetrasiloxane (MD2M)
2,4-Dihydroxybenzophenone	Dihydromethyljasmonate
4-Methylbenzylidene camphor	Dodecamethylcyclohexasiloxane(D6)
4-Oxoisophorone	
Acetylcedrene	Dodecamethylpentasiloxane(MD3M)
ADBI (celestolide)	Drometrizole
Ethylhexyl methoxycinnamate	Drometrizole trisiloxane (INCI)
Galaxolide	Methylsalicylate
g-Methylionone	Musk ambrette
Hexamethyldisiloxane (HM or HMDS)	Musk ketone
Hexylcinnamaldehyde	Musk xylene
Homosalate	Octamethylcyclotetrasiloxane (D4)
Isobornylacetate	Octamethyltrisiloxane (MDM)
Isobutyl paraben	Octocrylene
Methylparaben	Oxybenzone
Methyldihydrojasmonate (methyl 3-oxo-2-pentylcyclopentaneacetate)	Carvone
Methyl-iso-propylcyclohexenone	Propyl paraben
p-t-Bucinal (Lilial)	Tonalide
Category II: Personal care products/biocides compounds	Triclosan
N,*N*-Diethyltoluamide	D-Limonene
Category III: Personal care products/food additive compounds	
2,6-Di-*tert*-butylphenol	Triethylcitrate
Butylated hydroxyanisole	Butylated hydroxytoluene
2-Ethylthioacetic acid ethylester	Dipropyltrisulfide
2-Methylthioacetic acid ethylester	Ethylene brassylate
3-Methylthiopropionic acid	Habanolide
Category I: Pharmaceuticals compounds	
1-Hydroxy ibuprofen	Cyclophosphamide
2-Hydroxy ibuprofen	Desmethylnaproxen (metabolite of naproxene)
17-alpha-Estradiol	Danofloxacin
17-alpha-Ethinylestradiol	Dantrolene
17-beta-Estradiol	Dapsone
1,1,1-Trichloro-2,2-dihydroxyethane (chloral hydrate)	Daunorubicin

Acebutolol	Diethylstilbestrol
Acecarbromal	Difloxacin
Aceclofenac	Diphenhydramine
Acemetacin	Domperidone
Acetaminophen (Paracetamol)	Doxepine
Acetazolamide	Doxorubicin
Acetylsalicylic acid (Aspirin)	Doxycycline (anhydrous)
Acyclovir	Doxycycline (monohydrate)
Albuterol	Dexamethasone
Allobarbital	Diatrizoate
Alclofenac	Diazepam
Albuterol sulfate	Diclofenac
Alprazolam	Dicloxacillin
Amitriptyline	Enoxacin
Ampicillin	Epirubicin
Amoxicillin	Enrofloxacin
Amobarbital	Escitalopram
Anthracene-1,4-dione	Erythromycin
Apramycin	Esomeprazole
Aprobarbital	Estriol
Atenolol	Estrone
Azithromycin	Estrone sulfate
Bezafibrate	Ethosuximide
Baquiloprim	Etofibrate
Betamethasone	Fenofibric acid (metabolite of fenofibrate)
Beta-sitosterol	Fenfluramine
Betaxolol	Fenofibrate
Baclofen	Famotidine
Bisoprolol	Fenoprofen
Bromazepam	Flumequine
Butalbital	Fenoterol
Carbamazepine	Flucloxacillin
Carazolol	Fenoprofen calcium salt dihydrate
Caffeine	Fluorouracil
Cefacetrile	Fluoxetine
Cefapirin	Fluvoxamine
Cefalonium	Furosemide
Cefalexin	Gemfibrozil
Cefazoline	Gentamicin
Cefoperazone	Glibenclamide (glyburide)
Ciprofloxacin	Hexobarbital

Clofibric acid (metabolite of clofibrate)	Hydrocodone
Clarithromycin	Hydrochlorothiazide
Citalopram	Chlortetracycline
Clotrimazole	Chlorobutanol
Clenbuterol	Chloramphenicol
Crotamiton	Ibuprofen
Cloxacillin	Cholesterol
Codeine	Ifosfamide
Category II: Pharmaceutical Compounds	
Iopamidol	Penicillin G
Iminostilbene	Penicillin V
Indomethacin	Pentoxifylline
Iohexol	Pentobarbital
Iomeprol	Paroxetine
Imapramine	Phenazone
Iopromide	Phenylbutazone
Ivermectin	Phenobarbital
Josamycin	Phenytoin
Kanamycin sulfate	Pindolol
Lansoprazole	Prednisolone
Lamotrigine	Pravastatin
Ketoprofen	Pipamperon
Levetiracetam	Primidone
Lidocaine	Propranolol
Lincomycin	Salbutamol
Lorazepam	Ranitidine
Loratadine	Roxithromycin
Lithium carbonate	Propyphenazone
Lovastatin	Sarafloxacin
Marbofloxacin	Sotalol
Meprobamate	Secobarbital sodium
Meclofenamic acid	Sertraline
Medazepam	Streptomycin
Metformin	Secobarbital
Mebeverine	Spectinomycin
Mestranol	Spiramycin
Mefenamic acid	Simvastatin
Minocycline	Sulfamerazine
Methylphenobarbital	Sulfadimethoxin
Metoprolol	Sulfadoxin
Mevastatin	Sulfadiazine

Methicillin	Sulfamethazine
Nandrolone	Sulfamethoxazole
Nafcillin	Sulfapyridine
Nadolol	Tetracycline
Naproxen	Temazepam
N-Methylphenacetine	Terbutaline
Neomycin B	Taloxa
Norfloxacin	Tolfenamic acid
Nordiazepam	Tilmicosin
Novobiocin	Timolol
Ofloxacin	Tiamulin
Oxacillin	Tramadol
Omeprazole	Trimethoprim
Oleandomycin	Tylosin
Oxazepam	Verapamil
Oxytetracycline	Valnemulin
Oxprenolol	Zolpidem

Table 2.
Identified pharmaceuticals and personal care products (NORMAN [16, 20]).

More than 1036 EC and secondary metabolites as well as biotransformation products are identified on NORMAN List in **Table 2** (NORMAN [20]). The most common classes/categories of ECs include; industrial chemicals, disinfection by-products, pesticides, sweeteners endocrine disrupting compounds, nanoparticles, sunscreens, UV filters, pharmaceuticals and personal care products among others [21–23].

3. Potential routes emerging pollutants

Series of anthropogenic activities such as agricultural, domestic and industrial activities leads to the discharged of the pollutants into our environments (**Figure 1**). Water and sediments serve as a sink to these contaminants [25, 26]. Constant consumption of drugs due to less attention given to traditional medicine for the treatment aliments and frequent use of personal care products as vogue has led to the release of different by-products at low concentrations into our environments [27]. The concentration of these pollutants are based on the production processes of some products (drugs) applied in various countries. For example, the concentration of bisphenol A in European water and North American were 43 and 12 ppb correspondingly [28, 29]. Their presence in water has affected the water physicochemical parameter and required urgent attention to drinking issues. Essentially however, many wastewater treatment plant (WWTP) are not considered or designed for the removal of emerging contaminants as shown **Figure 1**. As a result of their hydrophobic nature PPCPs and other EC metabolites as well as associated particular mater settled below water surface when discharged in water. Treated and untreated urban water as well as WWTP (**Figure 1**) are the main sources and path route of EC.

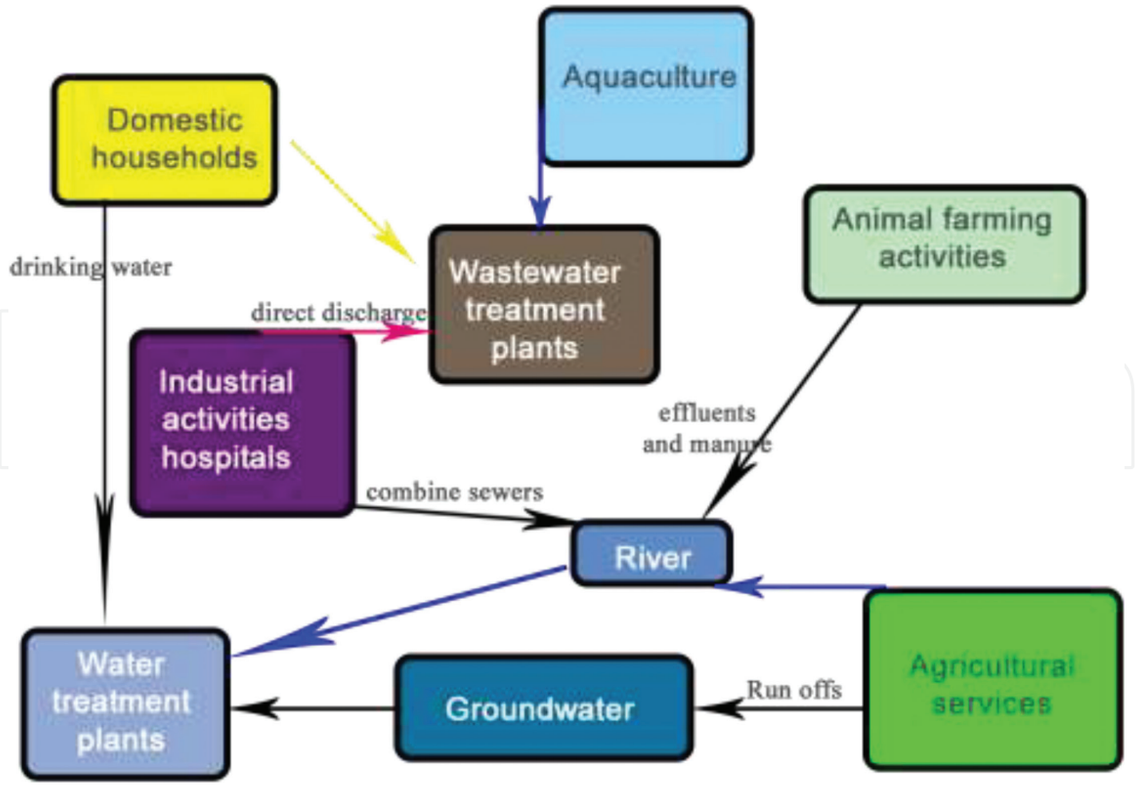

Figure 1.
Potential sources of PPCPs/EDCs in water cycle modified [24].

4. Risk of emerging pollutants

PPCPs are present in our environment at very low concentrations ranging from ng/L to μg/L but there is paucity of information about the various secondary metabolites generated during the biotransformation of parent compounds [16] The impact of the metabolites could be more toxic than the main compounds and their adverse effect on non-target organism is less understood [30]. The longtime exposure to PPCPs pose severe threat to aquatic biota and human life. Also, many studies on environmental toxicology on the exposure of non-target organs to PPCP are results from acute toxicity data [31–33]. Many PPCPs contained bioactive ingredient that could have a chronic effect non-target biota. Goldfish shows bio-centration factor of 113 when it is exposed to high concentration of PPCPs for 14 days [34]. Chronic effect could lead to gene mutation and decline in fish population. For instance, diclofenac may cause ill-effect on fish organs. Fish are susceptible to PPPCPs contaminants since they live in the environment where these contaminants are present [35]. The presence of carbamazepine and diclofenac in aquatic environs damaged algal chloroplasts [36]. Long time exposure to Sulfamethoxazole cause severe toxicity and inhibit photosynthesis process [37]. Also, ciprofloxacin is toxic to green algae [38]. Natural bacteria developed antibiotic tolerance in PPCP antibiotic contaminated environments [39]. Endocrine disrupting chemicals are also referred to as hormones in aquatic or aqueous environments. Some endocrine chemicals reduce the proper functioning of endocrine system (ES) that is physiological activities [40]. For example, retardation in reproductive processes such as sex variation, poor metabolic and embryonic developments [41]. These environmental hormones could cause serious effects on both aquatic and terrestrials animals through inhibition and modification of hormonal growth in ES and hormones in the cell correspondingly [42].

5. Conclusion

Nowadays there is increase in technologies for the production of goods and services as to meet up the demand of dense population, resulting to release of EC in our environs. EC is a serious environmental issue across globe that desires vital consideration. There is need to development new production technique that uses raw materials that are eco-friendly, less toxic metabolites and by-products in our environment in order to prevent the aquatic biota and ecosystem.

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References

[1] Dulio V, van Bavel B, Brorström-Lundén E, Harmsen J, Hollender J, Schlabach M, et al. Emerging pollutants in the EU: 10 years of NORMAN in support of environmental policies and regulations. Environmental Sciences Europe. 2018;*30*(1):1-13 https://doi.org/10.1186/s12302-018-0135-3

[2] Montes-Grajales D, Fennix-Agudelo M, Miranda-Castro W. Occurrence of personal care products as emerging chemicals of concern in water resources: A review. Science of the Total Environment. 2017;**595**:601-614

[3] NORMAN. NORMAN, NORMAN. Available from: https://www.norman-network.net/? In: q 5node/19. 2018

[4] https://www.whitehouse.gov/wp-content/uploads/2018/11/Plan-for-Addressing-Critical-Research-Gaps-Related-to-Emerging-Contaminants-in-Drinking-Water.pdf

[5] Villanueva CM, Kogevinas M, Cordier S, Templeton MR, Vermeulen R, Nuckols JR, et al. Assessing exposure and health consequences of chemicals in drinking water: Current state of knowledge and research needs. Environmental Health Perspectives. 2014;**122**(3):213-221

[6] Boxall ABA. New and emerging water pollutants arising from agriculture environment department, University of York. In: United Kingdom. Meeting the Policy Challenge, which is available at: OECD study Water Quality and Agriculture; 2012 www.oecd.org/agriculture/water

[7] EPA Method 1694, 2007. (Environmental Protection Agency). Pharmaceuticals and personal care products in water, soil, sediment, and biosolids by HPLC/MS/MS, December 2007, EPA-821-R-08-002

[8] Ferrer I, Zweigenbaum JA, Thurman EM. Analysis of 70 Environmental Protection Agency priority pharmaceuticals in water by EPA method 1694. Journal of Chromatography. A. 2010;**1217**(36):5674-5686. DOI: 10.1016/j.chroma.2010.07.002

[9] Glassmeyer ST, Furlong ET, Kolpin DW, Batt AL, Benson R, Boone JS, et al. Nationwide reconnaissance of contaminants of emerging concern in source and treated drinking waters of the United States. Science of the Total Environment. 2017;**581**:909-922

[10] US Department of Health and Human Services, Agency for Toxic Substances and Disease registry (ATSDR) (2015), Draft toxicological profile for Polybrominated diphenyl ethers (PBDEs). Public Health Service, Atlanta, GA.

[11] Yahaya A. Method development for the identification and quantitative analysis of seven nitrosamines using gas chromatography mass spectrometry. Chemical data collection. 2019;**21**:1-12 https://doi.org/10.1016/j.cdc.2019.100231

[12] Yahaya A, Babatunde DE, Olaniya LWB, Agboola O. Application of chromatographic techniques in the analysis of total nitrosamines in water. Heliyon Journal. 2020;**6**:1-8 https://doi.org/10.1016/j.heliyon.2020.e03447

[13] Houtz EF, Higgins CP, Field JA, Sedlak DL. Persistence of perfluoroalkyl acid precursors in AFFF-impacted groundwater and soil. Environmental Science & Technology. 2013;**47**(15):8187-8195

[14] US EPA, 2016. Drinking Water Health Advisory for Perfluorooctane Sulfonate (PFOS). U.S. Environmental

Protection Agency Office of Water (4304T) Health and Ecological Criteria Division Washington, DC. 20460. https://www.epa.gov/sites/production/files/201605/documents/pfos_health_advisory_final_508.pdf

[15] Carmichael WW. The cyanotoxins. In: Advances in Botanical Research. Vol. 27. Academic Press; 1997. pp. 211-256

[16] Dey, S., Bano, F., Malik, A., 2019. Pharmaceuticals and personal care product (PPCP) contamination—a global discharge inventory. In Pharmaceuticals and Personal Care Products: Waste Management and Treatment Technology (pp. 1-26). Butterworth-Heinemann.

[17] Yahaya, A., Sale, F. J., Salehdeen, M.U. 2020b. Analytical Methods for Determination of Regulated and Unregulated Disinfection by-Products in Drinking Water: A ReviewCaJoST, 2020, 1, 25-36

[18] Bu Q et al. Pharmaceuticals and personal care products in the aquatic environment in China: A review. Journal of Hazardous Materials. 2013;**262**:189 211. Available from: https://doi.org/. DOI: 10.1016/j.jhazmat.2013.08.040

[19] Yang, Y., OK, Y.S; Kim, K., Kwon, E.E., Tsang, Y.F. 2017. Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: a review. Sci. Total Environ. 596 597, 303 320. Available from: https://doi.org/10.1016/j.scitotenv.2017.04.102.

[20] Network NORMAN. List of NORMAN emerging substances (mostly frequently discussed). In: Available from: ,https://www.norman-network.net/sites/default/files/files/ Emerging_substances_list_Feb_16/NORMAN list_2016_FINAL.XLSX. 2016

[21] Li, W.C., 2014. Occurrence, sources, and fate of pharmaceuticals in aquatic environment and soil. Environmental Pollution 187, 193 201. Available from: https://doi.org/10.1016/j.envpol.2014.01.015.

[22] Richardson SD, Ternes TA. Water analysis: Emerging contaminants and current issues. Analytical Chemistry. 2014 Available from: https://doi.org/10.1021/ac500508t

[23] Rodriguez-Narvaez, O.M., et al., 2017. Treatment technologies for emerging contaminants in water: A review. Chemical Engineering Journal 323, 361 380. Available from: https://doi.org/10.1016/j. cej.2017.04.106.

[24] Petrovic M, Gonalez S, Barcelo D. Analysis and removal of emerging contaminants in wastewater and drinking water. Trends in Analytical Chemistry. 2003;**22**(10):685-696

[25] Yahaya A, Okoh OO, Adeniji AO. Occurrences of organochlorine pesticides along the course of the Buffalo River in the eastern cape of South Africa and its health implications. International Journal of Environmental Research and Public Health. 2017;**1372**(14):1-16

[26] Yahaya, A., Adegbe, A. A. & Emorutu, J. E. 2012. Assessment of heavy metal content in the surface water of Oke – Afa canal, Isolo- Lagos Nigeria. Scholars Research Library: Archives of Applied Science Research, 4, 6, pp.2322-2326.

[27] Yu C-P, Chu K-H. Occurrence of pharmaceuticals and personal care products along the west prong little Pigeon River in East Tennessee, USA. Chemosphere. 2009;**75**:1281-1286

[28] Klecka GM, Staples CA, Clark KE, Van der Hoeven N, Thomas DE, Hentges SG. Exposure analysis of bisphenol-a in surface water

systems North America and Europe. Environmental Science and Technology. 2009:6145-6150

[29] Rogers JA, Metz L, Wee Yong V. Review: Endocrine disrupting chemicals and immune responses: A focus on bisphenol-a and its potential mechanisms. Molecular Immunology. 2013;**53**:421-430

[30] World Health Organization. WHO Multi-Country Survey Reveals Widespread Public Misunderstanding about Antibiotic Resistance. World Health Organization; 2015

[31] Harrison EZ, Oakes SR, Hysell M, Hay A. Organic chemicals in sewage sludges. Science of the Total Environment. 2006;**367**:481-497

[32] Kimberly, G. J. (2007). Applications of Radiation Chemistry to Understand the fate and Transport of Emerging Pollutants of Concern in Coastal Waters. A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy Marine, Earth, and Atmospheric Sciences, USA.

[33] Tijani JO, Fatoba OO, Petrik LF. A review of pharmaceuticals and endocrine-disrupting compounds: Sources, effects, removal, and detections. Water. Air, & Soil Pollution. 2013;**224**(11):1770

[34] Mimeault C, Woodhouse AJ, Miao XS, Metcalfe CD, Moon TW, Trudeau VL. The human lipid regulator, gemfibrozil bioconcentrates and reduces testosterone in the goldfish, Carassius auratus. Aquatic Toxicology. 2005;*73*(1):44-54 https://doi.org/10.1016/j.aquatox.2005.01.009

[35] Mehinto AC, Hill EM, Tyler CR. Uptake and biological effects of environmen-tally relevant concentrations of the nonsteroidal anti-inflammatory pharmaceutical diclo-fenac in rainbow trout (Oncorhynchus mykiss). Environmental Science & Technology. 2010 Available from: https://doi.org/10.1021/es903702m

[36] Vannini C, Domingo G, Marsoni M, De Mattia F, Labra M, Castiglioni S, et al. Effects of a complex mixture of therapeutic drugs on unicellular algae Pseudokirchneriella subcapitata. Aquatic Toxicology. 2011;**101**(2):459-465 https://doi.org/10.1016/j.aquatox.2010.10.011

[37] Liu BY, Nie XP, Liu WQ, Snoeijs P, Guan C, Tsui MT. Toxic effects of erythromycin, ciprofloxacin and sulfamethoxazole on photosynthetic apparatus in Selenastrum capricornutum. Ecotoxicology and Environmental Safety. 2011;**74**(4):1027-1035 https://doi.org/10.1016/j.ecoenv.2011.01.022

[38] Halling-Sorensen B. Environmental risk assessment of antibiotics: Comparison of mecillinam, trimethoprim and ciprofloxacin. The Journal of Antimicrobial Chemotherapy. 2000 Available from: https://doi.org/10.1093/jac/46.suppl_1.53

[39] Novo, A., André, S., Viana, P., Nunes, O.C. and Manaia, C.M., 2013. Antibiotic resistance, antimicrobial residues and bacterial community composition in urban wastewater. Water Research, 47(5), pp.1875-1887. https://doi.org/10.1016/j.watres.2013.01.010.

[40] Schug TT, Janesick A, Blumberg B, Heindel JJ. Endocrine disrupting chemicals and disease susceptibility. The Journal of Steroid Biochemistry and Molecular Biology. 2011;**127**:204-215

[41] Flint S, Markle T, Thompson S, Wallace E. Bisphenol a exposure, effects, and policy: A wildlife

perspective. Journal of Environmental Management. 2012;**104**:19-34

[42] Olujimi OO, Fatoki OS, Odendaal JP, Okonkwo JO. Endocrine disrupting chemicals (phenol and phthalates) in the south African environment: A need for more monitoring. Review. Water SA. 2010;**36**(5):671-682