Mitigation Strategies of Emerging Pollutants from Cosmetic Industry Effluent: A Review

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Abstract:
The cosmetic industry is a significant contributor to environmental pollution, releasing a wide array of emerging pollutants (EPs) into aquatic ecosystems through its effluents. These EPs, including microplastics, synthetic fragrances, UV filters, and preservatives, originate from various cosmetic products and have been increasingly detected in surface water, municipal wastewater, groundwater, and even drinking water sources. The presence of EPs in these environments poses significant risks to both ecological integrity and human health, necessitating urgent mitigation efforts. This review critically evaluates existing mitigation strategies aimed at reducing the environmental impact of EPs from cosmetic industry effluents. It examines the multifaceted nature of the issue, highlighting the need for comprehensive approaches that encompass regulatory, technological, and collaborative efforts. Regulatory measures are essential for setting standards and enforcing compliance to limit the discharge of harmful chemicals into water bodies. However, technological advancements are equally crucial, with the adoption of advanced treatment processes such as advanced oxidation processes, membrane filtration, adsorption, and biodegradation, offering effective means of removing EPs from effluents. Moreover, raising public awareness about the environmental impact of cosmetic industry effluents is paramount to driving collective action and encouraging consumer demand for eco-friendly products. By implementing and continually refining these mitigation strategies, stakeholders can work towards safeguarding ecosystems and promoting a more sustainable future for generations to come. This comprehensive review provides valuable insights for researchers, policymakers, industry stakeholders, and consumers alike, emphasizing the importance of concerted efforts to address the challenge of emerging pollutants from cosmetic industry effluents.

Keywords: Waste water treatment, bioremediation, emerging contamination, emerging pollutants.

Introduction
Emerging pollutants (EPs), also known as micropollutants, have become a serious concern for the worldwide population in recent years due to the potential harm they pose to the environment and human health. Pharmaceuticals and personal care products (PPCPs) are in high demand for health and cosmetic purposes, which has resulted in the rapid emergence of environmental contaminants. EPs affect the environment in a variety of ways. EPs come from animal or human sources and are either directly released into bodies of water or slowly leached through soils. As a result, water quality will suffer,
drinking water sources will become contaminated, and health problems will occur. Because drinking water treatment plants rely on water resources, the spread of this contamination in aquatic habitats, particularly surface water, is a major issue. For instance, the cosmetics business creates more than 3000 artificial substances that are used to treat the symptoms of different diseases, including antibiotics, analgesics, opioids, and contraceptives (Beiras 2021). Regrettably, while the manufacturing of cosmetics continues to develop, waste generation also rises (Bogacki et al., 2020), with industrial wastewater being one of the most significant sources of pollution (Kyzas et al., 2021). Waste is created when chemicals produced in cosmetics are washed away from equipment and by-products using a solution of water, surfactants, and disinfectants (Bogacki J et al., 2020). Significant amounts of antidepressants like fluoxetine (FLU), antibiotics like sulfamethoxazole (SMX), and anti-inflammatory medications like ibuprofen (IBU) have been discovered in aquatic environments (Beiras R et al., 2021). The primary cause of both cosmetics and pollutants ending up in significant amounts in the environment is the failure to remove such chemicals during wastewater treatment (Montes-Grajales et al., 2017). Pharmaceuticals and personal care products (PPCPs) are two parts of the bigger chemical puzzle that the cosmetic sector uses (Alalm et al., 2016). PPCPs are utilized as preservatives for the most problematic compounds found in cosmetics. These ingredients include contrast agents, hormones, preservatives, sunscreen UV filters, contrast agents, anti-inflammatory medications, cleansers, disinfectants, and detergents. After entering the wastewater at first, they are moved to wastewater treatment facilities (Thomaidi et al., 2017, Awfa et al., 2018). Because of their wide range of applications and bioactive qualities, particulate matter pollutants (PPCPs) have drawn a lot of attention to their destiny. This has been made possible by recent advancements in analytical science, which have made it possible for researchers to identify compounds at trace levels (Yenkie and K. M. 2019). To extract more complex pollutants, chemical methods are typically combined with physical operations (Hussein et al., 2021). The majority of treatment facilities employ a technology from each phase, though frequently more than one is needed depending on the purity goals, the characteristics of the contaminants, and their concentration in order to successfully eliminate them. Some can also occasionally be skipped (Hussein et al., 2021). Hence, in this study, the effects of different cosmetic product components released as byproducts and accumulated in the effluents have been investigated. In order to evaluate the possible steps necessary to limit the presence of cosmetics in the environment, this review stressed on the detection of cosmetics in the environment and concentrated on the technologies employed in treating cosmetic wastewater.

**Sources and Characteristics of Emerging Pollutants from the Cosmetic Industry**

Cosmetics fall into two general categories: rinse-off and leave-on. In contrast to rinse-off cosmetics, which include shampoos, soaps, shower gels, and toothpastes, leave-on cosmetics are designed to stay on a person's skin for an extended amount of time. Examples of such products are perfumes, body and face creams, and deodorants (Juliano et al., 2017). Personal care products and makeup can be applied externally to the skin, nails, hair, lips, and so on, or internally for oral hygiene purposes, such as cleaning, anti-microbial protection, fresh breath, upkeep, and beauty enhancement (Aranaz et al., 2018). Furthermore, due to their excessive use by bigger groups of individuals for longer periods of time, cosmetics are given higher priority than pharmaceuticals (Juliano et al., 2017). The two main sources of PPCPs discharged into the environment are sewage outfalls and wastewater treatment plants (Luo et al., 2014, Tiwari et al., 2017). Along with advancements in process monitoring and analysis, a number of studies have looked at possible methods for extracting PPCPs from wastewater (Luo et al., 2014, Chen et al., 2016, Fu et al., 2019, Junaid et al., 2019, Kar et al.,
Biological treatment processes, technologies, compounds, and operational conditions all have a significant impact on how well personal care items are removed from treatment facilities (Alvarino et al., 2015). However, due to their low concentration levels and difficulties in analysis, these contaminants have proven difficult to remove before they can reach surface water (Oluwole A et al., 2020). A variety of physicochemical and/or biological procedures are typically used in typical wastewater treatments (Crini et al., 2019). The biological procedures use tiny organisms to remove and decompose hazardous material, while the physical processes are helpful in removing particles from wastewater, usually using screens and filters. Groundwater concentrations, however, may increase if the aquifer is near sources of contamination. The source type determines the degree of exposure as well as the qualities of the material (Gavrilescu et al., 2015). Figure 1 displays the sources and potential routes for EPs emitted into the atmosphere and dissolving in various receivers (ground, surface, and drinking water).

![Figure 1. Categories of Developing Pollutants Affecting Soil, Air, Water, Animals, Plants, Microorganisms, and Humans](image)

Source: Geissen et al., 2015, Ferreiro et al., 2020

Although many studies have been conducted on the occurrence, origins, behavior, affects, and hazards of EPs in the environment (Lei et al., 2015, Gogoï et al., 2018, Tang et al., 2019), there is currently no comprehensive data on their toxicity. Poor information and complex physicochemical properties of emerging contaminants might lead to unanticipated behavior in water, soil, and air (Lei et al., 2015, Gomes et al., 2017). Their impacts on living species include toxicological effects, endocrine disruption, acute and chronic toxicity, antibiotic resistance, and hazards to human health (Hlavinek et al., 2018). A third category of pollutants is referred to as "contaminants of emerging concern", which consists of "well-known chemicals that have been used for decades (some of which are persistent or pseudopersistent) in specific programs and, cumulatively launched into the environment,
and the by-merchandise in their environmental degradation, which might be now being recorded in floor and groundwater resources, as well as in soils and sediments”.

The phrase "contaminants of emerging concern" refers to pollutants with unknown consequences to the environment and human health (Gomes et al., 2017, Hossain et al., 2023). Among the most often found EPs in the environment are personal care products, and pharmaceuticals (CECs, PPCPs, and PPCPs) (Lei et al., 2015, Gomes et al., 2017). (Reference Table 1). The world currently produces more than 3 million tons of phthalates, which are chemical substances that have been utilized as plasticizers in plastics and fixing agents in cosmetics for more than 50 years Hossain et al., 2023, Patrolecco et al., 2023).

### Table 1. Categories of Emerging Chemicals of Concern in the Water Environment, with Some Examples

<table>
<thead>
<tr>
<th>Groups</th>
<th>Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pharmaceutical compounds</td>
<td>Trimethoprim, Ciprofloxacin, Sulfamethoxazole</td>
</tr>
<tr>
<td>Antibiotics</td>
<td></td>
</tr>
<tr>
<td>Analgesics and anti-inflammatory</td>
<td>Naproxen, Ibuprofen, Diclofenac, Salicylic acid, Ketoprofen</td>
</tr>
<tr>
<td>Antiepileptics</td>
<td>Carbamazepine</td>
</tr>
<tr>
<td>Disinfectant</td>
<td>Triclosan</td>
</tr>
<tr>
<td>Diuretics</td>
<td>Furosemide, Hydrochlorothiazide, Amidortrizoc acid, Diametrizoste, Isotalamic acid</td>
</tr>
<tr>
<td>Lipid regulators</td>
<td>Fenofibrate, Gemfibrozil, Bezafibrate, Atenolol</td>
</tr>
<tr>
<td>Cosmetics</td>
<td>Galaxolide, Tonalide</td>
</tr>
</tbody>
</table>

**Source:** Lei et al., 2015, Gogoi et al., 2018, Tang et al., 2019

Pharmaceuticals are a significant developing contaminant due to their widespread usage in illness treatment and various physicochemical and biological properties. Effluents have been found to include a wide range of medicines, including those that are persistent (Khan et al., 2022). Pharmaceutical compounds (e.g., hormones, anti-inflammatory, anti-epileptic, statins, antidepressants, beta-blockers, antibiotics, contrast agents) are primarily excreted in their original form or as metabolites in urban wastewater, hospital sewers, and surface waters (Khan et al., 2021, Yehya et al., 2015, Vasilachi et al., 2021). They can contaminate groundwater, drinking water, and soil due to irrigation. Antibiotics are becoming more prevalent in the environment and contain a diverse range of chemicals. Antibiotic concentrations in some global rivers can surpass "safe" levels by up to 300 times (Vasilachi et al., 2021, Cycoń et al., 2019). Antibiotic resistance is the most significant hazard to world health, food security, and development, as reported by the World Health Organization. Antibiotics are becoming less effective due to environmental pollution, making treating infections and diseases more challenging (Kraemer et al., 2019).

### Toxicological Effects of EPs

The adverse effects of Emerging Pollutants (EPs) have become a significant concern for both society and the environment due to their potential to cause cancer and disrupt endocrine systems. Endocrine Disrupting Chemicals (EDCs) encompass a diverse range of synthetic or natural chemicals capable of interfering with hormone function in living organisms (Lee et al., 2018). Such disruption can lead to alterations in normal hormone levels, either by stimulating or inhibiting hormone production and metabolism (Haq et al., 2019, Adeel et al., 2017). EDCs represent a class of EPs that include various substances such as phthalates, polybrominated compounds, polychlorinated biphenyls (PCBs), steroid sex hormones, pesticides, pharmaceutical products, bisphenol A (BPA), alkylphenol ethoxylates, and alkylphenols. These compounds have the potential to disrupt endocrine systems in both humans and wildlife, posing significant risks to health and the environment.

### Impact of EP on Human Health

Humans are increasingly exposed to a range of growing organic pollutants (OPs), including
current brominated flame retardants, phthalate substitutes, organophosphate flame retardants, triclosan, bisphenol-A, artificial muscles, perchlorate, and polycyclic siloxanes, which can pose risks to human health (Kawa et al., 2021). Bisphenol, one of the most widely used plasticizers globally, has been associated with adverse effects on various systems in humans, including the thyroid, salivary glands, and male reproductive system, as well as contributing to various endocrine diseases. Bisphenol exposure has also been linked to increased breast cancer risk in women due to its hormonal effects and negative impacts on male fertility (Patel et al., 2017). Tetrabromodiphenyl ether has been linked to endocrine disruption, DNA damage, and mitochondrial dysfunction. Furthermore, brominated flame retardants can impact the production of thyroid hormones, androgens, progesterins, and estrogens, potentially leading to immune cell disruptions, genetic toxic effects, and anatomical abnormalities in females (Pereira et al., 2015). High concentrations of phthalates have been associated with pregnancy complications and terminations. Chemical pesticides can induce hormonal effects such as eggshell thinning, reduced male fertility, thyroid and ovarian tumors, and behavioral disorders. Musk xylol, a fragrance ingredient, has been found to accumulate in human tissues and has been identified as highly carcinogenic in rat studies, with potential neurotoxic effects (Lei et al., 2015).

Environmental Impact of EP
Establishing direct cause-and-effect relationships between contaminant exposure and its impact on human health is challenging, particularly at the environmental level where multiple organisms at various biological complexity levels and external factors complicate field data assessment. Surfactants have detrimental effects on living organisms, and certain substances can significantly impact the environment when present in high concentrations. Bisphenol-A exhibits neurotoxic effects and adversely affects plant development and cell division (Shahid et al., 2021). Exposure to alkylphenols during spermatogenesis in experimental mice has been associated with adverse effects, including various estrogenic effects on marine organisms leading to decreased male sexual competence. Toxic compounds like brominated dioxins, polychlorinated naphthalenes, and furans can cause congenital disabilities in animals and disrupt reproductive growth, immunity, and hormone systems. Perchlorate primarily affects thyroid function and brain development at lower concentrations, with rodent pups born to exposed mothers being particularly vulnerable to adverse effects (Rathi et al., 2021). Polybrominated diphenyl ethers have been associated with various detrimental health outcomes in laboratory animals, including thyroid disruption, cognitive issues, behavioral changes, hearing impairment, delayed puberty, reduced sperm quality, and fetal deformities. Triclosan can severely harm marine species, with its degradation products contaminating biodiversity, including methyl triclosan found in fish, primarily accumulating in fat cells (Rathi et al., 2021). Biological tests used to assess the ecotoxicological effects of emerging contaminants may be complemented by improved omics-related methods to categorize the detrimental effects of complex mixtures of pollutants from wastewater treatment (Jothirani et al., 2016).

Methods to Detect Emerging Pollutants (EPs)
Developing reliable and validated quantitative methodologies and materials for identifying novel pollutants poses a significant challenge for the global technical chemistry community. Accurately detecting and chromatographically separating emerging organic contaminants within different solid ecological matrices is crucial for thorough analysis. Prior to examination, several essential pretreatment steps are often necessary, such as filtration, pH adjustment, matrix isolation, and sample enrichment (Rathi et al., 2021). For every analysis of Emerging Pollutants (EPs), both sample preparation and instrumental analysis are indispensable.
Pretreatment of the Samples

Sophisticated analysis techniques involve a series of intricately calibrated and interrelated steps to enhance performance. These steps aim to handle specimens in a manner that preserves, collects, segregates, and concentrates analytes, ensuring consistency with instrument-based studies. Several alternative extraction methods, such as stirred sorptive bar extraction, automated solid-phase extraction, digital solid-phase extraction, molecularly imprinted polymers, solid-state microextraction, and magnetic solid-phase extraction using silica-based Fe₃O₄ nanoparticles, have been documented in literature (Rathi et al., 2021). Ultrasound-assisted extraction and adsorption offer advantages over traditional solvent extraction by using less solvent and requiring less time to complete, potentially enhancing sample processing efficiency and cleanliness (Hernández et al., 2015). Membrane technologies such as reverse osmosis, nanofiltration, and ultrafiltration are employed to separate larger organic compounds from smaller water molecules, thereby enhancing the stability of organic substances in a solvent. Derivatization processes are routinely employed to render polarized reagents suitable for analysis using specific analytical methods (Rathi et al., 2021).

Instrumental Analysis

Implementing novel atmospheric pollutants requires the application of physicochemical procedures, impact-monitoring techniques, environmental tactics, and management methodologies. Chromatography, both liquid and gas, is utilized to detect developing pollutants based on their polarization, volatility, and thermal characteristics (Lebedev et al., 2020). With over a thousand new and critical contaminants, conventional gas chromatography-mass spectrometry (GC-MS) faces challenges in tracing thousands of compounds (del Carmen Salvatierra-Stamp et al., 2015). Supercritical-fluid chromatography has been utilized to identify seven emerging pollutants, including pharmaceuticals, endocrine disruptors, bactericides, and pesticides, with recoveries over 94% and identification and quantitatve limits between 0.10 and 1.59 g L⁻¹ and 0.34 and 4.83 g L⁻¹, respectively (Snow et al., 2015). A novel analytical method is being developed to simultaneously detect 10 steroid hormones in farm soil or animal manure using gas chromatography-tandem mass spectrometry and the integrated elimination of high-pressure fluid (Snow et al., 2015). Liquid chromatography-tandem mass spectrometry is a well-known technology for target detection of EPs, such as determining the presence of 26 animal health penicillin in pig wastewater using electrospray, liquid chromatography, and tandem mass spectrometry (Zonja et al., 2014). Laboratory-scale characterization of emerging pollutant organic compounds has seen significant progress with the advancement of increased-resolution mass spectrometric equipment such as quadrupole time-of-flight and orbitrap mass spectrometry (Lebedev et al., 2020). While capillary electrophoresis is often less sensitive compared to HPLC methodology, its isolation specificity may complement that of HPLC, making it a suitable option for confirming HPLC results by an independent method (Lebedev et al., 2020). Immuno-analytical methods offer advantages such as minimal sample preparation, high precision, and cost-effectiveness compared to chromatographic and mass spectrometry-based techniques, making them potentially useful for trace analysis of organic environmental pollutants. However, due to their specificity, immunoassays cannot simultaneously analyze chemicals from different chemical classes. These examples of instrumental analysis of emerging pollutants are also listed in Table 2.
## Table 2. Different Instruments Used for the Detection of Different Emerging Pollutants

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Set up</th>
<th>Concentration range</th>
<th>Operation condition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of any pollutant is possible</td>
<td>Gas Chromatography × Gas Chromatography setup</td>
<td>&lt;1.00 mg/L</td>
<td>Solvent vent time: 6 s, inlet solvent vent flow: 100 ml/min, inlet solvent vent pressure: 5 psi, inlet purge time: 120 s, and inlet purge flow: 20 ml/min</td>
<td>(del Carmen Salvatierra-Stamp et al., 2015)</td>
</tr>
<tr>
<td>Triclosan</td>
<td>Supercritical-fluid chromatography coupled with diode-array detection</td>
<td>0.10–1.59 μg/L</td>
<td>Relative standard deviations &lt; 9.20 %</td>
<td>del Carmen Salvatierra-Stamp et al., 2015</td>
</tr>
<tr>
<td>Pharmaceutical compounds and personal care products</td>
<td>Ultra high-pressure liquid chromatography-tandem mass spectrometry</td>
<td>1.90 ng/L</td>
<td>-</td>
<td>(Zonja et al., 2014)</td>
</tr>
<tr>
<td>Antibiotics</td>
<td>High-pressure liquid chromatography - Mass Spectroscopy / Mass Spectroscopy in positive electrospray mode</td>
<td>0.10–3.60 ng/L</td>
<td>-</td>
<td>(Zonja et al., 2014)</td>
</tr>
<tr>
<td>Bisphenol-A</td>
<td>Supercritical-fluid chromatography coupled with diode</td>
<td>0.10–1.59 μg/L</td>
<td>Relative standard deviations &lt; 9.20 %</td>
<td>(del Carmen Salvatierra-Stamp et al., 2015)</td>
</tr>
<tr>
<td>17β-estradiol</td>
<td>Supercritical fluid chromatography coupled with diode-array detection</td>
<td>0.10–1.59 μg/L</td>
<td>Relative standard deviations &lt; 9.20 %</td>
<td>(del Carmen Salvatierra-Stamp et al., 2015)</td>
</tr>
<tr>
<td>Levamisole</td>
<td>Ultra high-pressure liquid chromatography-tandem mass spectrometry</td>
<td>9.20 ng/L</td>
<td>-</td>
<td>(Zonja et al., 2014)</td>
</tr>
</tbody>
</table>

### The Removal of EPs from the Environment as a Risk Mitigation Solution

The removal of EPs from water, as well as the potential development of disinfection byproducts, determine the quality of drinking water sources. EPs can be eliminated utilizing a variety of treatment approaches, including biological, physicochemical, and oxidative techniques. In order to comply with the current requirements regarding the discharge of treated effluents, this would guarantee an effective control of effluents. Figure 2 (de Oliveira et al., 2020, Mohapatra et al., 2019) illustrates the development of effective techniques for the advanced treatment of effluents contaminated with particulate matter (EPs). These techniques include physico-chemical and biological processes, such as sand and media filtration, chlorination, advanced oxidation processes, AOPs, adsorption using granular activated carbon, zeolite, or other clay materials, hydrolysis processes, constructed wetland (CW), membrane bioreactors, phytoremediation, and biosorption.
In order to decrease high organic loads, the activated sludge technique is typically applied to remove emerging contaminants; however, it is not appropriate for removing EPs, particularly at extremely low concentrations or traces of pollutants. Furthermore, EPs with high polarity, such as many pharmaceuticals, can be effectively removed through biological degradation and mineralization facilitated by specific microorganisms (Gogoi et al., 2018, Ahmed et al., 2017).

Conclusion

In conclusion, this review underscores the pressing need for robust mitigation strategies to address the proliferation of emerging pollutants in cosmetic industry effluents. The complexity of the issue demands a comprehensive approach that encompasses regulatory, technological, and collaborative efforts. Regulatory measures play a pivotal role in setting standards and enforcing compliance to limit the discharge of harmful chemicals into water bodies. However, technological advancements are equally crucial, with the adoption of advanced treatment processes offering effective means of removing emerging pollutants from effluents. Furthermore, embracing principles of green chemistry and promoting product innovation can help reduce the generation of hazardous compounds, fostering a shift towards more sustainable practices within the industry. Concurrently, raising public awareness and fostering industry collaboration are vital components in driving collective action towards
mitigating the environmental impact of cosmetic industry effluents. In essence, addressing the challenge of emerging pollutants from cosmetic industry effluents requires a concerted effort from all stakeholders, including regulatory bodies, industry players, academia, and consumers. By implementing and continually refining these mitigation strategies, we can strive towards safeguarding our ecosystems and promoting a more sustainable future for generations to come.

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**Conflict of Interests**

The authors declare no conflict of interest with anyone.

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