

Biotechnological Approaches and Policy Frameworks for Sustainable Management of Cosmetic Waste in India

Tanu Allen*, Aansh Chadha, Neeta Bhagat, Preeti Mehta Kakkar,
and Sohini Singh

Amity Institute of Biotechnology, Amity University Uttar Pradesh, Noida, India

*Corresponding author: allentanu@gmail.com

Abstract

Cosmetic waste is a toxic waste from the ever-evolving cosmetics and personal care market, that threatens environmental and health problems with complex components containing heavy metals, surfactants, preservatives, microplastics, and synthetic polymers. It classifies present treatment technologies into physical (filtration, sedimentation, adsorption), chemical (coagulation-flocculation, oxidation, advanced oxidation processes), and biological (aerobic digestion, enzyme-based approaches, constructed wetlands) options, highlighting the demand for more integrated and sustainable solutions. Key issues like insufficient biodegradability, lack of regulatory enforcement, and improper waste segregation are reported. Comparative regulatory frameworks around the world of USA, EU, and China are discussed with the existing legal provisions of India under CPCB and MoEFCC. The review also discusses emerging circular economy initiatives, resource recovery, biochar generation, nanotechnology, and collaborations within the industry (PPP).

Keywords: Cosmetic Sludge, Personal Care Products (PPCPs), Advanced Oxidation Processes (AOPs), Circular Economy, Environmental Sustainability

Introduction

Cosmetic sludge is a residual byproduct generated during the production of cosmetic and personal care products. It consists of a complex mixture of organic and inorganic substances, like heavy metals, surfactants, stabilizers, pigments, preservatives, and microplastics. This

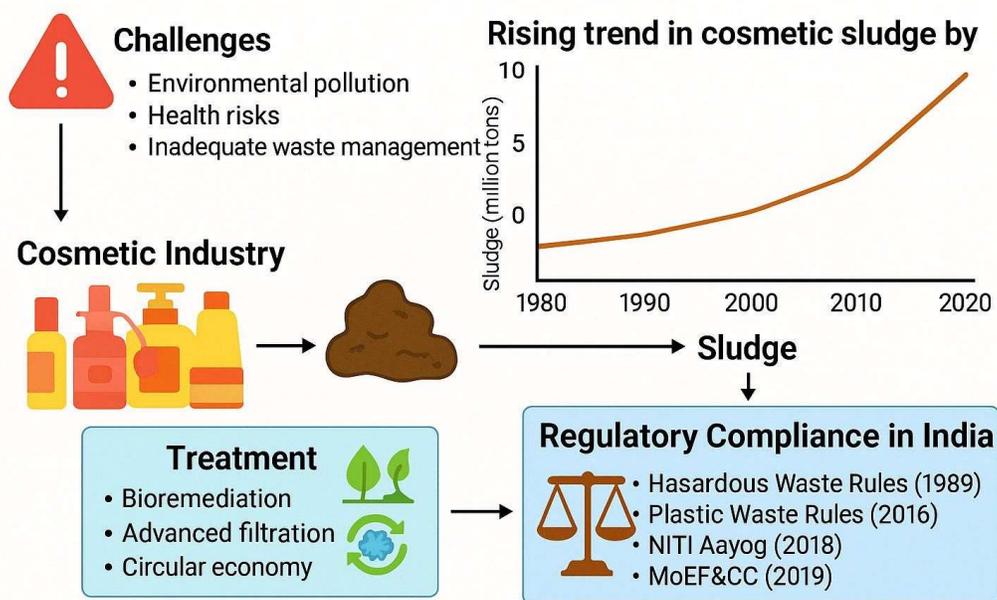
sludge is largely formed through processes such as synthesis of chemicals, extraction, filtration, and emulsification, and due to significant rise in cosmetic consumption globally, surge in sludge production has also been reported (1). Cosmetic products can be broadly classified into *Pharmaceuticals and Personal Care Products* (PPCPs) containing UV filters, hormones, preservatives, anti-inflammatory agents, disinfectants, and detergents, which can further be categorised as *leave-on* products (e.g., perfumes, body creams, deodorants) and *rinse-off* products (e.g., soaps, shampoos, shower gels, toothpaste) (1) as they are applied on the skin, hair, nails, or orally for hygiene and aesthetic purposes (2). Their potential for direct environmental contamination is significantly higher compared to pharmaceuticals (3,4), making cosmetic sludge an area of critical concern due to its widespread, continuous application by large populations (1,5, 6).

Cosmetic sludge is a residual byproduct generated during the production of cosmetic and personal care products. It consists of a complex mixture of organic and inorganic substances, like heavy metals, surfactants, stabilizers, pigments, preservatives, and microplastics. This sludge is largely formed through processes such as synthesis of chemicals, extraction, filtration, and emulsification, and due to significant rise in cosmetic consumption globally, surge in sludge production has also been reported (1). Cosmetic products can be broadly classified into *Pharmaceuticals and Personal Care Products* (PPCPs) containing UV filters, hormones, preservatives, anti-inflammatory agents, disinfectants, and detergents, which

can further be categorised as *leave-on* products (e.g., perfumes, body creams, deodorants) and *rinse-off* products (e.g., soaps, shampoos, shower gels, toothpaste) (1) as they are applied on the skin, hair, nails, or orally for hygiene and aesthetic purposes (2). Their potential for direct environmental contamination is significantly higher compared to pharmaceuticals (3,4), making cosmetic sludge an area of critical concern due to its widespread, continuous application by large populations (1,5, 6).

Cosmetic sludge production has risen over the past few decades, closely linked to the growth of the beauty and personal care industry. A study by (7) suggested 60% more increase in sludge production: from 1.2 million tons in the 1980s, to 2.5 million tons in the 1990s, to 5.0 million tons in the early 2000s, escalating to 8.5 million tons in 2010s and in 2020s with a record high of nearly 14 million tons. This increase is steered by diverse

product lines and excessive consumption, particularly in regions lacking robust waste management systems (7,8). The environmental impact of cosmetic sludge is considerable due to the accumulation of heavy metals like lead, mercury, and cadmium (9) and microplastics that degrade terrestrial and aquatic ecosystems (10). These toxic metals and chemicals in sludge can alter soil microbial communities, reduce fertility, and affect agricultural productivity (11). Moreover, volatile organic compounds (VOCs) released from poorly managed sludge, contribute to air pollution and associated health issues, including respiratory disorders (12). Furthermore, studies conducted by (13) in India and its cities, report the clogging of urban treatment plants and river pollution due to improper disposal of cosmetic sludge. Health risks associated with untreated sludge include dermatological conditions, respiratory problems, neurological disorders, endocrine disruption,



Sustainable Solutions for Cosmetic Waste: Challenges, Treatment, and Regulatory Compliance in India

Fig. 1: An overview of challenges, treatment and regulatory compliances are shown in the figure

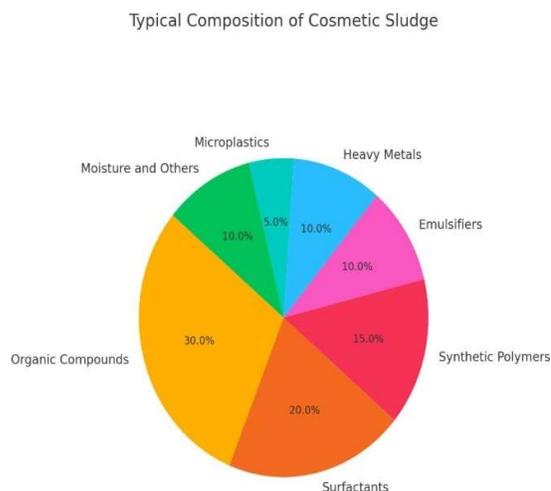


Fig. 2: Composition of cosmetic sludge as shown in the figure

and even cancer due to prolonged exposure to heavy metals and synthetic chemicals (14).

This review aims to explore the challenges, treatment technologies, and regulatory responses related to the management of cosmetic sludge (Fig. 1). It evaluates the environmental implications of cosmetic waste, assesses existing treatment approaches, and analyses regulatory compliance to propose pathways for sustainable and effective waste management in India.

Sources and Composition of Cosmetic Waste: A Growing Environmental Concern

Cosmetic sludge is a mix of organic and inorganic compounds, with 40–50% being organic, including surfactants (15%), oils (10%), polymers (8%), and preservatives (5–7%). Inorganic components make up 30–35%, consisting of heavy metals like lead and mercury (5–10%), pigments (10%), and silica or clay particles (8%). Microplastics and nanoparticles contribute 10–15%, mainly from exfoliants (5%) and sunscreens (7–10%). The remaining 5–10% includes solvents (3–5%) and stabilizers (2–3%). Due to its toxic composition, effective treatment and sustainable waste management are crucial to prevent environmental damage (1) (Fig. 2).

The cosmetic industry is a substantial producer of miscellaneous waste that can be categorized into liquid and solid chemical residues. The major waste part is liquid waste, mainly arising from manufacturing processes (e.g., cleaning and rinsing equipment) and consumer use of rinse-off products (PPCPs) such as shampoos, conditioners, soaps, and facial cleansers. These substances enter the sewage system directly, contributing to cosmetic sludge and pollution in wastewater. Solid waste includes discarded packaging (bottles, tubes, jars, compacts), single-use applicators, wipes, and unused products. These materials often consist of complex, unrecyclable composites like multilayer plastics, glass, metals, and residual cosmetic formulations like leftover ingredients including surfactants, preservatives (e.g., parabens, formaldehyde releasers), pigments, microbeads, fragrance compounds, and chelating agents in containers, contaminated packaging, and by-products from manufacturing processes which are ecologically harmful (3). Despite their biodegradability, their large volume leads to foaming, oxygen depletion, and aquatic life mortality in treatment systems (8). Preservatives and synthetic additives can persist in ecosystems, posing risks to both aquatic organisms and human health (3). Even at low concentrations (parts per billion), they can disrupt endocrine systems in aquatic species and contribute to antibiotic-resistant bacteria (15). Their persistence and toxicity make cosmetic waste a growing concern for environmental sustainability.

Treatment Technologies for Cosmetic Waste

Efficient treatment of cosmetic sludge is essential to abate environmental contamination and recover valuable by-products. As cosmetic sludge is a mix of organic and inorganic compounds, heavy metals, surfactants, microplastics and others, effective treatment strategies are necessary to prevent ecological and health hazards.

- **Physical Treatment**

Physical treatment techniques mainly rely on the separation of pollutants based on their physical characteristics, e.g., size, density, or surface affinity. Typical physical technologies used in the treatment of cosmetic wastewater are:

- **Filtration:** This is a process where wastewater is passed through a porous medium to eliminate suspended solids, such as particulate matter, pigments, and some larger polymer molecules (16). Various filters, including sand filters, membrane filters (e.g., microfiltration, ultrafiltration), and depth filters, provide different efficiencies of particle removal depending on their pore size (17). Membrane filtration, especially ultrafiltration, can efficiently remove emulsified oils and larger organic molecules, enhancing the effluent clarity (18).

- **Sedimentation:** This is a gravity-induced process permitting heavier suspended solids to settle from the wastewater under quiet conditions (19). Sedimentation tanks or clarifiers are widely applied as a primary treatment process for the removal of the load of total suspended solids (TSS) prior to following treatment processes (20). The effectiveness of sedimentation is based on the particle size, density, and detention time in the settling tank (21).

- **Adsorption:** This process includes the attachment of dissolved pollutants onto the surface of a solid adsorbent substance. Activated carbon is the most common adsorbent based on its huge surface area and capacity to capture a wide spectrum of organic impurities, ranging from dyes, fragrances, and surfactants to some extent (22). Some other adsorbents like activated alumina, silica gel, and bio-based adsorbents can be used depending on targeted pollutants (23). Adsorption is efficient in removing non-biodegradable organic pollutants and can exhibit high removal efficiencies under optimized scenarios (24).

- **Chemical Treatment**

Chemical processes involve the use of chemical reagents into wastewater to

enhance the removal or conversion of contaminants through chemical reaction. Some chemical processes commonly applied in treating cosmetic wastewater are:

- **Coagulation and Flocculation:** These processes are utilized to destabilize the colloidal particles and clump them together into larger, settleable flocs (25). Coagulants, e.g., aluminum sulfate (alum) or ferric chloride, neutralize the particles' surface charge, enabling them to aggregate. Flocculants, usually synthetic polymers, then span across these destabilized particles to form larger flocs that can easily be separated by sedimentation or flotation. Coagulation-flocculation is successful in removing suspended solids, turbidity, as well as some emulsified oils and pigments (26, 27).

- **Oxidation:** Chemical oxidation utilizes oxidizing agents, including chlorine, chlorine dioxide, ozone, or hydrogen peroxide, to decompose organic pollutants into less toxic byproducts (28). Oxidation may be effective in decolorizing wastewater, lowering the concentration of some organic compounds, and disinfecting the effluent. Disinfection byproduct (DBP) formation must be given careful consideration when employing chlorine-based oxidants (29).

- **Advanced Oxidation Processes (AOPs):** AOPs constitute a set of strong oxidation processes that produce extremely reactive hydroxyl radicals ($\bullet\text{OH}$) to break down a broad variety of recalcitrant organic contaminants (30). Some typical AOPs are Fenton's reagent ($\text{Fe}^{2+}/\text{H}_2\text{O}_2$), UV/ H_2O_2 , UV/ O_3 , and photocatalysis (e.g., TiO_2/UV) (31). AOPs have the capability to mineralize organic contaminants into carbon dioxide and water, providing a more extensive degradation than the traditional oxidation methods. They are especially efficient at eliminating refractory persistent organic pollutants (POPs) that are resistant to biological treatment (32).

- **Biological Treatment**

Biological processes offer eco-friendly solutions by breaking down organic pollutants.

Aerobic digestion, which utilizes oxygen and microbial activity, helps reduce pathogens, odours, and organic load in the sludge. *Anaerobic digestion*, conducted in oxygen-free environments, further stabilizes sludge and generates biogas for energy use—supporting circular economy goals (33). *Enzyme-based treatments* are also emerging as promising alternatives, using specific enzymes to degrade persistent contaminants, thus reducing sludge toxicity.

- **Activated Sludge:** This is a commonly used aerobic biological treatment process in which a microbial population (activated sludge) is grown and kept suspended in an aeration tank (34). These microorganisms use the organic pollutants present in the wastewater as a food source and convert them into simpler compounds, carbon dioxide, and new biomass (35). Treated effluent is then distinguished from the settled sludge in a secondary clarifier, and some of the sludge is recycled back to the aeration tank to balance the microbial population (36). Activated sludge processes are capable of removing biodegradable organic contaminants, surfactants, and some other organic substances from cosmetic wastewater (37).
- **Biofiltration:** Biofilters are a bed of packed inert media (e.g., sand, gravel, plastic) that allows for the development of a biofilm. Wastewater is flowed through the filter bed, and microorganisms in the biofilm break down the organic pollutant. Biofilters may operate aerobically or anaerobically and are efficient for the removal of biodegradable organic compounds and odour reduction (38).
- **Constructed Wetlands:** They are artificial systems that simulate natural wetlands for wastewater treatment (39). They are shallow basins planted with vegetation and contain a substrate for microbial support. There are many physical, chemical, and biological processes in the wetland system that result in the elimination of pollutants (40). These wetlands can successfully treat a variety of pollutants found in cosmetic wastewater, such as suspended solids, organic compounds, and nutrients, and provide an

alternative that is more sustainable and attractive (41).

Integrated Approach

Among the available methods, an integrated treatment strategy is considered most effective. Combining physical, chemical, and biological processes allows for comprehensive sludge stabilization, improved handling, and enhanced resource recovery (35). For example, physical dewatering can precede chemical detoxification and biological degradation, ensuring safe disposal and minimal environmental impact. Research suggests that integrated systems not only improve treatment efficiency but also align with sustainability and regulatory goals (42). As environmental standards become stricter, adopting innovative and combined treatment technologies will be critical to reducing the long-term ecological footprint of cosmetic waste (43).

Challenges in cosmetic Waste management

A key challenge is the diverse and persistent characteristics of sludge constituents, including surfactants, preservatives, synthetic polymers, emulsifiers, microplastics and heavy metals (44). These compounds often exhibit environmental persistence and low degradability rendering standard wastewater treatment methods insufficient for their thorough elimination (45, 46). Moreover, the rapid expansion of the cosmetics industry has resulted in a substantial increase in sludge volume, crushing existing waste management infrastructure, particularly in developing countries (7). Improper handling and disposal of cosmetic sludge have led to serious ecological and public health concerns, including soil and water contamination, bioaccumulation of toxic substances in aquatic organisms, and the release of volatile organic compounds (VOCs) into the atmosphere (10,12). Microplastics and heavy metals, such as cadmium and lead, present in the sludge, persist in the environment and disrupt terrestrial and aquatic ecosystems (47). Another critical issue is the absence or weak enforcement of regulatory frameworks,

which allows for the unchecked disposal of untreated or partially treated sludge into open landfills and water bodies (48). While India has enacted environmental policies such as the Hazardous Waste (Management and Handling) Rules, 1989 and the Plastic Waste Management Rules, 2016 -MoEFCC, 2019, enforcement challenges continue to hinder effective sludge control in other developing and developed countries. Additionally, there is a limited integration of circular economy practices and sustainable technologies—such as biochar production, phytoremediation, and resource recovery—within existing treatment systems (49, 50). These comprehensive issues emphasize the urgent need for advanced, cost-effective, and sustainable treatment solutions, as well as stronger policy enforcement and industry accountability in addressing the growing problem of cosmetic sludge.

Regulatory Compliance for Cosmetic Waste Management

The cosmetic industry produces substantial quantities of waste—ranging from hazardous chemicals and heavy metals to microplastics—that pose serious threats to

ecosystems if left unmanaged. This emphasizes the need for robust regulations and active oversight by governments and environmental agencies to ensure the safe treatment and disposal of such waste. However, the effectiveness of these efforts is often undermined by regulatory gaps, inconsistent enforcement, and regional disparities in policy implementation.

Globally, several countries have implemented strict regulatory frameworks to manage industrial and cosmetic sludge, establishing the effectiveness of strict compliance. In the United States, the Resource Conservation and Recovery Act (RCRA, 1976) mandates comprehensive tracking of hazardous waste, requiring industries to document each stage of sludge treatment to prevent illegal disposal. The European Union’s REACH Regulation and Wastewater Directive prohibit the use of hazardous substances like mercury and lead in cosmetics, while promoting sludge recycling into biofertilizers (51). China’s National Hazardous Waste Inventory enforces on-site sludge treatment and imposes heavy penalties for non-compliance, though enforcement remains inconsistent in

Table 1: Comparison of cosmetic waste management in India and other countries

Aspect	India	Global (USA, EU, China, etc)
Regulatory Bodies	CPCB, MoEFCC, CDSCO	EPA (USA), ECHA(EU), MEE(China), DEFRA(UK)
Waste Classification	Hazardous, solid and biomedical waste	Mostly hazardous waste under strict regulations.
Disposal Methods	Segregation, landfills, incineration	Advanced waste treatment like recycling & energy recovery
Industry Responsibility	Some rules on Extended Producer Responsibility (EPR)	Stronger enforcement of EPR for cosmetics & packaging
Law Enforcement	Moderate, with some compliance gaps	Stricter rules, heavy penalties for violations
Import/Export Rules	Restricted under Hazardous Waste Rules	Strict international trade restrictions for hazardous waste.
Environmental Protection	Focus on pollution control, but gaps exist	More advanced ecofriendly solutions in developed nations.

some regions (52). Japan, under its Waste Management and Public Cleansing Law, mandates near-zero waste policies, requiring the use of biodegradable ingredients and conversion of cosmetic sludge into industrial fuel—achieving over 80% sludge reutilization (53). These global models emphasize the importance of strict regulations, effective monitoring, and financial deterrents to minimize environmental harm (Table 1).

In contrast, India's regulatory framework, though well-intentioned, suffers from weak enforcement. Key legislations include the Environmental Protection Act (1986) and the Water (Prevention and Control of Pollution) Act (1974), which mandate pollution control measures and effluent treatment systems. However, enforcement is often hindered by poor oversight and systemic challenges (49). The Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 classify cosmetic sludge as hazardous when containing toxic substances, requiring special authorization

for its disposal. The Central Pollution Control Board (CPCB) has issued guidelines promoting on-site treatment and waste-to-energy practices, yet compliance remains low due to high implementation costs and lack of accountability (54). While global systems employ digital tracking and impose strict penalties, India lacks robust monitoring infrastructure, allowing for illegal dumping and non-compliance (55,56). Additionally, sustainable practices such as waste-to-energy conversion and biodegradable alternatives are still at a nascent stage in India, unlike their mainstream adoption in more advanced regulatory environments.. To address these gaps, India must strengthen its regulatory enforcement, increase penalties for violations, implement digital waste tracking, and incentivize sustainable practices. Adopting successful elements from international models could significantly improve compliance, reduce environmental impact, and promote long-term sustainability in cosmetic sludge management (Table 2).

Table 2: Authority, Regulations and key provisions for treatment and compliance of cosmetic Waste		
Regulation/Guideline	Authority	Key Provisions
Bio-Medical Waste Management Rules, 2016	MoEFCC(Ministry of Environment, Forest and Climate Change)	Cosmetic sludge containing hazardous waste must be treated as biomedical waste and disposed of accordingly.
Hazardous and Other Wastes (Management and Transboundary Movement) Rules,2016	CPCB (Central Pollution Control Board)	Restricts the import/export of hazardous cosmetic sludge and mandates proper treatment before disposal
Cosmetic Rules, 2020	CDSCO (Central Drugs Standard Control Organisation)	Defines safety standards for cosmetics, including waste management of expired or contaminated products
Solid Waste Management Rules, 2016	MoHUA (Ministry of Housing and Urban Affairs)	Mandates segregation, collection, and disposal of cosmetic waste.
Water (Prevention and Control of Pollution) Act, 1974	CPCB	Prevents cosmetic sludge from contaminating water sources
Air (Prevention and Control of Pollution) Act, 1981	CPCB	Ensures that waste incineration does not release harmful pollutants.

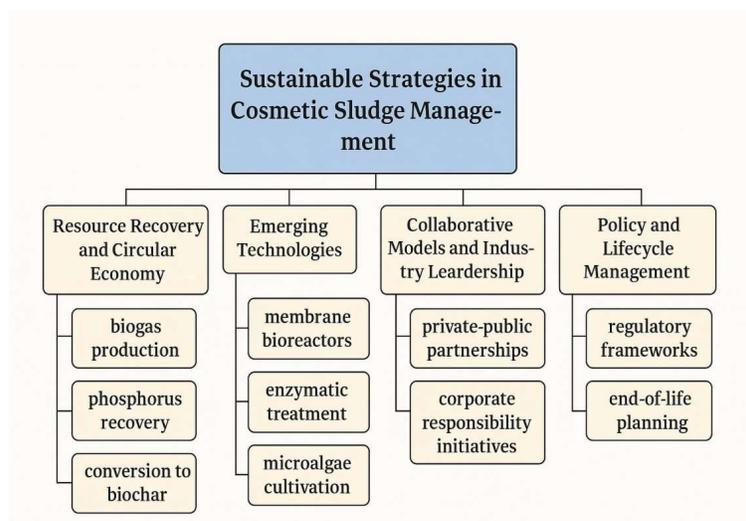


Fig. 3: Sustainable Strategies in Cosmetic Sludge Management

Sustainable Strategies in Cosmetic Waste Management

Global sustainability trends are reshaping cosmetic sludge management. The EU Circular Economy Action Plan promotes sludge recycling and zero-waste production, significantly reducing the cosmetics industry's environmental footprint (EU 2020). Similarly, the United Nations Industrial Development Organization (UNIDO) supports low-waste manufacturing and encourages sustainable practices. Tools like eco-labelling and green certifications empower consumers and incentivize companies to adopt responsible waste management (57). In India, policies such as Extended Producer Responsibility (EPR), waste-to-energy projects, and the CPCB's Green Manufacturing Guidelines signal progress toward sustainability. However, achieving meaningful impact will require stronger enforcement, industry cooperation, and government incentives (58) (Fig. 3).

- **Resource Recovery and Circular Economy**

Transforming cosmetic sludge into industrial fuel offers a promising waste

reduction strategy. Pyrolysis and gasification convert sludge into biofuel and electricity, while anaerobic digestion generates biogas through microbial degradation of organic matter—contributing to energy recovery and sustainability (59, 12). Sludge can also be repurposed into biofertilizers, construction materials (e.g., cement, bricks, asphalt), and even cosmetic ingredients such as oils, waxes, and silica. These applications support circular economy models by reducing waste and recovering valuable resources.

- **Emerging Technologies**

Nanotechnology has shown great potential in improving treatment efficiency. Nano-adsorbents effectively remove heavy metals, while nano-catalysts accelerate pollutant breakdown through advanced oxidation processes. Artificial intelligence (AI) and machine learning are being applied to predict sludge generation patterns, optimize treatment operations, and automate sorting processes (60,61). Additionally, advances in synthetic biology—such as CRISPR-engineered microbes—are enhancing the biodegradation of toxic cosmetic waste (62).

- Collaborative Models and Industry Leadership

Public-private partnerships are vital for fostering innovation. Government grants, industry-wide sustainability commitments, and support for green technologies can drive large-scale change. Major cosmetic brands like L'Oréal, Unilever, and Estée Lauder can lead by example, while academic institutions contribute through research and pilot projects. Industrial symbiosis programs, where waste from one industry is used as a resource in another, offer additional opportunities. For example, cosmetic sludge can be used in agriculture, biogas production, or construction (48).

- Policy and Lifecycle Management

Adopting closed-loop manufacturing and biodegradable formulations can drastically reduce hazardous sludge generation. Enforcing mandatory take-back programs and strengthening EPR policies will ensure manufacturers remain responsible for the full lifecycle of their products (49). Regional sludge treatment centres and retailer-led collection initiatives can further support large-scale recycling and reduce illegal dumping (53).

Conclusion

The management of cosmetic sludge presents a pressing global challenge, driven by the rapid expansion of the cosmetics industry and the hazardous nature of its waste. Containing heavy metals, synthetic chemicals, microplastics, and microbial contaminants, untreated cosmetic sludge poses serious long-term risks to ecosystems, water bodies, and human health. With the global demand for beauty products rising, effective and sustainable sludge management has become more critical than ever. The environmental consequences are severe. Soil pollution reduces agricultural productivity, while sludge-laden water bodies endanger marine life and contaminate drinking water sources. Bio accumulative substances from cosmetic waste, including endocrine disruptors and reproductive toxins, have been found in aquatic organisms, highlighting the far-reaching impact on ecosystems and food safety. The health implications are equally

alarming. Exposure to heavy metals and persistent organic pollutants has been linked to neurological damage, endocrine disruption, immune dysfunction, and reproductive issues. Microplastics and antibiotic-resistant bacteria in sludge elevate the risk of chronic illnesses and infectious diseases, especially in communities with limited access to clean water. The cosmetics industry must also lead by reformulating products using safer, biodegradable ingredients, reducing chemical use, and investing in cleaner production methods. Adopting circular economy practices—such as converting sludge into fuel, biofertilizers, or construction materials—can further minimize environmental impact. At the same time, consumers play a vital role by supporting eco-conscious brands and demanding transparency and sustainability in product sourcing and disposal. Ultimately, the future of cosmetic sludge management depends on collaborative action. Governments, industries, scientists, and consumers must unite to build an effective and sustainable waste management system. Without immediate intervention, cosmetic sludge will continue to pollute natural resources, endanger public health, and compromise the well-being of future generations. By prioritizing responsible production, advanced treatment technologies, and environmental accountability, the cosmetics sector can transition toward a cleaner, safer, and more sustainable future.

Conflict of Interest-

Author declares no conflicts of interest.

References

- 1 Juliano, C. & Magrini, G. (2017). Cosmetic ingredients as emerging pollutants of environmental and health concern: A mini review. *Cosmetics*, 4(2), p.11.
- 2 Aranaz, I., Acosta, N., Civera, C., Elorza, B., Mingo, J., Castro, C., Gandía, M.D.L.L. & Heras Caballero, A. (2018). Cosmetics and cosmeceutical applications of chitin, chitosan and their derivatives. *Polymers*, 10(2), p.213.
- 3 Daughton, C.G. & Ternes, T.A. (1999). Pharmaceuticals and personal care products

- in the environment: Agents of subtle change? Environmental Health Perspectives, 107(Suppl 6), pp.907–938.
- 4 Liu J-L, Wong M-H. (2013). Pharmaceuticals and personal care products (PPCPs): a review on environmental contamination in China. *Environ Int* 59:208-224.
- 5 Klaschka, U., Helm, D. & Lange, R. (2013). Occurrence and fate of pharmaceuticals and personal care products in the environment: Current research and regulatory perspectives. *Environmental Science Europe*, 25(1), pp.1–10.
- 6 Montes-Grajales D, Fennix-Agudelo M, Miranda-Castro W. (2017). Occurrence of personal care products as emerging chemicals of concern in water resources: A review. *Sci Total Environ.* 1; 595:601-614.
- 7 Bogacki, M., Kacprzak, M. & Bartkowska, I. (2020). Treatment of highly polluted cosmetic wastewater. *Environment Protection Engineering*, 43(2), pp.35–45.
- 8 Scott, M.J., & Jones, M.N. (2000). The biodegradation of surfactants in the environment. *Biochimica et Biophysica Acta (BBA)-Biomembranes*, 1508(1-2):1 235–251
- 9 Chen, S. (2019). Occurrence Characteristics and Ecological Risk Assessment of Heavy Metals in Sewage Sludge. *IOP Conference Series: Earth and Environmental Science*. 295.
- 10 Nguyen, M-K., Lin, C., Nguyen, H-L., Le, V-R., Priya, K.L., Singh, J., Chang, S.W., Um, M-J. and Nguyen, D.D. (2023). Emergence of microplastics in the aquatic ecosystem and their potential effects on health risks: The insights into Vietnam. *Journal of Environmental Management*, 344, p.118499.
- 11 Bamaniya, P-K., Iqbal, G. & Bambhaniya, I-J. (2023). Sewage and its impact on aquatic ecosystems. *AgriGate- An International Multidisciplinary e-Magazine* 03. 237- 243.
- 12 García, M., Serrano, J.A. & Martínez, M.(2020). Volatile organic compounds in cosmetic products: Emission sources and regulatory frameworks. *Journal of Environmental Management*, 260, p.110123.
- 13 Tiwari, B., Sellamuthu, B., Ouarda, Y., Drogui, P., Tyagi, R.D. and Buelna, G. 2017. Review on Fate and Mechanism of Removal of Pharmaceutical Pollutants from Wastewater Using Biological Approach. *Bioresource Technology*, 224, 1-12.
- 14 Liu, N., Jin, X., Feng, C., Wang, Z., Wu, F., Johnson, A.C., Xiao, H., Hollert, H. & Giesy, J.P. (2020). Ecological risk assessment of fifty pharmaceuticals and personal care products (PPCPs) in Chinese surface waters: A proposed multiple-level system. *Environment International*, 136, p.105454.
- 15 Fent, K., Escher, Bl., Diaz-Cruz, S., Posthuma, L., & de Zwart, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology*, 76(2), 122–159.
- 16 Cheryan, M. (1998). *Ultrafiltration and microfiltration handbook*. 2nd Ed-CRC press, 552.
- 17 Wakeman, R.J. (2007). Separation technologies for sludge dewatering. *Journal of Hazardous Materials*,144(3), 614-619
- 18 Crittenden, J., Trussell, R., Hand, D., Howe, K. and Tchobanoglous, G. (2012). *MWH's Water Treatment: Principles and Design*. 3rd Edition, John Wiley & Sons, Inc., New York
- 19 Reynolds, TD., & Richards, PA. (1996). *Unit operations and processes in environmental engineering*. 2nd Edition, PWS Publishing Company, Boston.
- 20 Tchobanoglous, G., Burton, FL., & Stensel, HD. (2003). *Wastewater Engineering, Treatment and Reuse*. 4th Edition, McGraw-Hill, Boston.
- 21 Metcalf & Eddy. (2014) *Wastewater Engineering: Treatment and Resource Recovery*. 5th Edition, McGraw-Hill, New York.
- 22 Bhatnagar, A., Sillanpää, M. (2017). Removal of natural organic matter (NOM) and its constituents from water by adsorption – A review, *Chemosphere*, 166, 497-510
- 23 Topare, NS., & Wadgaonkar, VS. (2022). A review on application of low-cost adsorbents for heavy metals removal from wastewater. *Materials Today: Proceedings*
- 24 Patel, D. (2017). Waste Water treatment by using low-cost adsorbent: A Review. *IJARIIIE*, 3 (2):3658-3669.
- 25 Bratby, J. (2016). *Coagulation and Flocculation in Water and Wastewater Treatment* (3rd ed., Vol. 15). IWA Publishing.

- 26 Mensah-Akutteh, H., Buamah, R., Wiafe, S. et al. (2022). Optimizing coagulation– flocculation processes with aluminium coagulation using response surface methods. *Appl Water Sci* 12, 188
- 27 Hongmei, C., Xing, H., Zhongchen, Y., Ping, C., & Xiaoling C. (2020). Application progress of enhanced coagulation in eater treatment. *RSC Advances*, 10, 20231-20244
- 28 Sawyer, CN., McCarty, PL. & Parkin, GF. (2003). *Chemistry for Environmental and Engineering Science*. 5th Edition, McGraw Hill Inc., New York, 587-590.
- 29 Richardson, S. (2003). Disinfection By-Products and Other Emerging Contaminants in Drinking Water, *Trends in Analytical Chemistry*, 22(10): 666-684.
- 30 Hübner, U., Spahr, S., Lutze, H., Wieland, A., Rütting, S., Gernjak, W., & Wenk, J. (2024). Advanced oxidation processes for water and wastewater treatment - Guidance for systematic future research. *Heliyon*, 10(9): 30402
- 31 Andreozzi, R., Caprio, V., Insola, A. and Marotta, R. (1999). Advanced Oxidation Processes (AOP) for Water Purification and Recovery. *Catalysis Today*, 53, 51-59
- 32 Martínez-Huitle, CA. & Panizza, M. (2018). Electrochemical Oxidation of Organic Pollutants for Wastewater Treatment. *Current Opinion in Electrochemistry*, 11, 62-71
- 33 Zhang, X., Li, J., Yang, W., Chen, J., Wang, X., Xing, D., Dong, W., Wang, H., Wang, J. (2022). The combination of aerobic digestion and bioleaching for heavy metal removal from excess sludge, *Chemosphere*, 290: 133231
- 34 Grady Jr., Daigger, CL., Love, GT., and Filipe, CD. (2011). *Biological Wastewater Treatment*. CRC Press, Boca Raton.
- 35 Rittmann, BE., & McCarty, PL. (2001). *Environmental Biotechnology: Principles and Applications*. McGraw-Hill Education, New York.
- 36 Henze, M., Harremoës, P., Jansen, JLC., & Arvin, E. (2001). *Wastewater Treatment Biological and Chemical Processes*, 3rd Edition, Springer, Berlin.
- 37 Wydro U, Wołejko E, Luarasi L, Puto K, Tarasevičienė Ž, Jabłońska-Trypuć A. (2024). A Review on Pharmaceuticals and Personal Care Products Residues in the Aquatic Environment and Possibilities for Their Remediation. *Sustainability*. 16(1):169.
- 38 Pachaiappan, R., Cornejo-Ponce, L., Rajendran, R., Manavalan, K., Femilaa Rajan, V., & Awad, F. (2022). A review on biofiltration techniques: recent advancements in the removal of volatile organic compounds and heavy metals in the treatment of polluted water. *Bioengineered*, 13(4), 8432–8477.
- 39 Cheng, YX., Chen, J., Wu, D., Liu, YS., Yang, YQ., He, LX., Ye, P., Zhao, JL., Liu, SS., Yang, B., Ying, GG. (2021). Highly enhanced biodegradation of pharmaceutical and personal care products in a novel tidal flow constructed wetland with baffle and plants. *Water Res* 193:116870.
- 40 Wu, H., Zhang, J., Ngo, HH., Guo, W., Hu, Z., Liang, S., Fan, J., Liu, H. (2015). A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. *Biores Technol* 175:594–601.
- 41 Vymazal J. (2011). Constructed wetlands for wastewater treatment: five decades of experience. *Environ Sci Technol*. 1;45(1):61-9.
- 42 Kumar, R., Laskar, MA., Hewaidy, IF., et al. (2019). Modified Adsorbents for Removal of Heavy Metals from Aqueous Environment: A Review. *Earth Systems and Environment*, 3, 83-93.
- 43 Aguiar, Joana & Martins, Ana & Almeida, Cristina & Ribeiro, Helena & Marto, Joana. (2022). Water sustainability: A waterless life cycle for cosmetic products. *Sustainable Production and Consumption*. 32.
- 44 Bilal M, Mehmood S, Iqbal HMN. (2020). The Beast of Beauty: Environmental and Health Concerns of Toxic Components in Cosmetics. *Cosmetics*, 7(1):13.
- 45 Luo, Y., Guo, W., Ngo, H. H., Nghiem, L. D., Hai, F. I., Zhang, J., Liang, S., & Wang, X. C. (2014). A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. *The Science of the total environment*, 1:473-474, 619–641
- 46 Klaschka U, von der Ohe PC, Bschorer A, Krezmer S, Sengl M, Letzel M. (2013). Occurrences and potential risks of 16 fragrances in five German sewage treatment plants and their receiving waters. *Environ Sci Pollut Res* 20(4):2456–2471.

- 47 Liu S., Shi, J, Wang, J., Dai, Y., Li, H., Li, J., Liu, X., Chen, X., Wang, Z., Zhang, P. (2021). Interactions Between Microplastics and Heavy Metals in Aquatic Environments: A Review *Frontiers in Microbiology*, 12.
- 48 Kumar S., Smith SR., Fowler G., Velis C., Kumar SJ, Arya S., Rena, Kumar R., and Cheeseman C. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Sci*, 4: 160764
- 49 Chen, H., Gao, Y., Li, J. et al. (2022). Engineered biochar for environmental decontamination in aquatic and soil systems: a review. *Carbon Research* 1: 4
- 50 Mishra, Ranjeet & Kumar, D. & Narula, Archana & Chistie, Syeda & Naik, Sneha. (2023). Production and beneficial impact of biochar for environmental application: A review on types of feedstocks, chemical compositions, operating parameters, techno- economic study, and life cycle assessment. *Fuel*. 343: 127968.
- 51 Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. *Toxics*, 9(3), 42.
- 52 Ministry of Ecology and Environment of People's Republic of China. (2023). List of new pollutants under key control.
- 53 Huang, Y., Yuhang Zhen, Lanling Liu, Xiaoyang Ning, Chenzhou Wang, Kai Li, Li Zhao, Qiang Lu. (2023). Comprehensive competitiveness assessment of four typical municipal sludge treatment routes in China based on environmental and techno-economic analysis, *Science of The Total Environment*, 895:165123
- 54 Patel, Suresh & Singh, Deepak & Singh, Deepesh & Kumar, Pradeep & Singh, Dhananjay. (2020). Physicochemical parametric and water quality index (WQI) analysis of Gomti River, Lucknow using MDSSS, *J. Indian Chem. Soc*, 97 (10a):1725-1730
- 55 Chen, J., Liu, Chenyu & Hua, Chunxiang. (2021). Efficient supervision strategy for illegal dumping of construction and demolition waste: A networked game theory decision-making model. *Waste Management & Research: The Journal for a Sustainable Circular Economy*. 40 (6): 0734242X2110320.
- 56 Chen, Sophia Shuang & Kimirei, Ismael & Yu, Cheng & Shen, Qiushi & Gao, Qun. (2022). Environmental Science and Pollution Research Assessment of urban river water pollution with urbanization in East Africa. *Environmental Science and Pollution Research*. 29:14
- 57 Zhang, Qinlin & Mi, Junlong & Shen, Hongtao. (2019). Green Labeling and Sustainable Development. In book: *Encyclopedia of Sustainability in Higher Education* (pp.1-7)
- 58 Singh, S., Balkrishna, Acharya., Pathak, Rakshit., & Arya, Ved. (2022). *Sludge Management: Current Scenario, Available Solutions and Way Forward*, Authorea.
- 59 Cao, Yucheng & Pawłowski, Artur. (2012). Sewage sludge-to-energy approaches based on anaerobic digestion and pyrolysis: Brief overview and energy efficiency assessment. *Renewable and Sustainable Energy Reviews*. 16. 1657–1665.
- 60 Bin Nasir, Fuad & Li, Jin. (2024). Comparative Analysis of Machine Learning Models and Explainable Artificial Intelligence for Predicting Wastewater Treatment Plant Variables. *Advances in Environmental and Engineering Research*. 05. 1-23.
- 61 Nguyen, Xuan & Nguyen, Thi Thanh & Tran Ba, Quoc & Bui, Xuan-Thanh & Ngo, Huu & Nguyen, Dinh Duc. (2022). Artificial intelligence for wastewater treatment. In book: *Current Developments in Biotechnology and Bioengineering* :587-608.
- 62 Minhas, Waqar & Saleemi, Mr & Raheem, Mohanad & Khalid, Shahad & Aslam, Hira & Ahmad, Waqas. (2024). Crispr-Engineered Microbes for Enhanced Biodegradation Of Recalcitrant Pollutants A Genomic Approach To Environmental Remediation. *Frontiers in Health Informatics*. 13.