Understanding the Environmental Distribution and Potential Health Risks of Pollutants from Deodorant Products: A Review

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Abstract. Deodorants are frequently used personal care products; however, questions have been raised concerning their possible toxicity to cause air and water pollution, and their potential impact on human health. The degree to which deodorant ingredients, such as fragrance chemicals, antibacterial compounds, aluminium compounds, and preservatives, are toxic depends on their chemical composition. Many of these chemicals have been connected to adverse health effects, such as skin rashes, allergic reactions, endocrine disruption, and respiratory problems. Understanding these chemicals' toxicity is crucial for determining any potential risks to human health. Spray formulations have the potential to release volatile organic compounds into the air, such as propellants and fragrance chemicals, which can be harmful to human respiratory health and lead to indoor and outdoor air pollution. Improper disposal and wastewater treatment can lead to the contamination of water bodies, potentially impacting aquatic ecosystems and human water supplies. This review provides an overview of the toxicity of deodorant ingredients in various formulations, including sprays, roll-ons, and sticks. The partition coefficients Log K_{aw} (air-water partition coefficient), Log K_{oa} (air-organic carbon partition coefficient), and Log K_{ow} (octanol-water partition coefficient), values of deodorant ingredients were summarized for assessing their potential for long-range transport, persistence in the environment, and bioaccumulation in organisms.

Keyword. air pollution, breast cancer, environmental impact, partition coefficients, phthalates

1 Introduction

Aromatherapy has been used in India for ages, with the rise of technology and increased consumption, India's traditional fragrance sector has seen significant shifts. India is among the top countries in terms of fragrance production, consumption, and market size. The Indian perfume market is anticipated to increase by USD 1328.31 million between 2022 and 2027 [1]. The three type-based categories of fragrance goods are comprised of perfumes, deodorants, and other fragrance products. In terms of revenue in 2019, deodorants occupied the highest percentage (60.65%), followed by perfumes (32.14%) [2]. Deodorant is the most often used scented product in the country because of its affordable price. Recently, roll-ons and sticks are also becoming popular among Indian consumers.

The toxic nature of the propellant and its contaminants is taken into account throughout the formulation of aerosol items. For instance, the propellant isobutane, which is used in aerosol sprays, may include the cancer-causing compound butadiene. Aerosol sprays produce incredibly tiny particles, that are harmful and may amplify their damaging effects if inhaled more deeply [3,4]. Aerosols frequently include very dangerous and harmful substances such as formaldehyde, xylene, neurotoxins, and carcinogens. The Environmental Protection Agency has classified these as hazardous. These components are utilized for a variety of purposes, yet despite this, they pose a serious danger to the environment and cause a great deal of pollution.

The ingredients that go into fragrance formulae remain trade secrets and are not listed on labels for the fragrance section of the product. More and more people are citing fragrance as a cause of illnesses including asthma, allergies, and migraines [5,6]. Additionally, it has been shown that certain scent components build up in adipose tissue and are identified in the mother's milk. There is speculation that other substances disrupt hormones. The consequences are not completely understood since systemic impacts have not received much attention. Fragrances are volatile molecules, which contribute to both indoor and outdoor air pollution [7-9]. Synthetic musk components pollute streams and aquatic life and are persistent in the environment [10].

In addition to fragrance, deodorants also include aluminium and zinc salts to block sweat ducts and prevent perspiration from reaching the skin's surface. The majority of traditional antiperspirants use aluminium compounds such as Aluminium trichlorohydrex glycine.

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There is some evidence to support the claims that certain aluminium compounds are neurotoxic, irritate the skin, and interact with estrogen, which raises the risk of breast cancer [11,12]. Deodorants also include heavy metals, which can contribute to pollution, in addition to organic compounds. For example, the Nivea Silver Protect deodorant had 0.3 ppm of silver [13]. Some deodorant sprays and roll-ons included chloride ions (Cl), chromium ions (Cr), cobalt ions (Co), fluoride ions (F), molybdenum ions (Mo), and antimony ions (Sb) [14].

This review aims to examine the environmental and human health effects associated with typical ingredients found in three common types of deodorants: sticks, roll-ons, and sprays. The partition coefficients Log K_{aw} (air-water partition coefficient), Log K_{oa} (air-organic carbon partition coefficient), Log K_{ow} (octanol-water partition coefficient), and Log K_{oc} (organic carbon-water partition coefficient) values of deodorant ingredients were summarized for assessing their potential for long-range transport, persistence in the environment, and bioaccumulation in organisms.

2 Composition and usage of deodorants

Deodorants can be applied as a stick, a liquid roller, or an aerosol can. Deodorant sticks are solid formulations typically packaged in plastic containers. Roll-ons consist of liquid solutions applied through a ball applicator, while sprays are aerosol-based products. The primary components of deodorants include antimicrobial agents (such as ethanol, and triclosan), odor-masking compounds (natural essential oils and/or perfume fragrances), odor absorbers, antiperspirant agents (several aluminum-containing substances), anti-oxidants, preservatives (such as parabens), and others. A small percentage of deodorant sprays contain antiperspirants and antibacterial chemicals which are used to control the growth of microorganisms on the skin that cause body odor. Essential oils (perfume) are used in some formulations as an antibacterial agent. Some of the deodorant ingredients function as a moisturizing agent for the skin since ethanol decreases natural oils in the epidermis.

The specific data regarding the percentage and concentration of ingredients in different types of deodorants can vary depending on the brand, formulation, and region. The details of the general composition and commonly found ingredients in different types of deodorants are given in Table 1 [15]. Typically, aerosol deodorants contain active ingredients like aluminum chlorohydrate, aluminum zirconium tetrachlorohydrex glycine, or triclosan. The concentration of these ingredients can range from 10% to 25%. Aerosol deodorants often contain propellants such as butane, isobutane, or propane, which help release the product from the container. The concentration of propellants can range from 10% to 30%. Fragrance compounds are added to provide a pleasant scent. The concentration of fragrance can vary, typically ranging from 0.5% to 5%. Roll-on deodorants commonly contain antiperspirant active ingredients ranging from 10% to 25%. They often contain water as a base ingredient, which can make up a significant percentage of the formulation, ranging from 50% to 70%. Ingredients like glycerin, propylene glycol, and cyclomethicone may be included to provide moisturization and help the product adhere to the skin. The concentration of these ingredients can range from 5% to 15%. Stick deodorants often incorporate waxes (e.g., beeswax, candelilla wax) and oils (e.g., coconut oil, mineral oil) to provide a solid consistency. The concentration of these ingredients can range from 10% to 60%.

The majority of deodorants contained four specific phthalates: Dibutyl phthalate (DBP), Diethyl phthalate (DEP), Di (2-ethylhexyl) phthalate (DEHP), and Dimethyl phthalate (DMP). Only two deodorants contained all four phthalates together. The concentration ranges of these phthalates were estimated as follows: DEP (23-924 ug/ml), DEHP (255-1402 ug/ml), DBP (7-2119 ug/ml), and DMP (16-84 ug/ml). Among these phthalates, DBP had the highest concentration, followed by DEHP and DEP. DMP was only detected in four samples, and its concentration was lower compared to the other phthalates [16]. Among the many fragrance compounds found in perfumes and deodorants, Benzyl salicylate (3346 μg/g), Lilial (11477 μg/g), Citronellol (2200 μg/g), Hexylcinnamic aldehyde (4664 μg/g), Limonene (1748 μg/g), Linalool (1557 μg/g), and Isomethyl ionone (1822 μg/g) exhibited the highest concentrations [17].

3 Distribution in environmental compartments

The toxicity of deodorant ingredients is primarily influenced by their chemical composition, as well as the specific type of deodorant products that dominate the market. Partition coefficients Log K_{aw}, Log K_{oa}, and Log K_{ow} play a crucial role in understanding the fate and behavior of deodorants in the environment. The transfer of the chemical compounds in the environmental compartments based on the partition coefficients is given in Figure 1 [18]. These partition coefficients along with the physio-chemical properties of the compounds provide insights into their potential transport and accumulation in air, organic carbon, and water compartments. The physical properties and partition coefficients of the typical organic compounds (about 40) used in the deodorants are given in Table 2. The data of vapor pressure, water solubility, Log K_{aw}, Log K_{oa}, Log K_{ow}, and Log K_{oc} of the selected organic compounds were collected from PubChem and EPI Suite software.

The air-water partition coefficient (K_{aw}) represents the distribution of a compound between air and water. It is a critical parameter for understanding the volatility and potential for atmospheric transport of deodorant ingredients. High K_{aw} values indicate a greater tendency for partitioning into the gas phase, potentially leading to long-range transport and subsequent deposition in water bodies. Commonly, Log K_{aw} values can range from approximately -5 to +10 or more, depending on the compound's properties and environmental conditions.

Table 1. Typical composition of deodorants: sticks, roller, and spray [15,19].

Ingredient	Compounds	Stick	Roller	Spray	Purpose
Anti-bacterial agents	Triclosan, Chlorhexidine, Alcohol, Polyhexamethylene Biguanide, Propylene Glycol, Quaternary Ammonium Compounds, Octoxyglycerin, 2-Ethylhexylglycerin, and Ethyllauryl Arginate Hydroxychloride	0.5%	1-3%		Kill bacteria
Antiperspirant (Aluminium and Zirconium compounds)	Aluminium Chlorohydrate (In Roll-Ons), Aluminium Zirconium Tetrachlorohydrex Glycine (In Stick), Aluminium Hydroxybromid, Aluminium Sesquichlorohydrate, Aluminium Bromide, Aluminium Lactate	10%	10%	10 - 30%	To clog pores, blocking body's ability to perspire
Emollient and Emulsifying	Cyclopentasiloxane, Stearyl Alcohol, Alkyl Benzoate, Hydrogenated Castor Oil, Dimethicone, Helianthus Annuus Seed Oil, Cetyl Alcohol	60%			Improves products consistency
Moisturizing and Skin conditioning agents	Glycerin, Citric Acid, Oils	5%	5-15%		Soothe and soften skin
Perfume	Citronellol, Limonene, Linalool, Phthalates, Eugenol, Geraniol, Hexylcinnamaldehyde	1.5%	0.3%	1%	Odour masking agents, usually labelled as "fragrance"
Odour absorbers	Sodium Acid Carbonate, Zinc Carbonate, And Talc				
Humectants	Polyols, Propylene Glycol		5%		Prevent the product from drying out
Propellant (in the case of aerosol formulation)	Butane, Isobutane, Propane			10 - 30%	Carry the product to the skin
Water and Solvent	Alcohols (Ethanol), Cyclomethicone, Decamethylcyclopentasiloxane	10%	60 - 80% (water)	37 - 47%	Carry active ingredients
Additives	Silica, EDTA, Sodium Benzoate, Parabens, Triethanolamine, Diethanolamine	8%	2-5%	2.5%	pH control, colorants, filler, preservatives, and chelating agents

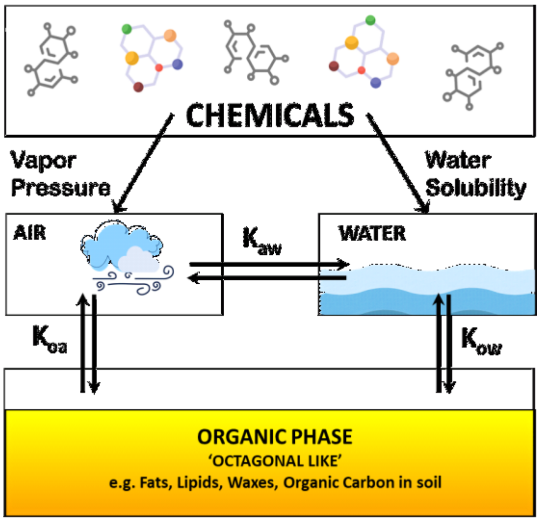

Fig. 1. The transfer of organic compounds between different environmental compartments based on partition coefficients.

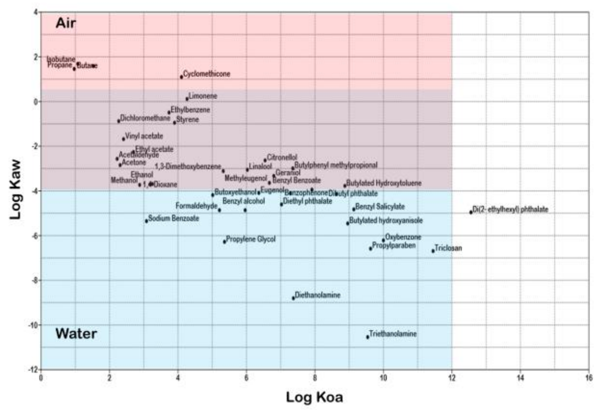

Fig. 2. Distribution of compounds present in the deodorants. based on Log Koa and Log Kaw.

Table 2. The physical properties and partition coefficients at 25°C of the typical organic compounds used in the deodorants.

Name	Formula	Vapor pressure (mm Hg)	Solubility in water (g/L)	Henry's law constant (atm-m^3/mol)	Log K_{ow}	Log K_{aw}	Log K_{oa}	Log K_{oc}
1,3-Dimethoxybenzene	$C_8H_{10}O_2$	0.195	1.105	2.45 x 10^{-5}	2.21	-3.112	5.322	2.259
1,4-Dioxane	$C_4H_8O_2$	38.1	>800	4.80 x 10^{-6}	-0.27	-3.707	3.18	1.23
Acetaldehyde	C_2H_4O	902	256.8	6.67 x 10^{-5}	-0.34	-2.564	2.224	0.613
Acetone	C_3H_6O	231	1000	3.97 x 10^{-5}	-0.24	-2.844	2.310	0.73
Benzophenone	$C_{13}H_{10}O$	1.93 x 10^{-3}	0.14	1.94 x 10^{-6}	3.18	-4.101	7.281	2.634
Benzyl alcohol	C_7H_8O	0.094	42.9	3.37 x 10^{-7}	1.1	-4.861	5.961	1.1
Benzyl Benzoate	$C_{14}H_{12}O_2$	2.24 x 10^{-4}	0.015	2.34 x 10^{-7}	3.97	-3.941	7.911	3.8
Benzyl Salicylate	$C_{14}H_{12}O_3$	7.8 x10^{-5}	0.025	2.7 x 10^{-6}	4.31	-4.824	9.134	3.41
Butane	C_4H_{10}	1820	0.0612	0.95	2.89	1.589	1.530	2.508
Butoxyethanol	$C_6H_{14}O_2$	0.88	64.47	1.6 x 10^{-6}	0.83	-4.184	5.014	0.882
Butylated hydroxyanisole	$C_{11}H_{16}O_2$	2.48 x 10^{-3}	0.2128	2.6 x 10^{-6}	3.06	-5.456	8.956	3.084
Butylated Hydroxytoluene	$C_{15}H_{24}O$	0.01	0.0006	3.38 x 10^{-6}	5.1	-3.774	8.874	3.913
Butylphenyl methylpropional	$C_{14}H_{20}O$	3.58 x 10^{-3}	0.008	8.48 x 10^{-6}	4.36	-2.992	7.352	3.107
Citronellol	$C_{10}H_{20}O$	0.02	0.3	2.1 x 10^{-5}	3.91	-2.634	6.544	2.676
Cyclomethicone	$C_{10}H_{30}O_5Si_5$	0.3	1.7 x 10^{-5}	33	8.06	1.097	4.103	4.513
Di(2- ethylhexyl) phthalate	$C_{24}H_{38}O_4$	1.42 x10^{-7}	0.0003	2.7 x 10^{-7}	7.6	-4.957	12.5557	4.94
Dibutyl phthalate	$C_{16}H_{22}O_4$	2.01 x 10^{-5}	0.0112	1.81 x 10^{-6}	4.50	-4.131	8.631	3.14
Dichloromethane	CH_2Cl_2	435	13.2	3.25 x 10^{-3}	1.25	-0.877	2.27	1.44
Diethanolamine	$C_4H_{11}NO_2$	2.8 x10^{-4}	1000	3.87 x 10^{-11}	-1.43	-8.801	7.371	-0.732
Diethyl phthalate	$C_{12}H_{14}O_4$	2.1 x 10^{-3}	1.08	6.10 x 10^{-7}	2.47	-4.603	7.023	1.84
Ethanol	C_2H_6O	59.3	1000	5 x 10^{-6}	-0.31	-3.689	3.25	0.2
Ethyl acetate	$C_4H_8O_2$	93.2	64	1.34 x 10^{-4}	0.73	-2.261	2.7	1.263
Ethylbenzene	C_8H_{10}	9.6	0.17	7.88 x 10^{-3}	3.15	-0.492	3.74	2.23
Eugenol	$C_{10}H_{12}O_2$	0.0221	2.46	1.92 x 10^{-6}	2.49	-4.09	6.36	2.403
Formaldehyde	CH_2O	3890	57	3.37 x 10^{-7}	0.35	-4.861	5.211	0.889
Geraniol	$C_{10}H_{18}O$	0.03	0.1	1.15 x 10^{-5}	3.56	-3.328	6.798	2.433
Isobutane	C_4H_{10}	2610	0.05	1.19	2.76	1.687	1.073	2.395
Limonene	$C_{10}H_{16}$	1.55	0.008	0.032	4.57	0.115	4.265	3.801
Linalool	$C_{10}H_{18}O$	0.176	1.59	2.15 x 10^{-5}	2.97	-3.056	6.026	2.156
Methanol	CH_3OH	127	1000	4.55 x 10^{-6}	-0.77	-3.730	2.88	0.44
Methyleugenol	$C_{11}H_{14}O_2$	0.012	0.5	5.6 x 10^{-6}	3.03	-3.64	6.670	2.713
Oxybenzone	$C_{14}H_{12}O_3$	6.62 x 10^{-6}	0.0037	1.5 x 10^{-8}	3.79	-6.212	10	3.440
Propane	C_3H_8	7150	0.0624	0.707	2.36	1.461	0.970	2.048
Propylene Glycol	$C_3H_8O_2$	0.13	811.1	1.3 x 10^{-8}	-0.92	-6.278	5.358	0.36
Propylparaben	$C_{10}H_{12}O_3$	3.07 x 10^{-4}	0.5	4.25 x 10^{-9}	3.04	-6.584	9.624	2.708
Sodium Benzoate	$C_7H_5NaO_2$	2.9 x 10^{-12}	556	7 x 10^{-16}	-2.27	-5.351	3.081	-1.1
Styrene	C_8H_8	6.4	0.31	2.75 x 10^{-3}	2.95	-0.949	3.899	2.96
Triclosan	$C_{12}H_7Cl_3O_2$	4.65 x 10^{-6}	0.005	2.1 x 10^{-8}	4.76	-6.69	11.45	3.925
Triethanolamine	$C_6H_{15}NO_3$	3.59 x 10^{-6}	1000	7.05 x 10^{-13}	-1.00	-10.54	9.54	-0.516
Vinyl acetate	$C_4H_6O_2$	115	30.25	5.11 x 10^{-4}	0.73	-1.68	2.41	1.23

The octanol-water partition coefficient (K_{ow}) describes the distribution of a compound between octanol (representing a lipophilic environment) and water. It is an indicator of the hydrophobicity or lipophilicity of a deodorant ingredient. High K_{ow} values suggest a greater affinity for partitioning into lipids or organic matter in water, which can lead to bioaccumulation in aquatic organisms. The typical range for Log K_{ow} values is from -3 (indicating high water solubility) to +10 (indicating strong water repellence) [20]. The air-octanol partition coefficient (K_{oa}) is a measure of the relative distribution of deodorant compounds between the air and octanol phases. It represents the ratio of the concentration of a compound in the air to its concentration in octanol at equilibrium. A higher K_{oa} value indicates a greater affinity for octanol, suggesting that the deodorant compound has a propensity to accumulate in lipid-rich environments. Log K_{oa} values may range from -10 to 10 or even beyond, depending on the volatility and affinity of the compound for organic carbon [21,22]. The K_{oa} parameter is essential for understanding the potential for bioaccumulation and assessing the environmental fate of deodorant compounds in relation to air pollution and their potential impacts on ecosystems and human health. Log K_{oc} represents the ratio of the concentration of a substance in organic carbon to its concentration in water at equilibrium. It helps assess the potential for adsorption onto organic matter, providing insights into the fate and transport of deodorant ingredients in soils and sediments. The typical values for the high water solubility range can vary, but it is generally considered to be above 1 g/L or even higher. Compounds with high water solubility are readily dissolved in water and can disperse easily. About 19 compounds namely, Diethyl phthalate, 1,3-Dimethoxybenzene, 1,4-Dioxane, Linalool, Eugenol, Dichloromethane, Vinyl acetate, Benzyl alcohol, Formaldehyde, Methanol, Ethyl acetate, Butoxyethanol, Acetaldehyde, Sodium Benzoate, Propylene Glycol, Diethanolamine, Triethanolamine, Ethanol, and Acetone had water solubility greater than 1 g/L and low Log K_{ow} values indicating their distribution mainly in water. According to Wanna (2016), compounds with log K_{aw} values below -2 and log K_{oa} values below 12 are referred to as "swimmers" because their low log K_{aw} values indicate a tendency to remain in water. On the other hand, compounds with log K_{aw} values above 0.5 and log K_{oa} values below 6 are categorized as "fliers" due to their high log K_{aw} values. Compounds with log K_{oa} values above 12 are defined as "hoppers," while an intermediate group called "multiple hoppers" typically have log K_{aw} values above -4 and log K_{oa} values below 12 [23,24]. Based on the above values the compounds that transfer to air and water is shown in Figure 2. Most of the compounds are in multiple hopper groups exhibiting substantial capability for transportation from sources, both directly and through association with particles (for compounds with extremely high Log K_{oa}). The compounds Butylated Hydroxytoluene, Di(2-ethylhexyl) phthalate, and Cyclomethicone exhibited high Log K_{ow} values (>4), as well as low vapor pressure and water solubility. This suggests that these compounds have a strong affinity for sediment or bioaccumulation. The compounds with Log K_{ow} greater than 8.5 are very hydrophobic and exhibit greater affinity to be present in the terrestrial food chain [25,26]. Most of the compounds in deodorants have Log Kow values less than 8.5 (Table 2). Chemicals falling within the range of Log K_{ow} = 2 to 5 and log $K_{oa} \geq 5$ represented a category of substances that have the potential for bioaccumulation, especially within food chains that involve air-breathing organisms [27,28]. About 50% of the compounds fall in this category and can accumulate in the air-breathing food chain. However, it is important to note that the partition coefficients of deodorants can also be influenced by environmental conditions, such as pH, temperature, and the presence of other chemicals. Additionally, the presence of organic matter in the environment can significantly affect the partitioning behavior of deodorant compounds.

1,4-Dioxane exhibits persistence in water and shows limited biodegradability. It has a high solubility in water, allowing for its easy migration into groundwater, where it maintains its resistance to biodegradation [29,30]. Benzyl Benzoate is considered moderately persistent in the environment. The low water solubility indicates that Benzyl Benzoate has a limited ability to dissolve in water, reducing its potential for distribution in aqueous environments such as surface water or groundwater. The higher log Koa suggests that Benzyl Benzoate has a little higher affinity for partitioning into the octonal phase, making it more likely to penetrate the skin and contribute to airborne concentrations. This indicates that skin contact, such as through the use of topical products containing Benzyl Benzoate, can result in its release into the surrounding air [31]. While some portion of Benzyl Benzoate may be washed off during activities like bathing or swimming, the majority is expected to remain on the skin, potentially leading to prolonged exposure and absorption through dermal contact. Benzyl Salicylate is known to be persistent and bioaccumulative. Benzyl Salicylate and Cyclomethicone, with their low water solubility and high log Koa and log Koc, are expected to persist and remain predominantly in the air and soil compartments without significant degradation. Cyclomethicone compounds have a relatively high vapor pressure, which means they readily volatilize into the air. Once in the atmosphere, they can undergo atmospheric degradation through various mechanisms, such as reaction with hydroxyl radicals (OH·) and photolysis by sunlight. These degradation processes can contribute to the removal of cyclomethicones from the air [32].

Butylated Hydroxyanisole does not persist in air, water, or soil, and it is not likely to accumulate significantly in organisms. It is also not considered to be highly toxic to aquatic organisms [33]. Butylated Hydroxytoluene is persistent in water and soil. DEHP is persistent in the environment and has the ability to accumulate in sediments and organisms as it had high Log K_{oa} (12.6) and Log K_{ow} values. This means that it does not readily degrade and can persist for a long time, posing a potential risk to the environment and organisms. Similar to DEHP, DBP is also persistent in the environment and can accumulate in organisms as it also had a high Log K_{oa} value. It does not easily break down and has the potential to pose environmental and biological risks. Diethyl phthalate is biodegradable in the environment. It has a much lower tendency to adhere to aquatic sediments compared to other phthalates. Approximately 70% to 90% diethyl phthalate is found in the water column instead of adhering to sediments. Furthermore, biomagnification, the process by which a substance increases its concentration up the food chain, is not expected to occur in the case of diethyl phthalate [34]. Styrene has the potential to be released into the air and is regarded as a volatile organic chemical. It can engage in photochemical interactions with other contaminants in the environment, contributing to the formation of smog. Styrene does not stay in the air for a long period because of its short atmospheric lifetime [35]. Styrene is poorly soluble in water and tends to partition into sediments as opposed to staying in the water column. Triclosan may accumulate in organisms and is persistent in the environment. The fact that triclosan is hydrophobic and has a high log Koa suggests that it has a greater affinity to lipids and organic materials. Due to this property, it can partition into lipid-rich tissues of organisms as opposed to staying in the water [36].

4 Potential health threats

These substances can provide a variety of health concerns, depending on the concentration, length of exposure, personal sensitivity, and overall product design. Table 3 lists the probable health impacts of the typical deodorant ingredients. More than 50% of the compounds can irritate eyes, skin, and lungs. Antiperspirant deodorants frequently contain aluminium compounds, such as aluminium chlorohydrate and aluminium zirconium tetrachlorohydrex gly, to decrease sweating and regulate body odor. However, concerns have been raised about the potential health dangers associated with the usage of these substances.

Table 3. Potential health hazards posed by common deodorant ingredients

Health effects	Compounds
Skin irritation	1,3-Dimethoxybenzene, Benzyl alcohol, Benzyl Benzoate, Benzyl Salicylate, Butylphenyl methylpropional, Citronellol, Diethanolamine, Eugenol, Geraniol, Limonene, Linalool, Methyleugenol, Propylene Glycol, Styrene, Triethanolamine
Respiratory irritation	1,4-Dioxane, Acetaldehyde, Acetone, Benzophenone, Benzyl alcohol, Benzyl Benzoate, Butane, Butoxyethanol, Butylated hydroxyanisole, Butylated Hydroxytoluene, Butylphenyl methylpropional, Citronellol, Cyclomethicone, Di(2-ethylhexyl) phthalate, Dibutyl phthalate, Diethanolamine, Diethyl phthalate, Ethanol, Ethyl acetate, Ethylbenzene, Eugenol, Formaldehyde, Geraniol, Isobutane, Limonene, Linalool, Methanol, Methyleugenol, Oxybenzone, Propane, Propylene Glycol, Styrene, Triclosan, Triethanolamine, Vinyl acetate
Carcinogenic	1,4-Dioxane, Acetaldehyde, Benzophenone, Dichloromethane, Formaldehyde, Methyleugenol, Styrene
Endocrine disruption	Benzophenone, Di(2-ethylhexyl) phthalate, Dibutyl phthalate, Diethyl phthalate, Oxybenzone, Propylparaben, Triclosan
Dizziness, Drowsiness, Headache, Nausea, and flammability	Butane, Isobutane, Propane
Eye irritation	Butoxyethanol, Ethyl acetate
Allergic reactions	Benzyl Salicylate
Developmental Toxicity	Di(2-ethylhexyl) phthalate, Dibutyl phthalate, Diethyl phthalate
Liver and Kidney Damage	Dichloromethane
Central nervous system (CNS) depression	Ethanol

Numerous studies have looked at the potential connection between aluminium exposure and health problems, such as Alzheimer's disease and breast cancer [37,38]. Aluminium compounds may also interfere with endocrine and hormonal functions. Although further research is needed to determine the degree of these effects and their implications for human health, they have the potential to mimic estrogen in the body and interfere with hormonal signaling. It is significant to highlight that the body has systems to remove aluminium and that only a little amount of aluminium may be absorbed via the skin. However, those with kidney problems could be less capable to eliminate aluminium, which might possibly raise their risk of aluminium buildup. To protect consumers, regulatory agencies like the European Chemicals Agency (ECHA) and the U.S. Food and Drug Administration (FDA) have set restrictions on the amount of aluminium in cosmetic items like deodorants [39].

Liver, lung, and kidney cancers have been linked to prolonged exposure to high amounts of 1,4-dioxane, benzophenone, dichloromethane, and styrene [40-44]. Styrene vapors can irritate the respiratory system, the eyes, and the central nervous system, resulting in symptoms including headache, weariness, and dizziness. Prolonged or repeated exposure to styrene has been associated with potential neurological and hematological effects. Triclosan exhibits an impact on the body by reducing serum thyroid hormone concentrations, as observed due to its structural similarity to thyroid hormones [45]. It acts as a disruptor by interfering with the estrogen, androgen, and thyroid systems of the body. Its ability to disrupt these hormone systems classifies it as an endocrine disruptor. Additionally, studies conducted on mice suggest that triclosan may have an allergic effect. When exposed to the skin, simulating the application of a lotion or deodorant, the mice displayed heightened reactions to allergens introduced into their lungs [46].

At high concentrations, Chlorhexidine can be harmful, and there have been reports of anaphylactic reactions [47]. Additionally, the by-products of chlorhexidine decomposition are considered more harmful to the environment than chlorhexidine itself. The substance can accumulate in aquatic organisms, leading to long-term harmful effects [47]. Prolonged or high-dose use of propylene glycol can result in toxicity, with reported adverse effects on the central nervous system, hyperosmolarity, hemolysis, cardiac arrhythmia, seizures, agitation, and lactic acidosis [48]. Phthalates, including DEP, are known as endocrine disruptors and have been associated with adverse effects on reproduction and development in animals and humans. Phthalates have been linked to abnormalities, nervous system sensitivity, reduced development and birth weight, and maternal mortality in mice. They may also irritate mucous membranes and the skin. Studies on people have connected phthalate exposure to issues with reproduction, diabetes, obesity, allergies, and asthma [49,50]. Parabens have been found in a number of human tissues and body fluids. In addition to being endocrine disruptors, paraben chemicals have also been linked to changes in hormone action, immunological function, lipid homeostasis, blood sugar levels, thyroid function, and tumors, notably breast tumors and male infertility [51]. Deodorant silica is known to irritate the skin, and it may contain crystalline quartz, which has been linked to respiratory conditions and the development of cancer cells [52].

Sustainable practices and alternatives must be considered to minimize the potential negative effects. One way to accomplish this is to choose deodorant products that are free of or contain less dangerous ingredients, opt for environmentally friendly packaging, promote recycling and proper disposal methods, and develop greener and more environmentally friendly formulas. Exploring bacterial-derived, plant-derived, and essential oil-derived compounds as substitute deodorant components has received a lot of attention recently [19]. While chemicals originating from plants offer a variety of useful qualities including odor control and skin-soothing benefits, compounds generated from bacteria have special antibacterial capabilities. Along with attractive fragrances, essential oils also have antibacterial and antioxidant qualities. Consumers often perceive nature-derived compounds as safer and more environmentally friendly alternatives to synthetic compounds. The emphasis on these all-natural options should be a part of a larger trend that aims to use natural components to make more powerful, environmentally responsible, and healthy deodorants.

5 Conclusion

In summary, this review article provides an overview of the presence and potential health hazards of contaminants used in deodorant products. Gaining knowledge about how these pollutants behave in the environment (air, water, and soil) and their potential effects on ecological systems and human well-being is vital in developing sustainable and safe deodorant formulations. Common substances like benzyl alcohol, diethyl phthalate, and ethanol may cause skin irritation, allergic responses, respiratory irritation, and, in certain circumstances, impacts on reproductive hormones. Furthermore, these substances are not confined to a specific environmental compartment. When applied, they can enter the atmosphere and then travel through several different channels to get to water and soil. While some substances naturally degrade, others linger in the environment for extended periods, which can cause bioaccumulation and subsequent human exposure via the food chain. It is essential for effective risk management and the creation of safer substitutes to have a thorough understanding of the environmental fate and potential health concerns related to deodorant pollutants. More research is needed to investigate the long-term effects of exposure, particularly among vulnerable populations. Given the potential health risks associated with certain deodorant compounds, manufacturers, regulators, and consumers must prioritize the use of safer ingredients and encourage the development and adoption of environmentally friendly formulations.

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