Personal Care Products: Ecological and Human Risk Assessment

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Abstract

Personal care products (PCPs) include fragrances, shampoos, soaps, lotions, cosmetics. From many years, consumption of these products increased, primarily because their reagent components including many dangerous and toxic chemicals remain in the environment causing strains on aquatic life and human health. These emissions which include synthetic musk compounds, ultraviolet (UV) filters, parabens, phthalates, and microplastics enter water via discharge of wastes and hydrogenation. Research has revealed the fact that PCPs interfere with endocrine systems, negatively affect aquatic plants and animals, and build up in food chains. Also, it is an allergen and toxic to humans in large quantities; contact may lead to skin rashes, while drinking water containing the chemicals may have long-term health impact including; reproductive toxicity and carcinogenicity. The mitigating strategies includes bioremediation strategies, as well as sustainable approaches for minimizing the environmental impact of PCPs. This has been emphasized to show that it is easier to evaluate the ecological health risks in addition to the human health risks in other to come up with better regulations and safer formulation of products. The coordinated measures should be taken to reduce the undesirable effects of PCPs on the biota and health of populations.

Keywords: Personal care products, Environmental impact, Toxicity, Bioremediation, Endocrine Disruption

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Introduction

Personal Care Products (PCPs) are part of everyone's everyday lives and can be remarkably diverse, ranging from cosmetics, soaps, shampoos, perfumes, sunscreens and toothpaste. However, their application has provoked release of their constituents into the environment and has been raising concerns about negative effects on the environment and human health. However, it is crucial to emphasize some of the challenges in the continued and biological accumulation of some of these chemicals, which represents a threat to ecological and human systems in particular (Alimi et al., 2017). This chapter gives an ecological and human risk assessment of PCPs including the identification of key compounds, the routes of entry into the environment, and risks associated with them. While exploring the correlation between their utility as indispensable products and their risk factors the given chapter seeks to contribute to the understanding of these products as both useful and threatening. Furthermore, there is the provision that they need to support sustainable processes to reduce the harm that these practices bring about.

3. Composition of PCPs

PCPs are formed by a large number of chemicals such as synthetic fragrances, preservatives, UV filters and microplastics. These extend the shelf life of products, protect them from sun or give the right texture. But they contaminate the environment causing ecological and human health complications. When used, these products make their way into the aquatic environment mainly in wastewater effluents. Among these substances recently found in aquatic systems includes synthetic musk compound that have been used as fragrance carrier (Jamil et al., 2025), parabens that have been utilized mainly as preservatives, and benzophenones that have been employed predominantly as UV filters (Riaz et al., 2025), have been found most commonly. Additionally, the other constituent of PCPs also known as microplastics is a significant in increasing pollution. These microplastics, which are used in scrubbing and washing products continue to affect water ecosystems while they also transport other toxic materials (Andrady, 2011). Consequently, people can ingest more of them from food chains and they may be deadly to marine organisms and other animals and hence may become biomagnified after having been accumulated. The effects of these contaminants also serve to light up the need to develop high end treatment methods and very firm laws to constrain emission of such materials (Atugoda et al., 2020).

4. Environmental Pathways

4.1. Aquatic Systems

Waste water treatment plants (WWTPs) discharge PCPs into the environment. Triclosan and bisphenol A, have been identified and found in effluent water which cause toxicity to aquatic organisms. These effects include hormonal disorders, changes in behavior of fish and other fauna living in the marine environment (Bakir et al., 2013). Their constant release also endangers the species diversity and the stability of the food pyramid and in general the ecosystem (Dris et al., 2015).

4.2. Soil and Sediments

Disposal of sewage sludge on land brings PCP residues into soils where they can both leach down to pollute groundwater or accumulate in sediments. In turn, the resulting accumulation of the chemical in the tissues of terrestrial living organisms affecting entire ecosystems (Barnes et al., 2009). Studies show that PCP in agricultural soils decreases the capacity of the soil as a plant nutrient and affect the microbial population present in the soil important in cycling nutrients (Bollmann et al., 2019).

4.3. Atmospheric Deposition

Contamination of the atmosphere also comes from aerosolized PCPs from such products as deodorants and sprays. These volatile suspensions can deposit on soil and water bodies which contribute a new aspect to the PCP problem (Artacho-Cordón et al., 2018). New findings indicate that when inhaled, these particles may cause respiratory disease to humans. Dry deposition on agricultural fields can cause indirect exposure to humans through ingestion 'contaminated' food products (Abiodun & Ayeleru, 2025). The cumulative outcomes of these pathways explain the extensive extents of PCP pollution and its capability to impact different environments through potential sources and pathways (Bollmann et al., 2019).

5. Toxicological Impacts

5.1. Aquatic Toxicity

A good portion of PCP constituents like synthetic musks and UV filters have been known to exert acute and chronic toxicity to aquatic life including fish and invertebrates. For example, the sunscreen component oxybenzone affects coral in such ways as to bleach the coral and disrupt the endocrine system of marine animals (Balázs et al., 2016). It does not only upset the marine organisms but also organisms which depend on the coral reefs hence causing a domino effect to other marine systems. Also, observed behavioral alteration in fish treated with such substances is evidence of a social cost associated with impaired instincts of the fish such as feeding and escaping from predators (Baranowska & Wojciechowska, 2013).

5.2. Bioaccumulation

Semi-volatile non-biodegradable lipophilic compounds, for instance, parabens and some phthalates, bioaccumulated in fishes consuming the contaminated water or bottoms (Chen et al., 2020). Biomagnification can result from this type of pollution; such a factor affects the life of apex predators and Food chain. For instance, biomagnified phthalates in fish organs have an influence on the prey-predator relationship and system resilience. In the long run, the influences flow into other changes within the aquatic biological community and even change the structure and dynamics of the ecosystem itself (Charles & Darbre, 2013).

5.3. Disruption of Microbial Communities

Triclosan disturbs the structure of microbial assemblages in sediments and wastewater affecting nutrient cycling (Chen et al., 2017). Some of these disruptions may trigger other ecological changes that affect ecosystem processes that are central to ecosystem stability, including primary production rate and decomposition rate. Moreover, changes in microbial richness can affect the ability of ecosystems to withstand pressure from environmental stressors that this study shows are already enhanced by PCP pollution (Blahova et al., 2020).

6. Ecological Risk Assessment of PCPs

The threats that PCPs pose to the ecology are the fulfillments of PBT, that is, the PCPs resist degradation, accumulate in living organisms, and are toxic. These properties make PCPs of particular concern to the environment because they are able to bioaccumulate in different ecosystems for years. Some of these chemicals can take a very long time to break down, hence the fact that they can circulate in the environment for long (Schür et al., 2021). They are able to bioaccumulate in organism and biomagnify into the higher organism, including predators and man. These chemicals also produce negative effects on the reproductive, neurological and immune systems of the aquatic organism. These risks range in severity and include risks associated with chemical nature of the pollutant, concentration, environmental conditions, and other coexisting pollutants. For instance, oxybenzone used in UV filters is used in cases of coral bleaching while parabens which are used in endocrine systems affecting fish and amphibians. Further, Wastewater Treatment Plants (WWTPs) that are inefficient in the removal of many of these non-degradable materials contribute to the problem by regularly discharging them to water bodies (Srain et al., 2020). These risks attest to the importance of undertaking systematic ecological risks in assessment; enhancing WWTPs technology; and enforcing stringent regulatory measures in the attempt to reduce diminishing effects of PCPs on ecosystems (Cahova et al., 2021).

7. Human Health Implications

Despite the fact that most of the PCPs are related to ecological systems, they cause serious health threats to human beings (De Sá et al., 2018). Consumption of products containing potentially hazardous chemicals phthalates, parabens triclosan, and synthetic musks exposes the body through dermal contact, breathing and systemic system. There is evidence that continual use of these products leads to various negative health effects such as; endocrine disruption and reproductive health complications and carcinogenicity. For example, phthalates used as plasticizers in PCPs disrupt the hormonal pathways, and impacts fetal development or fertility (Derraik, 2002). Like that, parabens were detected into human breast tissue, raising question if they cause carcinogenic hormone-dependent diseases. New studies indicate that relatively low, long-term levels of these chemicals can interfere with the hormonal and developmental processes gradually.

Another is aerosolized PCP in particular in sprays and powders; It has been noted that these products may emit fine particles on the surfaces and with these, one can breathe with irritation to the respiratory system as well as worsening existing illnesses, for instance, asthma. It has also been explained that exposure to these particles must also have systemic effects, leading to oxidative stress and inflammation in the respiratory tract after long time inhalation (De Sá et al., 2018).

In addition, indirect human infection through ingestion of contaminated food and water makes it even worse. For instance, the presence of PCP residues in food crops washed with wastewater or fish and other aquatic animals that are source of protein raises the comprehensive ways through which these chemicals find their way into human food chain. Because multiple forms of exposure are possible, especially when combined with exposures by other routes, the need for proper regulation regimes becomes more pertinent (Ebele et al., 2017).

8. Regulatory Frameworks and Global Perspectives

The ingredients in PCPs are highly regulated by the European Union REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals). This measure prescribes the use of certain chemicals in PCPs or PCP components and demands firms to disclose more information concerning the safety of chemicals present in PCPs. For example, microbead with rinse-off cosmetics which is under the microplastic restriction is being stepped down gradually. Likewise, the FDA regulates PCP safety, but its standard is not as strict as REACH, given the American organization emphasizes product labeling and monitors products after their release to the market. The absence of many synchronized pre-market testing requirements is that there may be circulation of an anticipated number of dangerous products (Karpińska & Kotowska, 2019).

On the other hand, regional bans including those that have been affected in Hawaii and Palau are blanket bans of individual PCP ingredients like oxybenzone and octinoxate which are known to affect coral reefs. Still, large regulatory gaps in legal requirements exist today. Some of the countries do not even possess a complete mechanism of standard monitoring and controlling of the PCP pollutants; hence they find themselves accidental polluters of ecosystems. The other issue is missing international cooperation, and since pollutants are not limited by state borders, the mentioned challenges are worsened. Because the problem of PCP pollution is global, reversing the situation requires a coordinated global strategy of research, enforcement, and education (Eerkes-Medrano et al., 2015).

9. Alternatives to Harmful PCP Ingredients

Substituting PCP formulation with eco-friendly products is the next big thing to ensure that environmental degradation is being tackled. Currently, natural waxes, starch-based polymers and cellulose derivatives have been adopted as materials that can replace microplastics. As for the other materials, they are biodegradable; reducing the occurrence of pollutants within the ecosystem. Likewise, parabens commonly used preservatives serve the same purpose as natural antimicrobials like grapefruit seed extract, essential oil, and their congeners that possess broad antimicrobial effectiveness (Czarczyńska-Goślińska et al., 2017). Currently replacing phthalates are other plasticizers such as citrate esters and adipates which are safe to human and the environment and perform the same job as phthalates but in a safer way. One can develop molecules with desired activity, lower toxicity, high biodegradation, and thus, low ecological impact of the formulated preparations. For instance, biosurfactants synthesized through enzymic processes and from natural renewable resources are gradually becoming preferred to the synthetic products. These biosurfactants find equal effectiveness as gasoline biosurfactants but have reduced impacts on the environment and also do not easily accumulate in water organisms (Montes et al., 2023).

Top PCP industry players are promising to ban hazardous substances in their supply chain by using accreditation such as 'Cradle to Cradle' and conform to global sustainability standards. Another force is the type of research collaborations between universities and companies that continuously advance the industry, improving new ingredients safety and effectiveness. Social factors such as policy supports and legal structures exert pressure on manufacturers to utilize environment friendly techniques and products satisfy a market which demands the link between profitability and environmentally-friendly products (Czarczyńska-Goślińska et al., 2017).

10. Economic Impacts of PCP Pollution

The problem of PCPs pollution is not simply an environmental issue; there are economic and social consequences as well. These pollutants are some of the toughest to remove from the environment, and are detrimental to the health of ecosystems, animals, and humans. These factors make cleanup activities necessary to remove PCP from the environment a considerable cost. Costs of contamination control are usually very high often requiring municipalities to spend large amount of funds in cases of water bodies, urban spaces and soil. For instance, water treatment to eliminate industrial effusion, bad waste disposal, or agricultural chemicals could cost millions of dollars per year, with local government having the problem of sourcing for these funds (Karpińska & Kotowska, 2019; Pant et al., 2025). Squeezed finances typically lead to fiscal issues in municipalities because the budget is thin, thus leaving little money for many other essential public goods like education, water and sewerage, health facilities (Elizalde-Velázquez et al., 2020).

The treatment of PCPs pollutants in water systems is quite complicated. Some of these chemicals are not easily biodegraded or simply known to be persistent in the environment and hence, needs special and expensive treatment methods like the AOP, adsorption as well as biotreatment processes. Often the cleanup takes years or even decades, in which case it endures as costly operation where municipal budgets are concerned (Pant et al., 2025).

11. Public Awareness and Consumer Behavior

There is no denial of the fact that community education programs are very effective in lowering the levels of pollution by PCP. Speakers like "Beat the Microbead" that inform consumers on the effect of microplastics to the environment, have greatly swayed consumer buying behavior. More PCPs recollection from their users can still reduce pollution through proper disposal, for example returning non-used products to collection centers (Ebele et al., 2017).

Consumer behavior analysis shows an increasing trend whereby clients are looking at environmentally friendly PCP products certified as being organic through United States Department of Agriculture (USDA) Organic and Ecolabel. These trends are well supported by social media, as brands engage in marketing their sustainability campaigns and reaching out to green customers. But for a change to be sustainable, all stakeholders, policies and standards need to support such behavior change by governments, NGO's and the business world (Fan et al., 2020).

12. Innovative Research and Future Directions

The investigation of pollution resulting from PCPs has also received substantial attention in the recent past due to growing awareness of pollution effects. Researchers are also concerned with the identification of the methods of detecting PCP pollution, methods of minimizing pollution, and researching possible environmentally friendly replacement materials for PCP containing chemicals. Another giant step made in this field is to acquire the techniques that allow for the real-time monitoring of pollutants in aquatic systems using sensors. Such sensors can be able to detect even the presence of contaminants with high accuracy, and therefore respond to contamination as soon as it happens. This capability is important in reducing the risks which different aquatic species will be exposed to in their natural habitat, thus destabilizing the food chain (Gao et al., 2019). Advancements in sensoring triggered increased opportunities for tracking the health of aquatic environment and promptly act to avoid deterioration. For instance, the wearable or portable sensor gadgets may be used in the different water bodies to monitor the levels of pollution to enhance decision making among the authorities. Furthermore, it is possible to incorporate such sensors into systems that carry out certain desired response actions, hereby initiating filtration systems or the release of neutralizers. Such development in monitoring tools presents a good opportunity through which better and more efficient interventions could be made in environmental management (Ebele et al., 2017).

Another practice in keeping PCP out of water bodies is bioremediation where microorganisms are used to decompose the dangerous chemical compounds into less toxic or non-toxic products. Bioremediation has been shown to be efficient, credible, and stable when used to remove pollutants, including that some bacterial species possess the ability to break down pollutants found in personal care products including parabens and phthalates. Engineers and environmental scientist have been trying to use the genetic engineering principles to attain a bacteria with a higher capacity to break down these substances and in turn optimizing bioremediation processes. The need for destroying pollutants has made it possible for example, to genetically modify bacteria which will go for specific chemical bonds within the pollutants and break them at a higher rate than would be normally possible (Falisse et al., 2017).

Future efforts in relation to controlling pollution through the reduction of PCP emissions are directed towards achieving 'near-zero' emissions by developing products that have insignificant levels of environmental impact. Another good idea emerging currently is the one which will focus on the development of PCPs that are safe for end-users and their environment with a limited lifespan. It encompasses all the phases of a product's life, manufacturing, utilization, decommissioning, disposal, and not contributing to the product's lingering in the system or causing system damage. Scientists are looking for ways of using biodegradable materials in the packaging, or creating packaging which can be recycled easily. If the companies decide to follow the new philosophy of the product development emphasizing the aspects of environmental interactions, the industry will decrease its ecological burden (Morales-Cano et al., 2023).

New ways of thinking, designing and manufacturing personal care products, aptly captured in the concept of 'benign by design' enhances the ability of the personal care production process to meet conservation objectives. The implementation of such an approach would require a strong cooperation between the researchers, the policymakers, and the representatives of enterprise industries. This will require key partnerships so that not only are solutions proposed technically feasible, but in addition they are also economically sustainable and integrated across society (Bollmann et al., 2019).

Conclusion

There is a necessity to pay substantial attention to ecological and human health concerns of PCPs. These are part of everyone's everyday lives and can be remarkably diverse, ranging from cosmetics, soaps, shampoos, perfumes, sunscreens and toothpaste. The constant pollution of water with toxic substances emanating from PCPs indicates the need to find improved solutions for product formulations and management of these products. It can eradicate impacts through improving detection technologies, bioremediation, and design for environment or ''benign by design'' of products. Because the long-term sustainability of PCP in ecological/environmental preservation and human welfare cannot be overemphasized, cross sectorial collaborations between researchers, policymakers and the industries will be necessary in the future development of PCP.

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