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REVIEW

Impact of Emerging Contaminants on Aquatic Ecosystems: A Mini-Review

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ABSTRACT

Emerging contaminants, such as pharmaceuticals, pesticides, microplastics, and per- and polyfluoroalkyl substances (PFAS), pose significant environmental and health risks due to their persistence, bioaccumulative nature, and ecological toxicity. This mini-review examines their major sources, including industrial effluents, urban runoff, and landfill leachate, and highlights their detrimental impacts on aquatic biodiversity and human health. By synthesizing current research, the review emphasizes the urgent need for improved monitoring, regulatory interventions, and innovative mitigation strategies. It provides a concise overview to guide future research and inform policies aimed at safeguarding aquatic ecosystems and public health.

Keywords: Emerging Contaminants; Aquatic Ecosystems; Water Pollution; Water Management

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1. Introduction

Aquatic ecosystems are increasingly threatened by a variety of human-induced stressors, exacerbated by climate change, pollution, and land-use changes [1–3]. While climate-induced shifts in water temperature, acidity, and habitat availability have garnered attention, anthropogenic activities remain the dominant drivers of ecosystem degradation, with industrial discharges, urban expansion, and agricultural practices identified as major contributors [3–5]. Among these, the growing concern over emerging contaminants, substances originating from human activities that disrupt aquatic life, has led to increased scientific inquiry. These contaminants include pharmaceuticals, personal care products, endocrine-disrupting chemicals, pesticides, microplastics, and hormones, each carrying unique threats to aquatic organisms and ecosystems [6–10].

Emerging contaminants are typically persistent in the environment, bioaccumulate in aquatic organisms, and can exert significant ecological and public health risks [11, 12]. While some of these substances are not novel, their harmful impacts, often previously unrecognized, have only recently come to light [13, 14]. As such, they are classified as ”contaminants of emerging concern,” encompassing substances whose environmental and biological effects are still being fully understood [15, 16]. A particularly alarming aspect of these contaminants is their resistance to conventional wastewater treatment methods due to their persistence and varied chemical compositions [1, 17]. Although several advanced removal technologies, such as Advanced Oxidation Processes [18], membrane filtration [19, 20], bioremediation [21], and adsorption [22], have been developed, these approaches still require optimization for wider application and cost-efficiency [1, 23].

Though present in low concentrations (ng/L or µg/L), emerging contaminants can accumulate in aquatic organisms and disrupt food webs, altering animal behavior and destabilizing ecological functions [24–27]. In particular, pharmaceuticals, including antibiotics, contribute significantly to the development and spread of antimicrobial resistance in aquatic environments [28, 29], with even non-antibiotic contaminants creating selective pressures that favor the growth of resistant microorganisms [30, 31]. The persistence of these resistant bacteria in water poses a significant public health threat, as they can lead to hard-to-treat infections via contaminated drinking water [32, 33].

The impact of emerging contaminants extends beyond individual organisms, affecting microbial communities within biofilms in both natural water bodies and drinking water systems. These communities are essential for maintaining ecosystem balance, and the introduction of contaminants such as pesticides and microplastics disrupts their composition and metabolic functions, threatening ecosystem stability [27, 34–37] . Furthermore, the COVID-19 pandemic significantly increased the use of personal protective equipment, disinfectants, and pharmaceuticals, leading to a surge in microplastics and chemical contaminants in the environment, further exacerbating pollution levels [38].

Recent studies [39–41] have underscored the need for updated exposure risk models and more accurate testing methodologies, especially for contaminants in drinking water. These reports indicate that current testing standards may fail to capture long-term ecological effects, highlighting the need for revised guidelines to address the growing threats posed by these substances.

This mini-review focuses on emerging contaminants, emphasizing their distinct impacts on aquatic ecosystems and the urgent need for advanced management strategies. By streamlining wastewater treatment methods, optimizing emerging contaminant removal technologies, and implementing regulatory measures, it is possible to mitigate the effects of these contaminants, safeguarding both ecosystem health and human well-being.

2. Emerging Contaminants: Sources and Effects on Aquatic Ecosystems

Emerging contaminants, illustrated in **Figure 1**, include a wide range of chemical substances that are not routinely monitored but may pose significant risks to ecological and human health. These include pharmaceuticals (e.g., antibiotics and painkillers), personal care products (such as soaps and cosmetics), endocrine disrupting chemicals (which interfere with hormonal systems), pesticides (commonly used in agriculture and urban settings), microplastic particles (originating from the degradation of larger plastics), and per- and polyfluoroalkyl substances (PFAS) (noted for their persistence and industrial use). Their widespread occurrence, persistence, and potential for bioaccumulation make them contaminants of emerging concern.

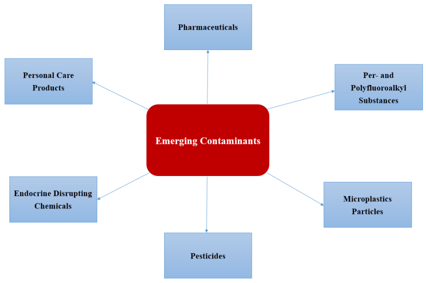

Figure 1. Category of Emerging Contaminants.

2.1. Pharmaceuticals

Pharmaceuticals have become integral to modern healthcare, improving the quality of life and extending life expectancy [42]. However, their pervasive use has led to unintended environmental consequences [43–45]. Residues of these compounds are increasingly being detected in various aquatic environments, raising concerns about their impact on aquatic ecosystems [42, 46]. These substances enter water bodies primarily through human excretion, improper disposal of unused drugs, and effluents from pharmaceutical manufacturing and healthcare facilities (**Figure 2**) [43, 47].

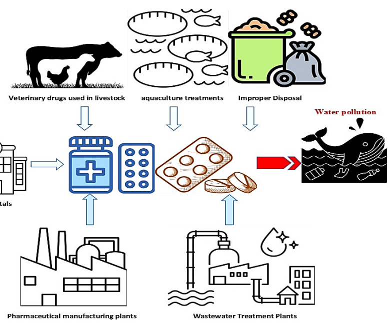

Figure 2. Sources of Pharmaceutical Contaminants in Aquatic Ecosystems.

Pharmaceuticals enter aquatic environments through multiple pathways, including the use of veterinary drugs in livestock, aquaculture treatments, improper disposal of unused medications, and effluents from hospitals and pharmaceutical manufacturing plants. Although wastewater treatment plants are designed to reduce pollutants, many pharmaceutical compounds, such as hormones, antidepressants, and antibiotics, are not effectively removed and persist in treated effluents. As a result, these substances have been widely detected in surface and groundwater across the globe, with elevated concentrations commonly found downstream of pharmaceutical production facilities [48–50]. The inability of conventional treatment systems to adequately eliminate these contaminants leads to their continuous discharge into aquatic ecosystems, posing significant environmental and health risks [51, 52].

Additionally, veterinary drugs used in agriculture and aquaculture often reach water bodies untreated, further contributing to environmental contamination [53–55].

The most detected pharmaceuticals in aquatic organisms are antibiotics, antidepressants, and antihypertensives [56] . Fish are the main focus, followed by bivalves, with less frequent studies on macroalgae and crustaceans [56]. Numerous studies show that antidepressants disrupt various biological processes in fish, impacting gene expression, neurotransmitters, hormones, growth, behavior, and reproduction [57].

Potential effects of pharmaceuticals include cytopathology, endocrine disruption, genotoxicity, mutagenicity, and behavioral changes. Zebrafish are commonly used as a model organism due to their similarities with humans, providing valuable insights into human diseases [58, 59].

2.2. Personal Care Products

Personal care products, including soaps, shampoos, deodorants, and cosmetics, are increasingly recognized as significant environmental contaminants when they enter aquatic systems [60, 61]. These products contain various chemical compounds, such as synthetic fragrances, preservatives, and antimicrobial agents, which can persist in water bodies and potentially harm aquatic organisms [62, 63].

Personal care products have garnered significant attention as emerging contaminants in aquatic environments, largely due to their widespread presence and potential risks to ecosystem health. These substances are frequently detected in water bodies and pose a growing concern for the well-being of aquatic organisms and overall ecosystem stability [64–67].

Additionally, studies indicate that conventional wastewater treatment plants are largely ineffective at completely removing personal care products-related contaminants, allowing these compounds to enter rivers, lakes through treated effluent [68, 69].

Ecotoxicological studies on personal care products and pharmaceuticals use ecological, chemical, physiological, and genetic indicators. Key concerns include disrupted physiology, reproductive harm, increased cancer risk, development of antibiotic-resistant bacteria, and toxicity from combined contaminants[70]. These compounds consistently release active and inactive ingredients into the environment, affecting the air, soil, and water, and posing risks to human health, wildlife, and aquatic ecosystems[71].

2.3. Endocrine Disrupting Chemicals

Endocrine-disrupting chemicals span a diverse group of synthetic and natural compounds that interfere with the body's hormonal system, potentially impacting health and development[72, 73]. Moreover, endocrine-disrupting chemicals pose significant risks to aquatic ecosystems, primarily due to their ability to interfere with hormone regulation in organisms[74, 75].

Endocrine-disrupting chemicals affect aquatic ecosystems significantly by altering hormone systems in fish, amphibians, and invertebrates[76, 77]. These effects include disrupted reproduction, impaired development, and altered behavior, leading to population-level changes[77, 78]. These dangerous compounds often enter aquatic environments through wastewater discharge, agricultural runoff, and industrial effluents, where they persist and bioaccumulate, impacting various trophic levels[79, 80]. These contaminants contribute to widespread environmental contamination, affecting both wildlife and human populations through various exposure pathways: ingestion, inhalation, and skin contact[8, 81, 82]. The following table (**Table 1**) summarizing key types of Endocrine-disrupting chemicals, their sources, and associated health and environmental concerns:

Table 1. Types of Endocrine-Disrupting Chemicals (EDC) and their impact on aquatic ecosystems and human health.

Type of EDC	Primary sources	Health and Environmental concerns	References
Organochlorine Compounds	Pesticides, industrial chemicals	Persistent in environment; bioaccumulate; disrupt reproduction and hormonal systems	[83, 84]
Halogenated Aromatic Hydrocarbons	Combustion processes, industrial waste	Affect reproductive hormones; potential neurodevelopmental toxicity	[85? , 86]
Brominated Flame Retardants	Household products, electronics	Disrupt thyroid function; neurotoxicity, especially in developing organisms	[88–90]
Per- and Polyfluoroalkyl Substances	Non-stick and water-repellent products	Persistent; linked to thyroid dysfunction, developmental and immune effects	[91, 92]
Alkylphenols and Phthalates	Plastics, personal care products	Impact androgen and estrogen receptors; reproductive toxicity	[93–95]
Bisphenol A and Analogues	Plastics, food packaging	Mimic estrogen; linked to developmental and metabolic disorders	[74, 96]
Pharmaceuticals and Personal Care Products	Medications, cosmetics	Affect aquatic life hormonal systems; interfere with reproductive processes	[97–99]
Organotins	Marine paints, PVC stabilizers	Cause obesity, immune dysfunction by affecting nuclear receptors	[100, 101]
Steroid Hormones	Medical therapies, recreational drugs	Contaminate water sources, affecting aquatic life reproduction and development	[102, 103]

2.4. Pesticides

Pesticides are extensively used worldwide on a daily basis, providing substantial benefits by enhancing health, nutrition, and the economy through lower food costs. Their primary applications include crop protection, food preservation, and the control of disease-carrying insects, leading to improved agricultural productivity and public health outcomes[54, 104, 105]. Pesticides encompass a wide range of chemical agents, each designed to target specific types of pests that threaten crops, human health, or structures[106]. These include:

a. Insecticides: Target insects. Examples include organophosphates, carbamates, and pyrethroids.
b. Herbicides: Used to kill or inhibit the growth of unwanted plants (weeds). Glyphosate and atrazine are common herbicides.
c. Fungicides: Control fungal problems like molds and mildew. Examples include chlorothalonil and mancozeb.
d. Rodenticides: Used to kill rodents such as rats and mice. Common examples include anticoagulants like warfarin.
e. Bactericides: Target bacteria. Copper sulfate is a widely used bactericide.
f. Nematicides: Control nematodes (parasitic worms). Fumigants like methyl bromide fall into this category.

While their primary aim is to improve agricultural yield and manage vector-borne diseases, pesticides are increasingly recognized as emerging contaminants due to their persistence, bioaccumulative potential, and widespread ecological impacts, their use also brings about harmful environmental consequences[107, 108]. They often fail to differentiate between target pests and other non-target organisms, posing a significant threat to a wide range of anim al species[109, 110]. The environment has experienced the spread of pesticide residues, leading to significant mortality among various non-human species, including bees, birds, amphibians, fish, and small mammals[5, 110, 111].

Pesticides are increasingly recognized for their significant role in endocrine disruption among aquatic fauna, influencing both individual organisms and entire populations[112, 113]. Moreover, pesticides such as organophosphates and organochlorines have a high lethal impact on aquatic community biota, leading to cascading effects on food webs[104, 114]. Pesticides can drastically reduce populations of primary producers like algae and phytoplankton, which are essential food sources for many aquatic species[115].

2.5. Microplastics Particles

Despite the surge in research on plastic pollution, significant knowledge gaps remain, with a notable bias favoring microplastics studies over macroplastics research. Microplastics, defined as plastic particles smaller than 5 millimeters, are increasingly recognized as a global environmental threat due to their persistence and widespread distribution in terrestrial and aquatic systems. Originating from various sources, including the breakdown of larger plastic debris and direct release from products like cosmetics and textiles, these particles can persist in the environment for decades (**Figure 3**)[116–118].

Figure 3. Sources of Microplastic Pollution.

Their small size allows them to be easily ingested by a wide range of organisms, from plankton to marine mammals, leading to physical and chemical harm[119].

In aquatic environments, microplastics can act as vectors for pollutants, adsorbing toxic chemicals like heavy metals, inorganic contaminants and persistent organic pollutants onto their surfaces[120, 121].

The ecological impact of microplastics includes reduced feeding efficiency, altered reproductive success, and impaired growth in affected organisms, indicating a pressing need for comprehensive research and mitigation strategies to address this pervasive contaminant[71, 122].

Microplastics migrate, transform, and disperse widely through wind, runoff, and currents, spreading across ecosystems. They undergo physical, chemical, and biological changes, such as fragmentation and contaminant adsorption, altering their properties and interactions. These particles can serve as surfaces for the attachment of biofouling organisms, much like natural surfaces (rocks, ship hulls, etc.). Microplastics are often covered by biofilms made up of microorganisms, including bacteria, algae, and other small organisms. This biofouling can increase the size and weight of microplastics, affecting their buoyancy and behavior in the water. The biofouling of microplastics complicates efforts to assess and mitigate the risks associated with microplastic pollution[123–125].

2.6. Per- and Polyfluoroalkyl Substances

Per- and polyfluoroalkyl substances are a group of synthetic chemicals increasingly identified as emerging contaminants due to their widespread use, persistence, and toxicity[126, 127]. However, their strong carbon-fluorine bonds make them highly resistant to degradation, allowing them to persist in the environment for years[128]. The most well-known sources of per- and polyfluoroalkyl substances include: non-stick cookware, waterproof fabrics, and firefighting foams[129]. Per- and polyfluoroalkyl substances can reach aquatic ecosystems through several pathways (**Table 2**).

In aquatic ecosystems, per- and polyfluoroalkyl substances accumulate in water bodies, sediments, and biota, posing significant ecological risks[130, 131]. These substances can disrupt endocrine functions, impair reproduction, and alter growth in aquatic organisms such as fish, amphibians, and invertebrates[72, 77]. Furthermore, per- and polyfluoroalkyl substances can biomagnify through the food chain, leading to higher concentrations in top predators and potential exposure risks for humans [132, 133]. The vast number of per- and polyfluoroalkyl Substances chemicals on the global market means many remain unassessed and under-regulated, creating large data gap [92].

Table 2. Major pathways of per- and polyfluoroalkyl substances contamination in aquatic ecosystems.

Pathway	**Description**
Industrial Discharge	Wastewater from factories using Per- and Polyfluoroalkyl Substances is released into nearby rivers and lakes [130].
Urban Runoff	Rainwater washes Per- and Polyfluoroalkyl Substances-containing products from surfaces into storm drains leading to water bodies [134].
Firefighting Foam Use	Runoff from firefighting foam applications carries these contaminant compounds into local water systems during training or emergencies [135].
Landfill Leachate	Landfills are common disposal sites for waste materials, including products containing Per- and Polyfluoroalkyl Substances. These contaminants from waste products leach into groundwater and surface water through rainwater filtration [136, 137].
Atmospheric Deposition	Per- and Polyfluoroalkyl particles travel via air and deposit into aquatic systems through rain or snow [138].
Agricultural Runoff	Runoff from fields treated with Per- and Polyfluoroalkyl Substances-containing biosolids transports chemicals to water bodies [139].

3. Mechanisms of Impact on Aquatic Ecosystems: Bioaccumulation and Biomagnification

Bioaccumulation occurs when chemicals accumulate in organisms through various environmental exposure routes, while biomagnification refers to the increasing concentration of toxic substances as they move up the food chain. As predators consume prey contaminated with pollutants like heavy metals or persistent organic pollutants, these substances accumulate in the predators' tissues, leading to higher toxin concentrations in top predators compared to organisms at lower trophic levels [140, 141].

Understanding bioaccumulation and biomagnification mechanisms is essential for assessing how contaminants impact aquatic ecosystems [142, 143]. The extent of bioaccumulation is influenced by several factors, including the chemical proper ties of contaminants, the dietary patterns of aquatic organisms, and environmental conditions [144–146]. For example, many fish species exhibit high bioaccumulation levels due to their ability to ingest or absorb contaminants from their environment [147, 148]. On the other hand, biomagnification describes the gradual increase in contaminant concentration as they ascend the food web [145].

Future research on bioaccumulation and biomagnification of emerging contaminants must consider top predators and obtain comprehensive data on the distribution of these contaminants across the entire aquatic ecosystem, including water, sediment, and biota. It is expected that predator species will exhibit greater bioconcentration of these substances than herbivores, especially when biomagnification is at play [149, 150].

The bioaccumulation of pharmaceuticals, particularly antibiotics, in aquatic organisms has far-reaching consequences. Residual antibiotics in water bodies **select for resistant bacterial strains**, promoting the spread of antibiotic-resistant genes (ARGs) through horizontal gene transfer [30, 31]. For example, fluoroquinolones and β-lactams detected in fish tissues correlate with elevated ARG levels in gut microbiomes, posing risks to humans who consume contaminated seafood [29?]. Alarmingly, ARGs can biomagnify: resistant bacteria ingested by plankton transfer resistance traits to predators, amplifying resistance up the food web [32, 149]. This creates **ecological traps** where top predators, including commercially important fish species, become reservoirs for multidrug-resistant pathogens [33].

4. Policy and Management Measures for Emerging Contaminants

Effective management of emerging contaminants is vital to prevent their persistence in the environment, bioaccumulation, and toxic effects on aquatic life and human health. Conventional treatments often fail to eliminate these contaminants [151]. Addressing this issue requires advanced detection, regulatory measures, and innovative remediation methods to protect water quality and ecosystem health. This part highlights key policy measures essential for managing emerging contaminants effectively (**Table 3**).

Table 3. Strategic policy and management initiatives for emerging contaminants.

Key Policy	Method
Lifecycle Approach to Pollution Prevention	To mitigate the accumulation of emerging contaminants in water sources, policies must address every stage of a product's lifecycle. This includes minimizing the release of contaminants at the source by improving industrial processes and enhancing wastewater treatment systems. Additionally, stricter controls should be implemented on chemicals that persist in the environment, to limit their accumulation and environmental impact [58, 152].
Promoting Circular Economy Innovations	Adopting a circular economy model involves designing products for durability, reuse, and recycling, which reduces waste and maximizes resource efficiency. By reprocessing waste materials into new products, this approach minimizes environmental impact and fosters a sustainable, closed-loop system [153, 154].
Role of Government in Supporting Research	Governments have a pivotal role in encouraging research and development aimed at converting byproducts into useful materials, as well as redesigning processes to minimize pollutants that cannot be reused [155].
Comprehensive Monitoring Programs	Establish comprehensive monitoring systems to regularly detect and track emerging contaminant levels across various water bodies. Additionally, perform ongoing assessments to identify new pollutants and evaluate their potential environmental impact [26].
Using Advanced Treatment Methods	To effectively remove emerging contaminants from polluted water, employ modern remediation techniques such as adsorption, advanced oxidation processes, and membrane bioreactors. Integrating multiple treatment methods significantly improves the efficiency of contaminant removal, providing a more thorough purification process and effectively minimizing the environmental risks posed by these persistent pollutants [107, 156, 157].
Raising Public Awareness	Raise public awareness about the risks of emerging contaminants and promote the responsible use of pharmaceuticals and personal care products. Educate both industries and consumers on proper disposal practices to prevent contaminants from entering water systems, helping to reduce pollution and protect aquatic environments [153].

The strategic measures outlined in **Table 3** represent a multi-tiered framework essential for addressing the complexity of emerging contaminants (ECs) in aquatic environments. A lifecycle approach ensures upstream control by integrating pollution prevention into product design and industrial processes, reducing the burden on downstream treatment infrastructure [158]. Meanwhile, circular economy principles complement this by transforming waste into a resource, thereby limiting the release of persistent chemicals into water systems [159]. Governmental support in funding research and scaling innovations is vital for bridging laboratory successes with real-world applications, especially in resource-limited regions. Furthermore, the establishment of comprehensive monitoring networks enables timely detection of ECs and helps prioritize regulatory interventions based on ecological and public health risk. Advanced treatment technologies, while effective, must be implemented strategically due to their operational costs and energy demands [160, 161]. Finally, public engagement plays a pivotal role, as consumer behavior directly affects the prevalence of contaminants like pharmaceuticals and personal care products in domestic wastewater. Together, these integrated approaches not only enhance contaminant management but also reinforce the need for collaborative governance among policymakers, scientists, industries, and communities to protect aquatic ecosystems and ensure water safety.

5. Conclusions and Recommendations

Emerging contaminants such as pharmaceuticals, microplastics, PFAS, and endocrine disruptors pose significant risks to aquatic ecosystems through persistent pollution and bioaccumulation. Despite growing awareness, limitations in monitoring methods, toxicological data, and regulatory frameworks hinder effective management. These pollutants threaten biodiversity, ecosystem services, and human health.

To address these challenges, interdisciplinary efforts are needed. Innovations in green chemistry, bioremediation, and real-time monitoring must be paired with stricter policies and public engagement. Future research should focus on long-term impacts, standardized detection methods, and the interplay between contaminants and climate stressors. A coordinated global approach is essential to protect water resources and ensure ecological resilience.

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Conceptualization, E.A., A.E., and A.N.; methodology, E.A., A.E., A.N., and A.A.B.; software, E.A., A.E., and A.N.; validation, E.A., A.E., A.N., and A.A.B.; formal analysis, E.A., A.A.B.; investigation, E.A.; resources, E.A., A.E., and A.N.; data curation, E.A.; writing—original draft preparation, E.A.; writing—review and editing, E.A., A.E., A.N., and A.A.B.; visualization, E.A., A.A.B.; supervision, E.A., A.A.B.; project administration, E.A., A.A.B. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Mukherjee, S., Rizvi, S.S., Biswas, G., et al., 2023. Aquatic Eco-systems under Influence of Climate Change and Anthropogenic Activities: Potential Threats and Its Mitigation Strategies. Hydrogeochemistry of Aquatic Ecosystems. 307–331.

[2] Shukla, N., Gupta, S., Rai, S., 2023. Potential impacts of climatic changes and human activity on water quality. In Environmental Processes and Management: Tools and Practices for Groundwater. Cham: Springer International Publishing. 103–111.

[3] Akhtar, N., Syakir Ishak, M.I., Bhawani, S.A., et al., 2021. Various natural and anthropogenic factors responsible for water quality degradation: A review. Water. 13(19), 2660. DOI: https://doi.org/10.3390/w13192660

[4] Mishra, R.K., 2023. Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies. 4(3), 1–78.

[5] Muruganandam, M., Rajamanickam, S., Sivarethinamohan, S., et al., 2023. Impact of climate change and anthropogenic activities on aquatic ecosystem–A review. Environmental Research. 238, 117233. DOI: https://doi.org/10.1016/j.envres.2023.117233

[6] Kye, H., Kim, J., Ju, S., et al., 2023. Microplastics in water systems: A review of their impacts on the environment and their potential hazards. Heliyon. 9(3). DOI: https://doi.org/10.1016/j.heliyon.2023.e14359

[7] Chaturvedi, P., Shukla, P., Giri, B.S., et al., 2021. Prevalence and hazardous impact of pharmaceutical and personal care products and antibiotics in environment: A review on emerging contaminants. Environmental Research. 194, 110664. DOI: https://doi.org/10.1016/j.envres.2020.110664

[8] Pironti, C., Ricciardi, M., Proto, A., et al., 2021. Endocrine-disrupting compounds: An overview on their occurrence in the aquatic environment and human exposure. Water. 13(10), 1347. DOI: https://doi.org/10.3390/w13101347

[9] Syafrudin, M., Kristanti, R.A., Yuniarto, A., et al., 2021. Pesticides in drinking water—a review. International Journal of Environmental Research and Public Health. 18(2), 468. DOI: https://doi.org/10.3390/ijerph18020468

[10] Sacdal, R., Madriaga, J., Espino, M.P., 2020. Overview of the analysis, occurrence and ecological effects of hormones in lake waters in Asia. Environmental Research. 182, 109091. DOI: https://doi.org/10.1016/j.envres.2019.109091

[11] Noorani, K.R.P.M., Flora, G., Surendarnath, S., et al., 2024. Recent advances in remediation strategies for mitigating the impacts of emerging pollutants in water and ensuring environmental sustainability. Journal of Environmental Management. 351, 119674. DOI: https://doi.org/10.1016/j.jenvman.2023.119674

[12] Egbuna, C., Amadi, C.N., Patrick-Iwuanyanwu, K.C., et al., 2021. Emerging pollutants in Nigeria: A systematic review. Environmental Toxicology and Pharmacology. 85, 103638. DOI: https://doi.org/10.1016/j.etap.2021.103638

[13] Okom, S.U., Eze, E.M., Etaware, P.M., et al., 2024. Economic Management and Challenges Faced in the Management of

[14] Geissen, V., Mol, H., Klumpp, E., et al., 2015. Emerging pollutants in the environment: a challenge for water resource management. International Soil and Water Conservation Research. 3(1), 57–65. DOI: https://doi.org/10.1016/j.iswcr.2015.03.002

[15] Arman, N.Z., Salmiati, S., Aris, A., et al., 2021. A review on emerging pollutants in the water environment: Existences, health effects and treatment processes. Water. 13(22), 3258. DOI: https://doi.org/10.3390/w13223258

[16] Vasilachi, I.C., Asiminicesei, D.M., Fertu, D.I., et al., 2021. Occurrence and fate of emerging pollutants in water environment and options for their removal. Water. 13(2), 181. DOI: https://doi.org/10.3390/w13020181

[17] Rout, P.R., Zhang, T.C., Bhunia, P., et al., 2021. Treatment technologies for emerging contaminants in wastewater treatment plants: A review. Science of the Total Environment. 753, 141990. DOI: https://doi.org/10.1016/j.scitotenv.2020.141990

[18] Giwa, A., Yusuf, A., Balogun, H.A., et al., 2021. Recent advances in advanced oxidation processes for removal of contaminants from water: A comprehensive review. Process Safety and Environmental Protection. 146, 220–256. DOI: https://doi.org/10.1016/j.psep.2020.11.006

[19] Cevallos-Mendoza, J., Amorim, C.G., Rodríguez-Díaz, J.M., et al., 2022. Removal of contaminants from water by membrane filtration: a review. Membranes. 12(6), 570. DOI: https://doi.org/10.3390/membranes12060570

[20] Kim, S., Chu, K.H., Al-Hamadani, Y.A., et al., 2018. Removal of contaminants of emerging concern by membranes in water and wastewater: a review. Chemical Engineering Journal. 335, 896–914. DOI: https://doi.org/10.1016/j.cej.2017.11.044

[21] Rempel, A., Gutkoski, J.P., Nazari, M.T., et al., 2021. Current advances in microalgae-based bioremediation and other technologies for emerging contaminants treatment. Science of the Total Environment. 772, 144918. DOI: https://doi.org/10.1016/j.scitotenv.2020.144918

[22] Cheng, N., Wang, B., Wu, P., et al., 2021. Adsorption of emerging contaminants from water and wastewater by modified biochar: A review. Environmental Pollution. 273, 116448. DOI: https://doi.org/10.1016/j.envpol.2021.116448

[23] Kahkeci, J., El-Din, M.G., 2023. Biochar-supported photocatalysts: Performance optimization and applications in emerging contaminant removal from wastewater. Chemical Engineering Journal. 146530. DOI: https://doi.org/10.1016/j.cej.2023.146530

[24] Starling, M.C.V., Amorim, C.C., Leão, M.M.D., 2019. Occurrence, control and fate of contaminants of emerging concern in environmental compartments in Brazil. Journal of Hazardous Materials. 372, 17–36. DOI: https://doi.org/10.1016/j.jhazmat.2018.04.043

[25] Sridharan, S., Kumar, M., Bolan, N.S., et al., 2021. Are microplastics destabilizing the global network of terrestrial and aquatic ecosystem services?. Environmental Research. 198, 111243. DOI: https://doi.org/10.1016/j.envres.2021.111243

[26] Yadav, D., Rangabhashiyam, S., Verma, P., et al., 2021. Environmental and health impacts of contaminants of emerging concerns: Recent treatment challenges and approaches. Chemosphere. 272, 129492. DOI: https://doi.org/10.1016/j.chemosphere.2020.129492

[27] Gomes, I.B., Maillard, J.Y., Simões, L.C., et al., 2020. Emerging contaminants affect the microbiome of water systems—strategies for their mitigation. NPJ Clean Water. 3(1), 39. DOI: https://doi.org/10.1038/s41545-020-00086-w

[28] Felis, E., Kalka, J., Sochacki, A., et al., 2020. Antimicrobial pharmaceuticals in the aquatic environment-occurrence and environmental implications. European Journal of Pharmacology. 866, 172813. DOI: https://doi.org/10.1016/j.ejphar.2019.172813

[29] Hanna, N., Tamhankar, A.J., Lundborg, C.S., 2023. Antibiotic concentrations and antibiotic resistance in aquatic environments of the WHO Western Pacific and South-East Asia regions: a systematic review and probabilistic environmental hazard assessment. The Lancet Planetary Health. 7(1), e45–e54. DOI: https://doi.org/10.1016/S2542-5196(22)00254-6

[30] Sun, S., Shen, J., Li, D., et al., 2022. A new insight into the ARG association with antibiotics and non-antibiotic agents—antibiotic resistance and toxicity. Environmental Pollution. 293, 118524. DOI: https://doi.org/10.1016/j.envpol.2021.118524

[31] Jiang, Q., Feng, M., Ye, C., et al., 2022. Effects and relevant mechanisms of non-antibiotic factors on the horizontal transfer of antibiotic resistance genes in water environments: A review. Science of the Total Environment. 806, 150568. DOI: https://doi.org/10.1016/j.scitotenv.2021.150568

[32] Duarte, A.C., Rodrigues, S., Afonso, A., et al., 2022. Antibiotic resistance in the drinking water: old and new strategies to remove antibiotics, resistant bacteria, and resistance genes. Pharmaceuticals. 15(4), 393. DOI: https://doi.org/10.3390/ph15040393

[33] Voigt, A.M., Ciorba, P., Döhla, M., et al., 2020. The investigation of antibiotic residues, antibiotic resistance genes and antibiotic-resistant organisms in a drinking water reservoir system in Germany. International Journal of Hygiene and Environmental Health. 224, 113449. DOI: https://doi.org/10.1016/j.ijheh.2019.113449

[34] Li, W., Chen, X., Li, M., et al., 2022. Microplastics as an aquatic pollutant affect gut microbiota within aquatic animals. Journal of Hazardous Materials. 423, 127094. DOI: https://doi.org/10.1016/j.jhazmat.2021.127094

[35] Visca, A., Barra Caracciolo, A., Grenni, P., et al., 2021. Legacy and emerging pollutants in an urban river stretch and effects on the bacterioplankton community. Water. 13(23), 3402. DOI: https://doi.org/10.3390/w13233402

[36] Pereira, A.R., Simões, M., Gomes, I.B., 2023. Parabens as environmental contaminants of aquatic systems affecting water quality and microbial dynamics. Science of the Total Environment. 905, 167332. DOI: https://doi.org/10.1016/j.scitotenv.2023.167332

[37] Samuel, P.O., Edo, G.I., Oloni, G.O., et al., 2023. Effects of chemical contaminants on the ecology and

evolution of organisms a review. Chemistry and Ecology. 39(10), 1071–1107. DOI: https://doi.org/10.1080/02757540.2023.2250424
[38] Picó, Y., Barceló, D., 2023. Microplastics and other emerging contaminants in the environment after COVID-19 pandemic: The need of global reconnaissance studies. Current Opinion in Environmental Science & Health. 33, 100468. DOI: https://doi.org/10.1016/j.coesh.2023.100468
[39] Levin, R., Villanueva, C.M., Beene, D., et al., 2024. US drinking water quality: exposure risk profiles for seven legacy and emerging contaminants. Journal of Exposure Science & Environmental Epidemiology. 34(1), 3–22. DOI: https://doi.org/10.1038/s41370-023-00597-z
[40] Luo, Y., Jin, X., Zhao, J., et al., 2024. Ecological implications and drivers of emerging contaminants in Dongting Lake of Yangtze River Basin, China: A multi-substance risk analysis. Journal of Hazardous Materials. 472, 134519. DOI: https://doi.org/10.1016/j.jhazmat.2024.134519
[41] Shah, A., Manning, G., Zakharova, J., et al., 2024. Particle size effect of Moringa oleifera Lam. seeds on the turbidity removal and antibacterial activity for drinking water treatment. Environmental Chemistry and Ecotoxicology. 6, 370–379. DOI: https://doi.org/10.1016/j.enceco.2024.03.002
[42] OECD., 2019. Pharmaceutical residues in freshwater: Hazards and policy responses. OECD Studies on Water, OECD Publishing, Paris 2019, 1–20. DOI: https://doi.org/10.1787/c936f42d-en
[43] Caban, M., Stepnowski, P., 2021. How to decrease pharmaceuticals in the environment? A review. Environmental Chemistry Letters. 19, 3115–3138. DOI: https://doi.org/10.1007/s10311-021-01194-y
[44] Polianciuc, S.I., Gurzău, A.E., Kiss, B., et al., 2020. Antibiotics in the environment: causes and consequences. Medicine and Pharmacy Reports. 93(3), 231. DOI: https://doi.org/10.15386/mpr-1742
[45] Bilal, M., Mehmood, S., Rasheed, T., et al., 2020. Antibiotics traces in the aquatic environment: persistence and adverse environmental impact. Current Opinion in Environmental Science & Health. 13, 68–74. DOI: https://doi.org/10.1016/j.coesh.2019.11.005
[46] Kayode-Afolayan, S.D., Ahuekwe, E.F., Nwinyi, O.C., 2022. Impacts of pharmaceutical effluents on aquatic ecosystems. Scientific African. 17, e01288. DOI: https://doi.org/10.1016/j.sciaf.2022.e01288
[47] Bavumiragira, J.P., Yin, H., 2022. Fate and transport of pharmaceuticals in water systems: A processes review. Science of the Total Environment. 823, 153635. DOI: https://doi.org/10.1016/j.scitotenv.2022.153635
[48] Almazrouei, B., Islayem, D., Alskafi, F., et al., 2023. Steroid hormones in wastewater: Sources, treatments, environmental risks, and regulations. Emerging Contaminants. 9(2), 100210. DOI: https://doi.org/10.1016/j.emcon.2023.100210
[49] Jia, W.L., Song, C., He, L.Y., et al., 2023. Antibiotics in soil and water: Occurrence, fate, and risk. Current Opinion in Environmental Science & Health. 32, 100437. DOI: https://doi.org/10.1016/j.coesh.2023.100437
[50] Sahay, P., Mohite, D., Arya, S., et al., 2023. Removal of the emergent pollutants (hormones and antibiotics) from wastewater using different kinds of biosorbent—a review. Emergent Materials. 6(2), 373–404. DOI: https://doi.org/10.1007/s42247-022-00450-3
[51] Sanusi, I.O., Olutona, G.O., Wawata, I.G., et al., 2023. Occurrence, environmental impact and fate of pharmaceuticals in groundwater and surface water: a critical review. Environmental Science and Pollution Research. 30(39), 90595–90614. DOI: https://doi.org/10.1007/s11356-023-28802-4
[52] Gworek, B., Kijeńska, M., Zaborowska, M., et al., 2019. Pharmaceuticals in aquatic environment. Fate and behaviour, ecotoxicology and risk assessment–a review. Acta Poloniae Pharmaceutica-Drug Research. 76(3), 397–407. DOI: https://doi.org/10.32383/appdr/103427
[53] Kim, K., Choi, Y., Mok, S., et al., 2023. Optimization of the QuEChERS method for multi-residue analysis of pharmaceuticals and pesticides in aquaculture products. Food Chemistry. 399, 133958. DOI: https://doi.org/10.1016/j.foodchem.2022.133958
[54] Gržinić, G., Piotrowicz-Cieślak, A., Klimkowicz-Pawlas, A., et al., 2023. Intensive poultry farming: A review of the impact on the environment and human health. Science of the Total Environment. 858, 160014. DOI: https://doi.org/10.1016/j.scitotenv.2022.160014
[55] Albou, E.M., Abdellaoui, M., Abdaoui, A., et al., 2024. Agricultural Practices and their Impact on Aquatic Ecosystems–A Mini-Review. Ecological Engineering & Environmental Technology (EEET). 25(1), 321–331. DOI: https://doi.org/10.12912/27197050/176684
[56] Świacka, K., Maculewicz, J., Kowalska, D., et al., 2022. Presence of pharmaceuticals and their metabolites in wild-living aquatic organisms–current state of knowledge. Journal of Hazardous Materials. 424, 127350. DOI: https://doi.org/10.1016/j.jhazmat.2021.127350
[57] Moreira, D.G., Aires, A., de Lourdes Pereira, M., et al., 2022. Levels and effects of antidepressant drugs to aquatic organisms. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 256, 109322. DOI: https://doi.org/10.1016/j.cbpc.2022.109322
[58] Rebelo, D., Antunes, S.C., Rodrigues, S., 2023. The

Silent Threat: Exploring the Ecological and Ecotoxicological Impacts of Chlorinated Aniline Derivatives and the Metabolites on the Aquatic Ecosystem. Journal of Xenobiotics. 13(4), 604–614. DOI: https://doi.org/10.3390/jox13040038

[59] Porretti, M., Arrigo, F., Di Bella, G., et al., 2022. Impact of pharmaceutical products on zebrafish: An effective tool to assess aquatic pollution. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 261, 109439. DOI: https://doi.org/10.1016/j.cbpc.2022.109439

[60] Islam, J.M., Akter, T., Mokbul, M., et al., 2022. Textiles in cosmetics and personal care. In Medical Textiles from Natural Resources. Woodhead Publishing. 457–497. DOI: https://doi.org/10.1016/B978-0-323-90477-3.00022-5

[61] Bilal, M., Mehmood, S., Iqbal, H.M., et al., 2020. The beast of beauty: environmental and health concerns of toxic components in cosmetics. Cosmetics. 7(1), 13. DOI: https://doi.org/10.3390/cosmetics7010013

[62] Martín-Pozo, L., del Carmen Gómez-Regalado, M., Moscoso-Ruiz, I., et al., 2021. Analytical methods for the determination of endocrine disrupting chemicals in cosmetics and personal care products: A review. Talanta. 234, 122642. DOI: https://doi.org/10.1016/j.talanta.2021.122642

[63] Srinivasulu, M., 2022. Personal care products—fragrances, cosmetics, and sunscreens—in the environment. Environmental Micropollutants. Elsevier. 131–149. DOI: https://doi.org/10.1016/B978-0-323-90555-8.00007-5

[64] Chen, Y., Li, M., Gao, W., et al., 2024. Occurrence and risks of pharmaceuticals, personal care products, and endocrine-disrupting compounds in Chinese surface waters. Journal of Environmental Sciences. 146, 251–263. DOI: https://doi.org/10.1016/j.jes.2023.05.020

[65] Su, C., Cui, Y., Liu, D., et al., 2020. Endocrine disrupting compounds, pharmaceuticals and personal care products in the aquatic environment of China: which chemicals are the prioritized ones. Science of the Total Environment. 720, 137652. DOI: https://doi.org/10.1016/j.scitotenv.2020.137652

[66] Xiang, Y., Wu, H., Li, L., et al., 2021. A review of distribution and risk of pharmaceuticals and personal care products in the aquatic environment in China. Ecotoxicology and Environmental Safety. 213, 112044. DOI: https://doi.org/10.1016/j.ecoenv.2021.112044

[67] Yu, X., Sui, Q., Lyu, S., et al., 2020. Municipal solid waste landfills: An underestimated source of pharmaceutical and personal care products in the water environment. Environmental Science & Technology. 54(16), 9757–9768. DOI: https://doi.org/10.1021/acs.est.0c00565

[68] Loganathan, P., Vigneswaran, S., Kandasamy, J., et al., 2023. Treatment trends and combined methods in removing pharmaceuticals and personal care products from wastewater—a review. Membranes. 13(2), 158. DOI: https://doi.org/10.3390/membranes13020158

[69] Liu, T., Aniagor, C.O., Ejimofor, M.I., et al., 2023. Technologies for removing pharmaceuticals and personal care products (PPCPs) from aqueous solutions: Recent advances, performances, challenges and recommendations for improvements. Journal of Molecular Liquids. 374, 121144. DOI: https://doi.org/10.1016/j.molliq.2023.121144

[70] Wang, H., Xi, H., Xu, L., et al., 2021. Ecotoxicological effects, environmental fate and risks of pharmaceutical and personal care products in the water environment: a review. Science of the Total Environment. 788, 147819. DOI: https://doi.org/10.1016/j.scitotenv.2021.147819

[71] Khalid, N., Aqeel, M., Noman, A., et al., 2021. Linking effects of microplastics to ecological impacts in marine environments. Chemosphere. 264, 128541. DOI: https://doi.org/10.1016/j.chemosphere.2020.128541

[72] Metcalfe, C.D., Bayen, S., Desrosiers, M., et al., 2022. An introduction to the sources, fate, occurrence and effects of endocrine disrupting chemicals released into the environment. Environmental Research. 207, 112658. DOI: https://doi.org/10.1016/j.envres.2021.112658

[73] Vieira, W.T., de Farias, M.B., Spaolonzi, M.P., et al., 2021. Endocrine-disrupting compounds: Occurrence, detection methods, effects and promising treatment pathways—A critical review. Journal of Environmental Chemical Engineering. 9(1), 104558. DOI: https://doi.org/10.1016/j.jece.2020.104558

[74] Czarny-Krzymińska, K., Krawczyk, B., Szczukocki, D., 2023. Bisphenol A and its substitutes in the aquatic environment: Occurrence and toxicity assessment. Chemosphere. 315, 137763. DOI: https://doi.org/10.1016/j.chemosphere.2022.137763

[75] Cuvillier-Hot, V., Lenoir, A., 2020. Invertebrates facing environmental contamination by endocrine disruptors: Novel evidences and recent insights. Molecular and Cellular Endocrinology. 504, 110712. DOI: https://doi.org/10.1016/j.mce.2019.110712

[76] Chen, Y., Yang, J., Yao, B., et al., 2022. Endocrine disrupting chemicals in the environment: Environmental sources, biological effects, remediation techniques, and perspective. Environmental Pollution. 310, 119918. DOI: https://doi.org/10.1016/j.envpol.2022.119918

[77] Gonsioroski, A., Mourikes, V.E., Flaws, J.A., 2020. Endocrine disruptors in water and their effects on the reproductive system. International Journal of Molecular Sciences. 21(6), 1929. DOI: https://doi.org/10.

3390/ijms21061929

[78] Celino-Brady, F.T., Lerner, D.T., Seale, A.P., 2021. Experimental approaches for characterizing the endocrine-disrupting effects of environmental chemicals in fish. Frontiers in Endocrinology. 11, 619361. DOI: https://doi.org/10.3389/fendo.2020.619361

[79] Xiao, Y., Han, D., Currell, M., et al., 2023. Review of Endocrine Disrupting Compounds (EDCs) in China's water environments: Implications for environmental fate, transport and health risks. Water Research. 120645. DOI: https://doi.org/10.1016/j.watres.2023.120645

[80] Kasonga, T.K., Coetzee, M.A., Kamika, I., et al., 2021. Endocrine-disruptive chemicals as contaminants of emerging concern in wastewater and surface water: A review. Journal of Environmental Management. 277, 111485. DOI: https://doi.org/10.1016/j.jenvman.2020.111485

[81] Sangeetha, S., Vimalkumar, K., Loganathan, B.G., 2021. Environmental contamination and human exposure to select endocrine-disrupting chemicals: A review. Sustainable Chemistry. 2(2), 343–380. DOI: https://doi.org/10.3390/suschem2020019

[82] Plunk, E.C., Richards, S.M., 2020. Endocrine-disrupting air pollutants and their effects on the hypothalamus-pituitary-gonadal axis. International Journal of Molecular Sciences. 21(23), 9191. DOI: https://doi.org/10.3390/ijms21239191

[83] Burgos-Aceves, M.A., Migliaccio, V., Di Gregorio, I., et al., 2021. 1, 1, 1-trichloro-2, 2-bis (p-chlorophenyl)-ethane (DDT) and 1, 1-Dichloro-2, 2-bis (p, p'-chlorophenyl) ethylene (DDE) as endocrine disruptors in human and wildlife: A possible implication of mitochondria. Environmental Toxicology and Pharmacology. 87, 103684. DOI: https://doi.org/10.1016/j.etap.2021.103684

[84] Martyniuk, C.J., Mehinto, A.C., Denslow, N.D., 2020. Organochlorine pesticides: Agrochemicals with potent endocrine-disrupting properties in fish. Molecular and Cellular Endocrinology. 507, 110764. DOI: https://doi.org/10.1016/j.mce.2020.110764

[85] Xie, J., Tao, L., Wu, Q., et al., 2021. Environmental profile, distributions and potential sources of halogenated polycyclic aromatic hydrocarbons. Journal of Hazardous Materials. 419, 126164. DOI: https://doi.org/10.1016/j.jhazmat.2021.126164

[86] Wickrama-Arachchige, A.U.K., Guruge, K.S., Inagaki, Y., et al., 2021. Halogenated polycyclic aromatic hydrocarbons in edible aquatic species of two Asian countries: Congener profiles, biomagnification, and human risk assessment. Food Chemistry. 360, 130072. DOI: https://doi.org/10.1016/j.foodchem.2021.130072

[87] Hansen, L.G., 2019. Halogenated aromatic compounds. In Basic Environmental Toxicology. CRC Press. 199–230. DOI: https://doi.org/10.1201/9780429269633-9

[88] Zhang, Q., Wang, Z., Xiao, Q., et al., 2023. The effects and mechanisms of the new brominated flame retardant BTBPE on thyroid toxicity. Food and Chemical Toxicology. 180, 114027. DOI: https://doi.org/10.1016/j.fct.2023.114027

[89] Feiteiro, J., Mariana, M., Cairrão, E., 2021. Health toxicity effects of brominated flame-retardants: From environmental to human exposure. Environmental Pollution. 285, 117475. DOI: https://doi.org/10.1016/j.envpol.2021.117475

[90] Hou, R., Lin, L., Li, H., et al., 2021. Occurrence, bioaccumulation, fate, and risk assessment of novel brominated flame-retardants (NBFRs) in aquatic environments—A critical review. Water Research. 198, 117168. DOI: https://doi.org/10.1016/j.watres.2021.117168

[91] Banyoi, S.M., Porseryd, T., Larsson, J., et al., 2022. The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses. Environmental Pollution. 315, 120422. DOI: https://doi.org/10.1016/j.envpol.2022.120422

[92] Mahoney, H., Xie, Y., Brinkmann, M., et al., 2022. Next generation per-and poly-fluoroalkyl substances: status and trends, aquatic toxicity, and risk assessment. Eco-Environment & Health. 1(2), 117–131. DOI: https://doi.org/10.1016/j.eehl.2022.08.002

[93] Grześkowiak, T., Szymański, A., Zgoła-Grześkoviak, A., et al., 2021. Alkylphenols and Alkylphenol Ethoxylates Their Impact on Living Organisms, Biodegradation, and Environmental Pollution. In Biodegradation, Pollutants and Bioremediation Principles. CRC Press. 1–32. DOI: https://doi.org/10.1201/9781003140220-1

[94] Alavi, S.M.H., Barzegar-Fallah, S., Rahdar, P., et al., 2021. A review on environmental contaminants-related fertility threat in male fishes: effects and possible mechanisms of action learned from wildlife and laboratory studies. Animals. 11(10), 2817. DOI: https://doi.org/10.3390/ani11102817

[95] Chen, C.F., Ju, Y.R., Wang, M.H., et al., 2024. Endocrine Disruptors (Phthalates and Alkylphenols) in Harbor Surface Sediments Reflect Anthropogenic Pollution. Soil and Sediment Contamination: An International Journal. 33(2), 155–174. DOI: https://doi.org/10.1080/15320383.2024.2302353

[96] Liu, J., Zhang, L., Lu, G., et al., 2021. Occurrence, toxicity and ecological risk of Bisphenol A analogues in aquatic environment–A review. Ecotoxicology and Environmental Safety. 208, 111481. DOI: https://doi.org/10.1016/j.ecoenv.2020.111481

[97] Mezzelani, M., Regoli, F., 2022. The biological effects of pharmaceuticals in the marine environment. Annual

Review of Marine Science. 14(1), 105–128. DOI: https://doi.org/10.1146/annurev-marine-032221-084230

[98] Lozano, I., Pérez-Guzmán, C.J., Mora, A., et al., 2022. Pharmaceuticals and personal care products in water streams: Occurrence, detection, and removal by electrochemical advanced oxidation processes. Science of the Total Environment. 827, 154348. DOI: https://doi.org/10.1016/j.scitotenv.2022.154348

[99] Ojoghoro, J.O., Scrimshaw, M.D., Sumpter, J.P., 2021. Steroid hormones in the aquatic environment. Science of the Total Environment. 792, 148306. DOI: https://doi.org/10.1016/j.scitotenv.2021.148306

[100] Gao, J.M., You, J., Wu, J.C., et al., 2023. Factors affecting the accumulation of organotins by wild fish: A case study in the Three Gorges Reservoir, China. Environmental Science and Pollution Research. 30(59), 124407–124415. DOI: https://doi.org/10.1007/s11356-023-31091-6

[101] Shu, S.N., Jiang, R.T., Yin, J., et al., 2023. Characteristics, sources and health risks of organotin compounds in marine organisms from the seas adjacent to the eastern ports of China. Regional Studies in Marine Science. 61, 102929. DOI: https://doi.org/10.1016/j.rsma.2023.102929

[102] Islam, P., Hossain, M.I., Khatun, P., et al., 2024. Steroid hormones in fish, caution for present and future: A review. Toxicology Reports. 101733. DOI: https://doi.org/10.1016/j.toxrep.2024.101733

[103] Yazdan, M.M.S., Kumar, R., Leung, S.W., 2022. The environmental and health impacts of steroids and hormones in wastewater effluent, as well as existing removal technologies: a review. Ecologies. 3(2), 206–224. DOI: https://doi.org/10.3390/ecologies3020016

[104] Rani, L., Thapa, K., Kanojia, N., et al., 2021. An extensive review on the consequences of chemical pesticides on human health and environment. Journal of Cleaner Production. 283, 124657. DOI: https://doi.org/10.1016/j.jclepro.2020.124657

[105] Sharma, A., Shukla, A., Attri, K., et al., 2020. Global trends in pesticides: A looming threat and viable alternatives. Ecotoxicology and Environmental Safety. 201, 110812. DOI: https://doi.org/10.1016/j.ecoenv.2020.110812

[106] Garud, A., Pawar, S., Patil, M.S., et al., 2024. A Scientific Review of Pesticides: Classification, Toxicity, Health Effects, Sustainability, and Environmental Impact. Cureus. 16(8). DOI: https://doi.org/10.7759/cureus.52856

[107] Morin-Crini, N., Lichtfouse, E., Liu, G., et al., 2022. Worldwide cases of water pollution by emerging contaminants: a review. Environmental Chemistry Letters. 20(4), 2311–2338. DOI: https://doi.org/10.1007/s10311-022-01447-4

[108] Zeshan Umer Shah, Saltanat Parveen., 2020. A review on pesticides pollution in aquatic ecosystem and probable adverse effects on fish. Pollution Research. 39(2), 309–321. DOI: https://doi.org/10.53550/PR.2020.v39i02.001

[109] Kumar, R., Sankhla, M.S., Kumar, R., et al., 2021. Impact of pesticide toxicity in aquatic environment. Biointerface Research in Applied Chemistry. 11(3), 10131–10140. DOI: https://doi.org/10.33263/BRIAC113.1013110140

[110] Rao, M.V., Venkaiah, Y., 2020. Impact of malathion (an organophosphate) on biochemical constituents (proteins, carbohydrates and free aminoacids) of fresh water fish channa punctatus (bloch). Uttar Pradesh Journal of Zoology. 41(10), 51–58. DOI: https://doi.org/10.56557/upjoz/2020/v41i103067

[111] WHO., 2017. Agrochemicals, health and environment: directory of resources. Available from: http://www.who.int/heli/risks/toxics/chemicalsdirectory/en/index1.html

[112] Miranda, R.A., Silva, B.S., de Moura, E.G., et al., 2023. Pesticides as endocrine disruptors: programming for obesity and diabetes. Endocrine. 79(3), 437–447. DOI: https://doi.org/10.1007/s12020-022-03274-7

[113] Bertram, M.G., Gore, A.C., Tyler, C.R., et al., 2022. Endocrine-disrupting chemicals. Current Biology. 32(13), R727–R730. DOI: https://doi.org/10.1016/j.cub.2022.04.063

[114] Kadiru, S., Patil, S., D'Souza, R., 2022. Effect of pesticide toxicity in aquatic environments: A recent review. International Journal of Fisheries and Aquatic Studies. 10, 113–118. DOI: https://doi.org/10.22271/fish.2022.v10.i1b.2633

[115] Polazzo, F., Dos Anjos, T.B.O., Arenas-Sánchez, A., et al., 2022. Effect of multiple agricultural stressors on freshwater ecosystems: The role of community structure, trophic status, and biodiversity-functioning relationships on ecosystem responses. Science of the Total Environment. 807, 151052. DOI: https://doi.org/10.1016/j.scitotenv.2021.151052

[116] Koelmans, A.A., Belay, B.M.G., Mintenig, S.M., et al., 2023. Towards a rational and efficient risk assessment for microplastics. TrAC Trends in Analytical Chemistry. 165, 117142. DOI: https://doi.org/10.1016/j.trac.2023.117142

[117] Hrustić, A., 2022. EU restrictions on intentionally added microplastics–small plastic, low ambition. Anali Pravnog fakulteta Univerziteta u Zenici. 15(31), 7–32. DOI: https://doi.org/10.51728/issn.2232-969X.2022.31.7

[118] Vivekanand, A.C., Mohapatra, S., Tyagi, V.K., 2021. Microplastics in aquatic environment: Challenges and perspectives. Chemosphere. 282, 131151. DOI: https://doi.org/10.1016/j.chemosphere.2021.131151

[119] Issac, M.N., Kandasubramanian, B., 2021. Ef-

fect of microplastics in water and aquatic systems. Environmental Science and Pollution Research. 28, 19544–19562. DOI: https://doi.org/10.1007/s11356-021-13184-2
[120] Kinigopoulou, V., Pashalidis, I., Kalderis, D., et al., 2022. Microplastics as carriers of inorganic and organic contaminants in the environment: A review of recent progress. Journal of Molecular Liquids. 350, 118580. DOI: https://doi.org/10.1016/j.molliq.2022.118580
[121] Amelia, T.S.M., Khalik, W.M.A.W.M., Ong, M.C., et al., 2021. Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. Progress in Earth and Planetary Science. 8, 1–26. DOI: https://doi.org/10.1186/s40645-021-00404-1
[122] Chen, G., Li, Y., Wang, J., 2021. Occurrence and ecological impact of microplastics in aquaculture ecosystems. Chemosphere. 274, 129989. DOI: https://doi.org/10.1016/j.chemosphere.2021.129989
[123] Zhao, S., Zhang, Z., Chen, L., et al., 2022. Review on migration, transformation and ecological impacts of microplastics in soil. Applied Soil Ecology. 176, 104486. DOI: https://doi.org/10.1016/j.apsoil.2022.104486
[124] Liu, S., Huang, Y., Luo, D., et al., 2022. Integrated effects of polymer type, size and shape on the sinking dynamics of biofouled microplastics. Water Research. 220, 118656. DOI: https://doi.org/10.1016/j.watres.2022.118656
[125] Darabi, M., Majeed, H., Diehl, A., et al., 2021. A review of microplastics in aquatic sediments: occurrence, fate, transport, and ecological impact. Current Pollution Reports. 7, 40–53. DOI: https://doi.org/10.1007/s40726-021-00182-8
[126] Khan, B., Burgess, R.M., Cantwell, M.G., 2023. Occurrence and bioaccumulation patterns of per-and polyfluoroalkyl substances (PFAS) in the marine environment. ACS ES&T Water. 3(5), 1243–1259. DOI: https://doi.org/10.1021/acsestwater.2c00621
[127] Lewis, A.J., Yun, X., Spooner, D.E., et al., 2022. Exposure pathways and bioaccumulation of per- and polyfluoroalkyl substances in freshwater aquatic ecosystems: Key considerations. Science of the Total Environment. 822, 153561. DOI: https://doi.org/10.1016/j.scitotenv.2022.153561
[128] Evich, M.G., Davis, M.J., McCord, J.P., et al., 2022. Per-and polyfluoroalkyl substances in the environment. Science. 375(6580), eabg9065. DOI: https://doi.org/10.1126/science.abg9065
[129] Newland, A., Khyum, M.M., Halamek, J., et al., 2023. Perfluoroalkyl and polyfluoroalkyl substances (PFAS)—Fibrous substrates. TAPPI Journal. 22(9), 559–572. DOI: https://doi.org/10.32964/TJ22.9.559
[130] Kurwadkar, S., Dane, J., Kanel, S.R., et al., 2022. Per- and polyfluoroalkyl substances in water and wastewater: A critical review of their global occurrence and distribution. Science of the Total Environment. 809, 151003. DOI: https://doi.org/10.1016/j.scitotenv.2021.151003
[131] Ankley, G.T., Cureton, P., Hoke, R.A., et al., 2021. Assessing the ecological risks of per-and polyfluoroalkyl substances: Current state-of-the science and a proposed path forward. Environmental Toxicology and Chemistry. 40(3), 564–605. DOI: https://doi.org/10.1002/etc.4869
[132] Liang, X., Yang, X., Jiao, W., et al., 2022. Simulation modelling the structure related bioaccumulation and biomagnification of per-and polyfluoroalkyl substances in aquatic food web. Science of the Total Environment. 838, 156397. DOI: https://doi.org/10.1016/j.scitotenv.2022.156397
[133] Chu, K., Lu, Y., Hua, Z., et al., 2022. Perfluoroalkyl acids (PFAAs) in the aquatic food web of a temperate urban lake in East China: Bioaccumulation, biomagnification, and probabilistic human health risk. Environmental Pollution. 296, 118748. DOI: https://doi.org/10.1016/j.envpol.2021.118748
[134] Codling, G., Yuan, H., Jones, P.D., et al., 2020. Metals and PFAS in stormwater and surface runoff in a semi-arid Canadian city subject to large variations in temperature among seasons. Environmental Science and Pollution Research. 27, 18232–18241. DOI: https://doi.org/10.1007/s11356-020-08336-9
[135] Pozo, K., Moreira, L.B., Karaskova, P., et al., 2022. Using large amounts of firefighting foams releases per-and polyfluoroalkyl substances (PFAS) into estuarine environments: A baseline study in Latin America. Marine Pollution Bulletin. 182, 113938. DOI: https://doi.org/10.1016/j.marpolbul.2022.113938
[136] Rehnstam, S., Czeschka, M.B., Ahrens, L., 2023. Suspect screening and total oxidizable precursor (TOP) assay as tools for characterization of per-and polyfluoroalkyl substance (PFAS)-contaminated groundwater and treated landfill leachate. Chemosphere. 334, 138925. DOI: https://doi.org/10.1016/j.chemosphere.2023.138925
[137] Masoner, J.R., Kolpin, D.W., Cozzarelli, I.M., et al., 2020. Landfill leachate contributes per-/polyfluoroalkyl substances (PFAS) and pharmaceuticals to municipal wastewater. Environmental Science: Water Research & Technology. 6(5), 1300–1311. DOI: https://doi.org/10.1039/D0EW00045K
[138] D'Ambro, E.L., Pye, H.O., Bash, J.O., et al., 2021. Characterizing the air emissions, transport, and deposition of per-and polyfluoroalkyl substances from a fluoropolymer manufacturing facility. Environmental Science & Technology. 55(2), 862–870. DOI: https://doi.org/10.1021/acs.est.0c06580
[139] Kolpin, D.W., Hubbard, L.E., Cwiertny, D.M., et

al., 2021. A comprehensive statewide spatiotemporal stream assessment of per-and polyfluoroalkyl substances (PFAS) in an agricultural region of the United States. Environmental Science & Technology Letters. 8(11), 981–988. DOI: https://doi.org/10.1021/acs.estlett.1c00750

[140] Uddin, M.N., Desai, F., Asmatulu, E., 2020. Engineered nanomaterials in the environment: bioaccumulation, biomagnification and biotransformation. Environmental Chemistry Letters. 18(4), 1073–1083. DOI: https://doi.org/10.1007/s10311-020-01004-x

[141] Miller, M.E., Hamann, M., Kroon, F.J., 2020. Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. PloS One. 15(10), e0240792. DOI: https://doi.org/10.1371/journal.pone.0240792

[142] Grabicovà, K., Duchet, C., Švecová, H., et al., 2024. The effect of warming and seasonality on bioaccumulation of selected pharmaceuticals in freshwater invertebrates. Water Research. 254, 121360. DOI: https://doi.org/10.1016/j.watres.2024.121360

[143] Previšić, A., Rožman, M., Mor, J.R., et al., 2020. Aquatic macroinvertebrates under stress: Bioaccumulation of emerging contaminants and metabolomics implications. Science of the Total Environment. 704, 135333. DOI: https://doi.org/10.1016/j.scitotenv.2019.135333

[144] Miller, M.E., Motti, C.A., Hamann, M., et al., 2023. Assessment of microplastic bioconcentration, bioaccumulation and biomagnification in a simple coral reef food web. Science of the Total Environment. 858, 159615. DOI: https://doi.org/10.1016/j.scitotenv.2022.159615

[145] Danovaro, R., Cocozza di Montanara, A., Corinaldesi, C., et al., 2023. Bioaccumulation and biomagnification of heavy metals in marine micro-predators. Communications Biology. 6(1), 1206. DOI: https://doi.org/10.1038/s42003-023-05573-9

[146] Shah, S., Kumar, A., 2022. Bioavailability, Bioconcentration, and Biomagnification of Pollutants. In Environmental Toxicology and Ecosystem. 179–214. DOI: https://doi.org/10.1201/9781003308774-9

[147] Impellitteri, F., Multisanti, C.R., Rusanova, P., et al., 2023. Exploring the impact of contaminants of emerging concern on fish and invertebrates physiology in the Mediterranean Sea. Biology. 12(6), 767. DOI: https://doi.org/10.3390/biology12060767

[148] Arguello-Pérez, M.Á., Ramírez-Ayala, E., Mendoza-Pérez, J.A., et al., 2020. Determination of the bioaccumulative potential risk of emerging contaminants in fish muscle as an environmental quality indicator in coastal lagoons of the Central Mexican Pacific. Water. 12(10), 2721. DOI: https://doi.org/10.3390/w12102721

[149] Ecke, F., Golovko, O., Hörnfeldt, B., et al., 2024. Trophic fate and biomagnification of organic micropollutants from staple food to a specialized predator. Environmental Research. 261, 119686. DOI: https://doi.org/10.1016/j.envres.2024.119686

[150] Savoca, D., Pace, A., 2021. Bioaccumulation, biodistribution, toxicology and biomonitoring of organofluorine compounds in aquatic organisms. International Journal of Molecular Sciences. 22(12), 6276. DOI: https://doi.org/10.3390/ijms22126276

[151] Dhangar, K., Kumar, M., 2020. Tricks and tracks in removal of emerging contaminants from the wastewater through hybrid treatment systems: a review. Science of the Total Environment. 738, 140320. DOI: https://doi.org/10.1016/j.scitotenv.2020.140320

[152] Mofijur, M., Hasan, M.M., Ahmed, S.F., et al., 2024. Advances in identifying and managing emerging contaminants in aquatic ecosystems: Analytical approaches, toxicity assessment, transformation pathways, environmental fate, and remediation strategies. Environmental Pollution. 341, 122889. DOI: https://doi.org/10.1016/j.envpol.2023.122889

[153] Puri, M., Gandhi, K., Kumar, M.S., 2023. Emerging environmental contaminants: A global perspective on policies and regulations. Journal of Environmental Management. 332, 117344. DOI: https://doi.org/10.1016/j.jenvman.2023.117344

[154] Lin, X., Xu, J., Keller, A.A., et al., 2020. Occurrence and risk assessment of emerging contaminants in a water reclamation and ecological reuse project. Science of the Total Environment. 744, 140977. DOI: https://doi.org/10.1016/j.scitotenv.2020.140977

[155] Reichert, G., Hilgert, S., Fuchs, S., et al., 2019. Emerging contaminants and antibiotic resistance in the different environmental matrices of Latin America. Environmental Pollution. 255, 113140. DOI: https://doi.org/10.1016/j.envpol.2019.113140

[156] Shahid, M.K., Kashif, A., Fuwad, A., et al., 2021. Current advances in treatment technologies for removal of emerging contaminants from water–A critical review. Coordination Chemistry Reviews. 442, 213993. DOI: https://doi.org/10.1016/j.ccr.2021.213993

[157] Ahmed, S.F., Mofijur, M., Nuzhat, S., et al., 2021. Recent developments in physical, biological, chemical, and hybrid treatment techniques for removing emerging contaminants from wastewater. Journal of Hazardous Materials. 416, 125912. DOI: https://doi.org/10.1016/j.jhazmat.2021.125912

[158] Elnaggar, A., 2024. Nine principles of green heritage science: life cycle assessment as a tool enabling green transformation. Heritage Science. 12(1). DOI: https://doi.org/10.1186/s40494-024-01160-1

[159] Trivedi, R., Upadhyay, T.K., Khan, F., et al., 2024. Innovative strategies to manage polluted aquatic ecosystem and agri-food waste for circular economy. Environmental Nanotechnology, Monitoring & Manage-

ment. 21, 100928. DOI: https://doi.org/10.1016/j.enmm.2024.100928

[160] Akhtar, M.S., Ali, S., Zaman, W., 2024. Innovative adsorbents for pollutant removal: Exploring the latest research and applications. Molecules. 29(18), 4317. DOI: https://doi.org/10.3390/molecules29184317

[161] Gonçalves, J.O., Strieder, M.M., Silva, L.F.O., et al., 2024. Advanced technologies in water treatment: chitosan and its modifications as effective agents in the adsorption of contaminants. International Journal of Biological Macromolecules. 132307. DOI: https://doi.org/10.1016/j.ijbiomac.2024.132307