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# A Review: Exposure to Heavy Metals in Everyday Life: Food Security, Consumer Health and Policies

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## Abstract:

This comprehensive review addresses the dual concerns of heavy metal contamination in soil–food crop systems and cosmetic products, emphasizing the significant risks posed to both food security and consumer health. It explores the presence of heavy metals, including mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), and chromium (Cr), in these systems, elucidates contamination pathways, and delves into the mechanisms of metal uptake by food crops. Strategies for managing pollution to ensure sustainability are discussed. The importance of this research lies in its contribution to our understanding of the pervasive heavy metal pollution issue and its far-reaching consequences for both food security and public health. Simultaneously, the study quantified the concentrations of five heavy metals (Cd, Cr, Fe, Ni, and Pb) in various cosmetic products through atomic absorption spectrometry, assessing health risks using systemic exposure dosage (SED), margin of safety (MoS) and lifetime cancer risk (LCR). In order to implement these findings into action, governments, regulatory authorities and industries have to collaborate proactively to create and enforce intense heavy metal limitations on food and cosmetic items, ensuring consumer safety. The findings show increasing heavy metal levels in cosmetics, notably sunscreen creams, lipsticks, and lotions, which could pose health risks such as skin cancer. The study emphasizes the importance of constantly monitoring cosmetic items in order to protect customers. Furthermore, it examines worldwide food and cosmetics legislation, focusing on heavy metal restrictions such as mercury, lead, arsenic, and cadmium, highlighting international efforts to mitigate heavy metal dangers in these items.

*Keywords* **—Heavy Metals, Food Security, Consumer Health, Policies**

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## Introduction

Heavy metals are metallic elements that have a very high density [1]. Its toxicity can be very harmful to human health and can cause several health problems such as lung damage, vomiting, diarrhea, nausea, skin rashes, and increased blood pressure [2,3]. The most common types of heavy metals that are found are lead (Pb), arsenic (As), cadmium (Cd) and mercury (Hg) [4]. Many substances have been discovered which appear in the form of contaminants or traces of elements, in the majority of products or even in natural sources [5,6]. Heavy metals have been affecting globally throughout the world. Environmental pollution of heavy metals is increasingly becoming an alarming problem and has become of great concern worldwide due to its adverse effects. These inorganic pollutants are widely distributed in the environment through water, soil and into the atmosphere. Due to the rapidly growing agricultural, metal and pharmaceutical industries, through improper waste disposal, fertilizers and pesticides, raising concerns over their potential effects on human health and the environment. A lot of factors affect their toxicity, including the dose, route of exposure, and chemical species, as well as age, gender, heredity, and nutritional status of those who have been exposed. Arsenic, cadmium, chromium, lead, and mercury are among the priority metals of public health concern due to their high toxicity [7]. Heavy metals also have a particular consequence in ecotoxicology due to their long tenacity of biomagnification and bioaccumulation in the food chain [8].

Due to high traffic regions and industrial sectors, many Asian countries generally have issues with street dust. Dhaka (one of the capitals of Eastern South Asia) uses energy to disperse X-ray fluorescence spectroscopy. The maximum lead (Pb), cadmium (Cd), zinc (Zn), chromium (Cr), nickel (Ni), arsenic (As), manganese (Mn), and copper (Cu) levels in street dust samples were extremely high. According to this study, the geographical distribution of heavy metal density in Dhaka street dust samples revealed that the bulk of nickel (Ni), cadmium (Cd), arsenic (As), and lead (Pb) areas were primarily related with heavy traffic and industrial activity [9]. However, eastern South Asia is not the only Asian zone that is facing the problem. In addition, Myanmar, which is in Southeast Asia, has encountered heavy metal concentrations associated with gold. Such as lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), arsenic (As) and mercury (Hg). These heavy metals can increase in the environment through gold mining activities, which can result in pollution in the environment and toxicity to animals or even to people of Myanmar[10].

In Thailand, there is an increasing awareness in heavy metal toxicity [11,12]. During 2017 and 2019, 20 sampling stations of sediment and water from Thailand's Chao Phraya River were investigated for heavy metal concentrations such as mercury (Hg), cadmium (Cd), zinc (Zn), nickel (Ni), and lead (Pb) [13]. High concentrations of arsenic have been found in drinking water and have been associated with to a variety of clinical pathological conditions such as cardiovascular and peripheral vascular disease, developmental anomalies, neurologic and neurobehavioral disorders, diabetes, hearing loss, portal fibrosis, hematologic disorders (anemia, leukopenia, and eosinophilia), and carcinoma [14,15,16]. Thai fruits were chosen for research in 2023. Durian, jackfruit, mangosteen, pineapple, rambutan, and longkong are among them. Three public marketplaces in Rayong were visited to gather samples, the essential copper (Cu) and zinc (Zn) concentration ranged from 0.29 to 6.70. The amount of lead (Pb) in 16.70% of fruit samples exceeded the allowable contamination level. Cadmium (Cd), arsenic (As), and mercury (Hg) were also discovered in fruit samples collected for this study. Fruit contamination may occur as a result of heavy metal absorption after pesticide application and contamination of farmed regions [11].

The contamination of heavy metals may occur due to industrial expansion, mine tailing, combustion of fossil fuels, spillage of petrochemicals, disposal of high metal waste. As a result of anthropogenic, such as fertilizers, biosolids, pesticides and wastewater, pollutants have overloaded the system and natural equilibrium has been disturbed. Agricultural practices may accumulate high levels of potentially heavy metals in soils, which may have so significant consequences for the quality of the quality of plant health, soil biological processes and thus, through bio magnification enter the human body as well.

## Heavy metal in food

  

The main origins of heavy metals within the soil environment and agricultural practices encompass the deposition from the atmosphere, the application of livestock manure, the use of wastewater or polluted water for irrigation, the utilization of metal-based pesticides or herbicides, the application of fertilizers containing phosphates, and the incorporation of additives derived from sewage sludge [17,18]. Beyond natural sources, conventional and emerging human-made pollutants represent significant threats to human health through the consumption of food crops that have been contaminated by the transfer of pollutants from the soil to plant tissues via root absorption or direct deposition from the atmosphere onto the surfaces of plants [19,20]. Particulate matter (PM) released by industries and vehicles gradually accumulates in both the soil and the food chain [21,22]. Similarly, a number of potent source mechanisms (such as using wastewater for irrigation, incorporating sewage sludge as a soil amendment for food crops, and the pollution and deposition of particulate matter on soil and plants) present a concerning outlook for worldwide food safety.

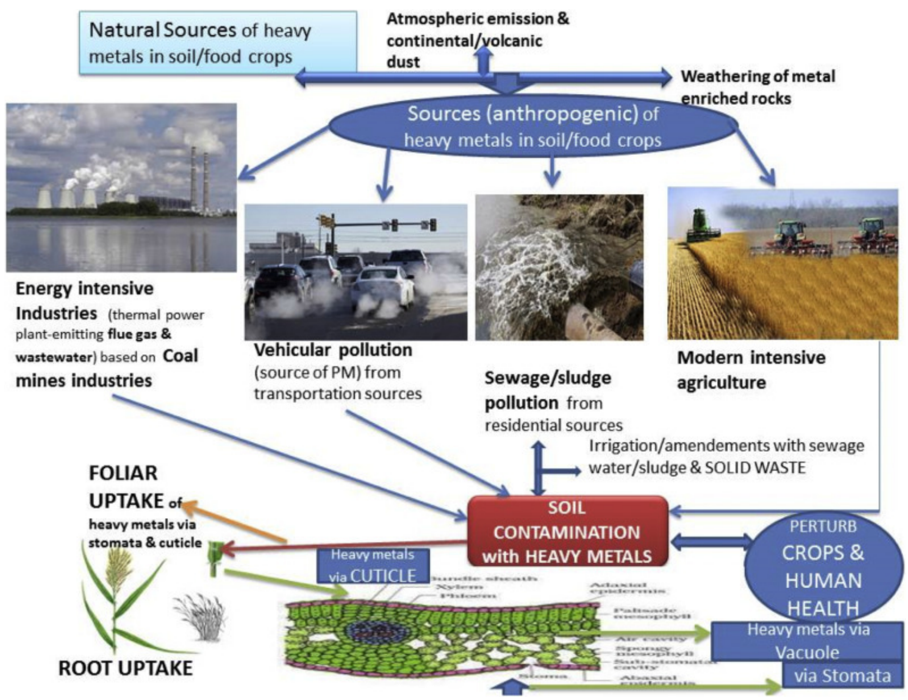


**Figure1.** Natural and anthropogenic sources of heavy metal contamination in food crops and mechanisms of their entrance (through stomata/cuticle) with resulting impacts on biota and humans [23].

An effective strategy and robust treatment systems are urgently required to tackle the escalating issue of heightened wastewater production from domestic and industrial processes, driven by the ever-expanding human population. In fact, numerous countries lack sufficient water resources to sustain their agricultural needs. In order to maintain agricultural output, inadequately treated wastewater and sewage sludge are extensively utilized on food crops. However, the quality and safety of food crops cultivated in soils irrigated with inadequately treated reclaimed water cannot be assured [24,25]. Sewage sludge is generated in substantial quantities to serve as a soil amendment for agriculture (for instance, 70 million tons in

Japan, 30 million tons in China, and 6 million tons in the USA) [26,27]. Nonetheless, adverse environmental and public health consequences have been reported due to the uncertain or partial treatment of effluent and sewage sludge used in this manner [28,29].

The sludge originating from distilleries as well as the chemical, electroplating, textile, and leather industries frequently contains markedly elevated concentrations of heavy metals (such as Fe, Cu, Cr, Pb, Ni, and Mn) [30]. Research indicates that heavy metals like Cd, Cr, Cu, Ni, and Zn from electroplating effluents can yield severe effects including inhibited growth, necrosis and chlorosis in leaves, and even plant death. Another study conducted in China unveiled that factories engaged in Pb-acid battery production released metals bound within particulate matter (PM), which subsequently settled on soils and crops within the agro-ecosystem [31,32]. Phosphogypsum stemming from waste produced by phosphate fertilizers can introduce an array of heavy metals into both soil and crops. Soil primarily experienced enrichment in Cd and Cr, while the highest bioavailability of Pb was observed in tomatoes and green peppers [33]. However, the daily intake of metals (DIM) and the health risk index (HRI) in that investigation were below 1, suggesting that while the health risks might not be excessively grave, the interconnected effects of metals through dermal and inhalation exposure could accentuate the susceptibility of humans, especially children, to diseases.

Soil operates as an intermediary interface with other non-living segments of the environment, thereby intense soil pollution can result in the pollution of sediment-groundwater and coastal regions [34,35,36]. The cultivation of crops in controlled indoor environments is not an absolute assurance of food safety. Even vegetables grown in greenhouses have exhibited contamination with heavy metals, primarily originating from human-made sources. Indoors, advanced statistical and geospatial tools can aid in identifying the sources of heavy metals [34,37]. In China, greenhouse-grown vegetables displayed higher sensitivity to Cd contamination than crops in open farmlands [38]. The results of a principal components analysis highlighted that Cr, As, and Ni are largely released from weathered rocks, while metallic contaminants like Hg and Pb are generated by industries, vehicle emissions, particulate matter (PM), and the reuse of wastewater for irrigation [38,39]. Identifying soil contaminants and their origins holds vital significance due to their close ties to human health [40,41]. The utilization of nanotechnology across various sectors (including medicine, energy, environment, and agriculture) carries environmental implications through the unregulated release of nanoparticles (NPs) and associated toxic metals [42,43]. A comprehensive impact assessment for nano-toxicity (e.g., CuONPs) should be conducted on food crops, as the presence of NPs can lead to adverse effects on both crop physiology (especially reduced photosynthesis) and human health [42].

This segment offers a comprehensive insight into the worldwide landscape concerning the contamination of food crops by heavy metals, encompassing their extensive human-made origins and the resulting ecotoxicological impacts on human health (as illustrated in Table 1 and Table 2). Undoubtedly, the accumulation of heavy metals within food crops and its repercussions on human health stand as significant global apprehensions. Nonetheless, insights into geographical patterns can aid in comprehending that the magnitude of their impact on human health issues might exhibit variations across countries, along with the diversity of sources for metallic contaminants, an aspect that has received limited scrutiny thus far.

Table 1. Heavy metal contamination from diverse sources in global food crops [23]

  

| No. | Food crops (cereals, fruits, vegetables, etc.) | Country where investigated | Sources of heavy metal contaminants affecting food chains | Metal concentrations recorded in food crops (dry weight) |
|---|---|---|---|---|
| 1. | Brassica sp., Chenopodium sp., leafy and root vegetables, grains | India | Sewage effluent (inadequately treated) | Cu 1.7–12.9 mg/kg<br>Pb 0.13 mg/kg<br>Zn 7.25–24.6 mg/kg<br>Cr 0.08–0.38 mg/kg<br>Pb 0.02–0.013 mg/kg<br>Cu 0.16–0.85 mg/kg<br>Zn |
| 2. | Rice, wheat, soybean (Glycine max), corn (Zea mays), potato | Brazil | Industrial/modern intensive urban agriculture | Below the standard limits hazardous to human health |
| 3. | Grain, maize (Zea mays), green cabbage, Brassica juncea L, radish (Raphanus sativus L), turnip, Brassica napus, spinach, cauliflower, and lettuce | China | Sewage effluent (inadequately treated using a biological approach) | Cr 0.08–0.38 mg/kg<br>Pb 0.02–0.013 mg/kg<br>Cu 0.16–0.85 mg/kg<br>Zn 0.16–0.53 mg/kg |
| 4. | Lettuce (Lactuca sativa); a leafy food crop/vegetable | Spain | Air (PM) from industries and vehicles | <0.02 mg Ni/kg, <0.008 mg Hg/kg, 0.005 mg As/kg and <0.005 mg Cd/kg |
| 5. | Brassica sp., food grains, and leafy vegetables | China | Both sewage and industrial waste (from smelter) drained into river water used for irrigation | Cr 0.01–0.19 mg/kg<br>Pb 0.12–0.23 mg/kg<br>Cu 0.15–0.86 mg/kg<br>Zn 0.42–0.95 mg/kg |

  

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| 6. | Soybean | Argentina | Industrial (battery) waste in soil | Metals (Pb & Zn) well above permissible limits |
| 7. | Triticum aestivum (wheat), Lycopersicumesculentum L. (tomato), radish, spinach, brinjal, carrot, Capsicum annum, Allium sativum (garlic), Coriandrum sativum (coriander), and okra | Pakistan | Metal-contaminated groundwater | Cr > 0.18 mg/kg<br>Pb 0.91–3.96 mg/kg |
| 8. | Rice and other paddy crops and vegetables | Australia (food crops imported from Bangladesh, India, Pakistan, Thailand, Italy, Canada and Egypt) | Arsenic- and metal-contaminated groundwater | Rice:<br>Cr 15–465 μg/kg<br>Pb 16–248 μg/kg<br>Cu 1.0–9.4 mg/kg<br>Zn 10.9–24.5 mg/kg<br>Cd 8.7–17.1 μg/kg<br>Co 7–42 μg/kg<br>Mn 61–356 μg/kg<br>Ni 61–356 μg/kg<br>Pb 670–16,500 μg/kg<br><br>Vegetables:<br>Cr 27–774 μg/kg<br>Pb 35–495 μg/kg<br>Cu 1–29 mg/kg<br>Zn 17–183 mg/kg<br>Cd 3–370 μg/kg<br>Mn 3–140 μg/kg<br>Ni 151–10,035 μg/kg<br>Pb 35–495 μg/kg |

  

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| 9. | French beans (Phaseolus vulgaris), beetroot (Beta vulgaris), and kale (Brassica oleracea var. acephala) | Australia | Urban stormwater | Cr 0.00078–0.049 mg/kg<br>Pb 0.001–0.11 mg/kg<br>Cu 0.016–0.66 mg/kg<br>Zn 0.038–0.145 mg/kg |
| 10. | Spinach | India | Sewage wastewater (inadequately treated) | Cu 0.09 mg/kg<br>Cr 2.9 mg/kg<br>Pb 3.1 mg/kg<br>Zn 10 mg/kg<br>Ni 3.2 mg/kg |
| 11. | Radish | China | Inadequately treated wastewater | Cu 0.34 mg/kg<br>Cr 0.03 mg/kg<br>Pb 0.07 mg/kg<br>Cd 0.012 mg/kg<br>Zn 2.48 mg/kg<br>Ni 0.07 mg/kg |
| 12. | Industrially processed food stuffs (e.g. candy) and pharmaceuticals | United States of America (USA), Spain, Portugal, Belgium, England, and Chile | Industries/food processing industries/modern pesticides based agriculture | Cr (0.10–17.7 ppm), Ni (0.01–7.01 ppm), Cu (0.01–6.44 ppm), Zn (0.01–6.44 ppm)<br>Pb (0.03–7.21 ppm) |
| 13. | Potato/other foodstuffs | Egypt | Inadequately treated wastewater | Cu 0.83 mg/kg<br>Cr nil<br>Pb 0.08 mg/kg<br>Cd 0.02 mg/kg<br>Zn 7.16 mg/kg |
| 14. | Potato | China | Inadequately treated urban wastewater | Cu 1.03 mg/kg<br>Cr 0.03 mg/kg<br>Pb 0.067 mg/kg<br>Cd 0.015 mg/kg<br>Zn 3.77 mg/kg<br>Ni 0.054 mg/kg |

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| 15. | Radish | India | Diverse contamination sources | Cu 5.96 mg/kg<br>Cr nil<br>Pb nil<br>Cd nil<br>Zn 22.5 mg/kg<br>Ni nil |
| 16. | Cauliflower | China | Urban wastewater | Cu 0.6 mg/kg<br>Cr 0.02 mg/kg<br>Pb 0.03 mg/kg<br>Cd 0.014 mg/kg<br>Zn 5.45 mg/kg<br>Ni 0.68 mg/kg |
| 17. | Amaranthus | India | – | Cu 1.4 mg/kg<br>Cr 2.4 mg/kg<br>Pb 2.9 mg/kg<br>Cd nil<br>Zn 8 mg/kg<br>Ni 3.1 mg/kg |
| 18. | Chinese cabbage | China | Pot experiment with exogenous supply of Cd | Cd 0.12–1.70 mg/kg |
| 19. | Lettuce (Lactuca sativa) | United States (Florida) | – | As 27.3 mg/kg<br>However, reduced by 21% |

Table 2. Health risks from the dietary intake of foodstuffs contaminated with heavy metals and metalloids [23]

| No. | Heavy metals and metalloid | Sources of metallic contamination | Route/ medium of exposure | Dose response details/toxicity limits | Dose response details/toxicity limits |
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| 1. | Mercury | Non-surgical tools, dental amalgams, chemical/chlor-alkali industries, energy-intensive industries such as thermal power plants | Methyl mercury enters the food chain through biomethylation; adversely affects the health of plants and humans | 10 µg/L (in whole blood); 20 µg/L (in urine) | Inorganic Hg leads to lung damage; kidney damage, proteinuria, allergy, and amalgam disease Organic Hg perturbs central nervous system (CNS) coordination and the health of plants | Neuropsychological symptoms; hypersensitivity (pink disease), nephrotic syndrome, historical Minamata disease on sea coast of Japan & Iraq killed thousands of people |
| 2. | Cadmium | Soil amendments with fertilizer and sewage sludge, Ni-Cd batteries, alloys, cigarette smoking | Food crops in non-smoking population; smoking; Fe status also affects gastrointestinal absorption | NOAEL (food): 0.01 mg/kg/day; RfD (mg/kg/day): $0.01 \times 10^{-2}$ | Adversely affects kidney functioning through increased secretion of low molecular weight proteins (β2-macroglobulin & α1-macroglobulin) & enzymes (N-acetyl-β-D-glucosaminidase), pneumonitis (oxide fumes), inhibition of sex hormones (progesterone &estradiol), endocrine disruption | Proteinuria in humans, kidney damage, human carcinogen (group I) causing lung & breast cancer, long-term exposure can result in itai-itai due to conjunction of osteomalacia& osteoporosis as evidenced in Japan |

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| 3. | Lead | Mining & smelting, paint, thermal power plants, crude petrol | Air/particulate deposition on food crops, occupational exposure | NOAEL:25 µg/dL; RfD (mg/kg/day): $0.35 \times 10^{-3}$ [toxic limit] Pb ≥ 70 µ/dL | Encephalopathy, nausea & vomiting, adverse impact on CNS, circulatory, & cardiovascular systems, children are vulnerable to problems with learning and concentration | Accumulation of erythrocyte protoporphyrin through inhibition of ferrochelatase, anemia, abdominal pain, nephropathy, possible human carcinogen |
| 4. | Copper | Irrigation with contaminated wastewater | Intake of contaminated food | LOAEL: 10 mg/kg/day | Can affect renal & metabolic functions | Excess protein droplets in epithelial cells of the proximal convoluted tubules in rats |
| 5. | Chromium | Electroplating/ chrome plating industries, dye industry, sewage wastewater/sludge | Intake of food contaminated by wastewater & soil amendment with industrial sludge | Toxic limits in humans not specified clearly | Kidney/renal dysfunction/failure, Cr (VI) is more health hazardous than Cr(III) due to rapid absorption, hemolysis& gastrointestinal hemorrhage | Collapse/ dysfunction of respiratory system through lung cancer & pulmonary fibrosis |
| 6. | Nickel | Ni-Cd batteries, wastewater | Intake of contaminated food | NOAEL: 5 mg/kg/day; RfD: $0.05 \times 10^{-1}$ | Can affect renal functioning, integral component of urease enzyme in kidney | Remarkable decrease in body & organ weights |

  

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| 7. | Arsenic (metalloid) | Inorganic As in contaminated groundwater, smelting of non-ferrous elements, thermal power plants using fossil fuels (coal), particulate deposition, minor sources include arsenical pesticides & wood preservatives | Contaminated drinking water & foodstuffs | Dose-response: 100 µg/L As can lead to cancer & 50–100 µg/L can lead to skin cancer [toxic limits] 24-h urine: ≥50 µg/L, or 100 µg/g creatinine | Multi-organ dysfunction, encephalopathy, bone marrow depression, hepatomegaly, melanosis, “rice-water” diarrhea, severe neuropathy, long QT syndrome, peripheral vascular disease (black foot disease of Taiwan) | Cancer in the lungs, kidney, bladder, and skin (hyperkeratosis & pigmentation); changes can occur from drinking As-contaminated water; diabetes & cardiovascular diseases |
| 8. | Zinc | Irrigation with contaminated wastewater (industrial & sewage) | Contaminated foodstuffs | LOAEL: 59.3 mg/kg/day; RfD: 1.00 × 10 mg/kg/day | Respiratory problems | Significant decrease (47%) in erythrocyte superoxide dismutase concentration in adult females |

Note/Abbreviations: No observed adverse effect level (NOAEL); lowest observed adverse effects level (LOAEL); RfD: reference dose (RfD, milligrams per kilogram per day) defined as the maximum tolerable daily intake of a specific metal that does not result in any deleterious health effects [23].

## Health Consequences and Risks Associated with Metals in Edible Crops

Due to the tendency of most heavy metals in soil to amass within crops, they can traverse various media via the food chain. The bioconcentration factor (BCF) of numerous heavy metals at the interface between crops and soil has been extensively observed, especially in major global staple crops such as wheat and corn [44,45] (Table 1). The consumption of vegetables tainted with heavy metals can lead to severe health problems in humans, including gastrointestinal cancer, compromised immune functions, developmental delays, and malnutrition [46,47,48]. The soil-to-plant transfer factor (TF) for metals and metalloids stands as a crucial parameter in assessing global health concerns [49,50]. The risks to human health are intricately associated with the consumption of food crops contaminated with metals (refer to Table 2). Heavy metals have the ability to accumulate in human bones or fatty tissues when ingested, potentially resulting in the depletion of vital nutrients and a weakened immune system. Certain heavy metals, such as Al, Cd, Mn, and Pb, are also suspected of contributing to intrauterine growth retardation [51,52]. Inhaling soil particles and consuming fruits, crops, and vegetables that are tainted with metals or metalloids can result in the development of gastrointestinal cancer [51]. To assess the bioavailability of these metals within the human gastrointestinal tract, concentrations of heavy metals were gauged in various types of vegetables, including leafy varieties such as lettuce and spinach, as well as non-leafy ones like radishes and carrots [53].

Health hazard indices are utilized to evaluate the potential risks to human health stemming from the consumption of food crops containing varying levels of heavy metals. In a study focused on health risks, particularly those associated with heavy metal-induced cancer, metals such as Cr, Pb, As, Hg, and Cd exhibited target hazard quotient (THQ) values surpassing 1 in food crops. Specifically, Pb and Hg were implicated in causing gastric and liver cancers, respectively [54]. Health risk assessments concerning the consumption of food crops were conducted in a developing country across 30 agro-ecological zones, utilizing health indices. The findings underscored that consuming vegetables contaminated with heavy metals, particularly Mn and Cu, posed greater threats to human health compared to the consumption of contaminated fruits [55]. Notably, research by Obiora highlighted that vegetables cultivated near a Pb-Zn mine carried heavy metal contamination, particularly Pb and Mn, which could contribute to conditions like Alzheimer's disease and manganism. Another study emphasized the cumulative health risks arising from a combination of Pb and Cd, rather than the effects of individual metals in isolation [56]. Cui's research also identified instances of renal dysfunction among individuals who consumed foods contaminated with a variety of metals [57].

## Heavy metals in appliances/cosmetics

The utilization of various cosmetics for personal grooming dates back to the earliest stages of human civilization. Over time, the demand for cosmetics has grown significantly worldwide. This surge can be attributed primarily to the heightened awareness of methods to enhance one's physical appearance [58]. Presently, the use of cosmetics for personal care and grooming has become a prevalent practice across the globe [59]. The global beauty product market has experienced an average annual growth rate of approximately 5%. Notably, the market for cosmetics and personal care items has exhibited consistent and steady expansion since its inception, continuing its progress even in economically uncertain times [60].

Cosmetic products consist of a diverse array of organic and inorganic components, encompassing both hydrophilic and hydrophobic substances. In the production of colored cosmetics, mineral pigments are frequently employed, which can introduce heavy metals (HMs) like Cu, Ni, Co, Pb, Cr, Cd, and other elements into the cosmetic products. These heavy metals are intentionally integrated into cosmetic products in various forms, serving as pigments, preservatives, UV filters, as well as agents for antiperspirant, antifungal, and antibacterial purposes [61].

Heavy metals can be introduced into the human body through various pathways, including kitchen utensils and food, which can have adverse effects on human health [62]. Regulations limit the presence of heavy metals in kitchen utensils to ensure safety, but there is still a possibility of contamination [63]. Some common heavy metals found in kitchen utensils include chromium (Cr), nickel (Ni), arsenic (As), cadmium (Cd), and lead (Pb) [62,63]. Similarly, heavy metals like lead (Pb), arsenic (As), mercury (Hg), aluminum (Al), zinc (Zn), chromium (Cr), and iron (Fe) have been discovered in cosmetics [64]. These heavy metals can enter the body through the skin, leading to various diseases. For instance, mercury can negatively impact the reproductive, immune, and respiratory systems. Lead can cross the placenta during pregnancy and harm the fetal brain, potentially leading to miscarriage. Moreover, heavy metals can contribute to skin conditions such as hyperkeratosis, hyperpigmentation, and various skin cancers [65].

In response to these concerns, people are increasingly attentive to the concentrations of heavy metals in cosmetics [66]. Legal regulations have been implemented to limit the amount of heavy metals in cosmetics, similar to kitchen utensils [64]. The use of ultraviolet (UV) filters in cosmetics, particularly sunscreens, aims to protect the skin from the harmful effects of UV radiation. However, some of these filters can be absorbed into the bloodstream and metabolized in the liver, potentially causing health issues [67]. Certain metals used as preservatives in cosmetics, such as parabens, can also act as endocrine disruptors and be absorbed through the skin, leading to adverse effects on health [68,69]. Some metals are used in cosmetics to peel and lighten the skin, but their use depends on regulatory laws in each country [59].

Unintentional contamination with heavy metals can occur at various stages of cosmetic production due to raw materials, additives, and even water used in the manufacturing process. Instrumentation used during sorting, manufacturing, and packaging can also contribute to heavy metal contamination [70]. Trace amounts of toxic metals like cadmium (Cd) and lead (Pb) have been found in products such as toothpaste, face makeup, and lipsticks [71]. Natural ingredients, including plant-based materials, can also introduce heavy metals into cosmetics [72]. International organizations recommend measuring toxic metal quantities in plants used as raw materials and in the final products to ensure quality and safety [73].

In the past, cosmetics were thought to have only local effects. However, concerns have arisen as research indicates that certain substances in cosmetics can penetrate the skin and potentially impact internal organs. Testing for penetration and toxicity of cosmetic ingredients has become important [74]. While the outermost layer of skin (stratum corneum) acts as a barrier, some heavy metals can still reach the circulatory system [72]. Some metals accumulate in the stratum corneum and cause allergies, while others can penetrate through sweat, tears, and sebum, or through cellular pathways, ultimately reaching the circulatory system. Consistent use of cosmetics can lead to increased exposure to heavy metals [75].

Excessive exposure to heavy metals can result in a range of health issues, including skin allergies, inflammation, cell damage, DNA damage, oxidative stress, neurological problems, memory loss, reproductive issues, and even carcinogenic effects [76,77,78].

## Health risk assessment

### Margin of safety

The potential danger to human health due to the exposure to heavy metal contaminants found in cosmetics can be evaluated using the concept of Margin of Safety (MoS). This can be determined by comparing the No Observed Adverse Effect Level (NOAEL) of the specific product being investigated to its systemic exposure dosage (SED), as previously documented [79]. The Systemic Exposure Dosage (SED) anticipates the quantity of chemicals that permeate the human body through different exposure pathways. It is determined by considering the concentration of the metal present in the product under investigation, the quantity of the product applied daily, the frequency of application, the skin surface area where the product is applied, and the average body weight [79,80]. A point of exposure at which no harmful effects are detected is referred to as the NOAEL (No Observed Adverse Effect Level), and its determination was grounded in dermal reference doses (RfDs) according to findings from ENERGY STAR's study [81].

As per the World Health Organization (WHO), a Margin of Safety (MoS) value of up to 100 is deemed acceptable, and a product with a MoS value exceeding 100 is considered safe for use. The Scientific Committee on Consumer's Safety (SCCS) acknowledges that in many traditional MoS calculations, if oral absorption data is unavailable, oral bioavailability is assumed to be 100%. Standard values for skin surface area (SSA) and amount applied (AA) for cosmetic products are established by the SCCS and can be found in Table S2. It is generally appropriate to assume that no more than 50% of an orally administered dose is systemically accessible [79].

The study involved the analysis of 30 different lotion brands (n = 90), and the measured levels of heavy metals (HMs) exhibited significant differences ($p < 0.05$) between different brands. All measured Cd levels in the lotions remained within the allowable limit of 3 mg/kg established by the Canadian authority for cosmetic products [82]. The observed range of Cd concentrations in this study was comparable to that reported by Ababneh and Al-Momani [83], but lower than that reported by Borowska and Brzóska [75].

Regarding chromium (Cr) concentration, 12 lotion brands (L4 to L13, L22, and L23) had Cr levels below the detection limit. The highest Cr concentration was found in L20 (0.69 ± 0.02 mg/kg). While the Cr levels in our samples were slightly higher than in a previous report [75], they still fell within the safe limit of 50 mg/kg established by the USFDA [84]. Although iron (Fe) is considered an essential mineral, excessive levels can lead to severe health problems [85]. In all lotion samples, measured Fe levels ranged from 0.27 to 7.01 mg/kg. The highest concentration was observed in L24 (7.01 ± 0.14 mg/kg), while the lowest was in L23 (0.27 ± 0.19), which was imported from South Africa. Among the lotions, the concentration of nickel (Ni) was highest (6.29 ± 0.12 mg/kg), while the lowest level was observed(0.01 ± 0.05 mg/kg) [75,83]. The recommended Ni level set by both the USFDA and Cosmetica Italia for cosmetics is 200 mg/kg [84]. However, for skin protection, it's suggested that Ni and Cr concentrations should be kept below 1.0 mg/kg in cosmetic products, especially those in direct contact with the skin. A concentration of 0.5 mg/kg of Ni is considered sufficient to cause dermatitis [86].

## Comparing the concentrations of heavy metals (HMs) in cosmetic products

A comparative evaluation of the average heavy metal contents in cosmetic products is summarized in Table 3. Exposure to cadmium (Cd) can lead to various harmful health effects, notably heart failure, kidney damage, liver impairment, and brain damage [77]. In some instances, high concentrations of Cd present in kohl have caused severe eye keratitis [78]. The average concentration of Cd ranged from 0.06 ± 0.01 to 0.26 ± 0.02 mg/kg in hair dyes and lotions, respectively. These values fall within the safe limit (3 mg/kg) for cosmetic products established by the USFDA [6].

Both forms of chromium, Cr (III) and Cr (VI), have the potential to cause adverse effects on the skin, including contact allergies and skin cancer [72]. The ascending order of the mean concentration of Cr in the cosmetic products was: sunblock > lipstick > whitening cream > lotion > foundation > hair dye. The average concentration of Cr ranged from 0.43 ± 0.01 to 0.09 ± 0.01 mg/kg, which is lower than the maximum limit (50 mg/kg) set by the USFDA [6].

While iron (Fe) is essential like zinc (Zn), excessive Fe concentrations in cosmetic products can lead to cellular death and subsequently increase the risk of colorectal cancer [87]. In this study, the average concentration of Fe varied from 0.31 ± 0.01 to 12.0 ± 1.75 mg/kg, with hair dyes and lipstick exhibiting these extremes. The descending order of Fe concentration in other products was: foundation > sunblock > whitening cream > lotion.

Table 3. Average concentration (±SE) of HMs in cosmetic products [77].

| Cosmetic products | No. of samples | Cd | Cr | Fe | Ni | Pb |
|---|---|---|---|---|---|---|
| Lotion | 90 | 0.26 ± 0.02 | 0.28 ± 0.01 | 2.14 ± 0.07 | 3.0 ± 0.1 | 2.81 ± 0.09 |
| Hair dyes | 18 | 0.06 ± 0.01 | 0.09 ± 0.01 | 0.31 ± 0.01 | 2.9 ± 0.3 | 4.50 ± 0.34 |
| Foundations | 27 | 0.115 ± 0.003 | 0.24 ± 0.004 | 9.6 ± 1.5 | 6.0 ± 0.1 | 3.05 ± 0.09 |
| Whitening creams | 18 | 0.123 ± 0.002 | 0.297 ± 0.003 | 2.2 ± 0.1 | 6.23 ± 0.04 | 3.25 ± 0.09 |
| Lipsticks | 18 | 0.15 ± 0.01 | 0.34 ± 0.02 | 12.0 ± 1.8 | 6.64 ± 0.03 | 4.49 ± 0.34 |
| Sunblock | 18 | 0.132 ± 0.002 | 0.43 ± 0.01 | 2.52 ± 0.04 | 8.0 ± 0.4 | 6.4 ± 0.1 |

Various brands of sunblock exhibited notably higher nickel (Ni) concentrations, followed by lipsticks, whitening creams, foundations, hair dyes, and lotions [Table 3]. Exposure to cosmetics contaminated with Ni can lead to skin allergies [75]. Lead (Pb) exposure to the human body can result in severe health effects including cellular death, DNA damage, oxidative stress, and neurotoxicity. It can also contribute to reproductive failure and carcinogenic health effects [76]. The average concentration of Pb was highest in sunblock at 6.37 ± 0.05 mg/kg, followed by lipsticks and hair dyes at 4.49 ± 0.34 and 4.50 ± 0.34 mg/kg, respectively.

The comparative analysis indicated that, overall, sunblock creams had the highest average concentrations of Cr, Ni, and Pb. Meanwhile, Fe and Cd concentrations were dominant in lipsticks and lotions, respectively.

## Lifetime cancer risk (LCR)

Chromium (Cr), lead (Pb), nickel (Ni), and cadmium (Cd) have been designated as carcinogenic heavy metals (HMs) by the International Agency for Research on Cancer [88]. These substances can enter the body primarily through two major routes: ingestion and dermal absorption. Due to their non-biodegradable nature, HMs tend to accumulate within the body over extended periods. Consequently, they not only disrupt cellular functions but also interfere with intracellular mechanisms [89]. This propensity to induce oxidative stress, DNA damage, and cell death can contribute to the development of cancer-related diseases [76]. The concept of lifetime cancer risk (LCR) involves estimating the potential cancer risk faced by users upon exposure to HMs present in cosmetic products. As per the United States Environmental Protection Agency (USEPA), an acceptable range for LCR falls between 1 × 10–6 and 1 × 10–4 [90].

## Cadmium background exposure levels from food and water

Several critical investigations have been conducted to assess cadmium intake through dietary food consumption. JECFA, in 2013, established that cadmium consumption in the United States ranged from 0.14 to 0.18 µg/kg/day. This determination was based on the FDA TDS data from 2004 to 2008, combined with NHANES WWEIA information from 2003 to 2006 [91]. An alternate study reported a lower cadmium intake of 0.07 µg/kg/day for adults. The values [92] derived for daily cadmium intake across the entire population could be lower than JECFA's findings due to their selection of exact TDS matches from the NHANES WWEIA survey. This approach might not account for the consumption of unmatched food items. Conversely, a recent study by [93] integrated all WWEIA food items into a TDS food item, thus encompassing the total consumption of the population. This study focused on cadmium and lead levels in children aged 1–6 years old, aligning NHANES WWEIA 2009–2014 consumption data with the most current TDS from 2014 to 2016. Unlike previous TDS studies that used atomic absorption spectrometry (AAS), this research employed inductively-coupled plasma mass spectrometry (ICP-MS), a more sensitive method. Cadmium background exposure levels for children were found to range from 0.38 to 0.43 µg/kg/day. Despite the strengths of the recent [93] study, it was confined to children up to the age of 6 years. The HMST tool's default inputs are based on adult consumption, but it allows for the inclusion of customized values, enabling the use of dietary background values specifically tailored to children.

### 1) Lead background exposure level from food and water

Divergent lead limits in drinking water are established by various regulatory agencies. The FDA enforces a bottled water lead limit of 5 parts per billion (ppb), while the WHO prescribes a lead water guideline of 10 ppb [94,95]. In contrast, the EPA has the most lenient water limit, with a Maximum Contaminant Level (MCL) for lead set at 15 ppb. Notably, the Maximum Contaminant Level Goal (MCLG) is set at a stringent 0 ppb [96]. The primary origin of lead contamination in tap drinking water stems from the corrosion of pipes that distribute water to households. Consequently, effectively determining and managing lead contamination on a national scale poses significant challenges. The EPA's action limit for lead isn't rooted in health-based guidance; rather, it was established as a practical value for public water systems to regulate pipe corrosion levels under the 1991 Lead and Copper Rule [97].

### 2) Mercury background exposure levels from food and water

A study conducted by utilized data from the Nurses' Health Study and Health Professionals Follow-Up Study, along with FDA TDS data from 1986 to 1991, to assess the background intake of mercury from food. In these studies, the food survey segment involved a questionnaire sent to participants, inquiring about their diet over the past year [98]. This approach yielded an estimated background methyl mercury level of 0.1 µg/kg/day. In 2002, Carrington and Bolger focused solely on seafood consumption to determine background mercury levels for children and adults. For this analysis, they employed FDA TDS data (1992–1993), the National Marine Fisheries Survey (1978), and a study by [99] as sources of mercury residue data specific to seafood. The Continuing Survey of Food Intake by Individuals (CSFII) from 1989 to 1991 served as the consumption database. Carrington and Bolger concluded that the background exposure level for children aged 2–5 years was 0.02 µg/kg/day, while for adults, it was 0.01 µg/kg/day.

  

[100] later determined background exposure levels of 0.03 µg/kg/day for children and 0.02 µg/kg/day for adults. These values were derived from NHANES WWEIA data from 1999 to 2006 and FDA TDS data from 1990 to 2002. In 2005, the WHO established a water limit for mercury at 6 µg/L [95]. Presently, both the EPA Maximum Contaminant Level and the FDA bottled water limit maintain water limits of 2 ppb [94,96]. Assuming an adult weighing 80 kg who consumes 1.2 L of water daily [101], it can be deduced that drinking water sources contribute to a mercury intake of 0.03 µg/kg/day.

### 3) Chromium background levels from food and water intake

The dietary background for chromium is typically assessed either as total chromium or trivalent chromium. A study conducted by [102] determined that US adults have a daily intake of total chromium of 76 µg/day. When considering an 80 kg adult, this corresponds to 0.95 µg/kg/day [101]. This value was established based on an investigation into high and low-fat content in typical American diets. The Institute of Medicine determined an Adequate Intake of 0.43 µg/kg/day for trivalent chromium, reflecting the intake level of most Americans [103]. This determination was derived from NHANES 1988–1994 data along with information from, which indicated that 13.4 µg of trivalent chromium was consumed per 1,000 kcal [104]. A study in 2002 calculated a total chromium intake of 0.47 µg/kg/day using databases such as CSFII and FDA TDS studies conducted from 1982 to 1994 [105].

Water limits, too, are usually reported as total chromium. Differentiating between trivalent chromium and the more toxic hexavalent chromium can be challenging since these forms can interconvert [105,106]. While hexavalent chromium is more water-soluble, the environmental conditions influence the predominant form. The water guideline established by the WHO in 2005 was 0.05 mg/L [107]. Both the FDA and EPA set their water limits for total chromium at 0.1 mg/L [94,96]. Assuming an 80 kg adult consumes 1.2 L of water daily, the estimated intake becomes 1.5 µg/kg/day [101]

## Regulation of Heavy Metals in Tools/Cosmetics

The proliferation of cosmetic products with diverse ingredients has raised significant health and safety concerns. In contemporary times, there is a general regulatory framework governing cosmetics [108]. A critical issue is the overlap in use and purpose between cosmetics and topical medicines. Various regulatory bodies have endeavored to establish a precise definition for cosmetic products to distinguish them from topical medicinal products. Within the European Union (EU), Council Directive 93/35/EEC [109] amending Council Directive 76/768/EEC provided a definition for cosmetic products in Article 1 of the directive. This definition delineates the external body parts that can be treated with cosmetics, excluding other body parts and implying that cosmetics shouldn't be applied to those excluded areas. The second part focuses on the permissible 'activities' for a product to be categorized as a cosmetic, setting cosmetics apart from topical medicinal products intended for controlling or treating conditions or making medical diagnoses [110]. However, while topical medicinal products undergo rigorous scrutiny before market placement, cosmetics don't undergo such thorough testing. Nonetheless, the safety of cosmetic products placed on the market is the responsibility of their manufacturers, distributors, and importers [111]. This regulation also explicitly outlines prohibited ingredients in cosmetic products. Among these prohibited ingredients, several heavy metals are included. While some metals and their salts are entirely prohibited (e.g., tin, arsenic, cadmium, nickel, and lead), others are allowed with specific limits, or only certain salts of those metals are permitted (e.g., cobalt, chromium, gold, mercury, and selenium, among others). Such inclusions might not always be deliberate, as the presence of certain minerals can be of natural origin. Heavy metals like cadmium (Cd), lead (Pb), nickel (Ni), arsenic (As), and mercury (Hg) have also been identified in various other raw materials used for producing cosmetics considered as natural products. These materials encompass honey, argan oil, olive oil, and citrus essential oils, among others [112,113,114,115].

Due to these concerns, several authorities have implemented restrictions on the presence of specific metals in cosmetic products. For instance, the Cosmetic Ingredient Review Expert Panel established by the Food and Drug Administration (FDA) in the USA has defined limits for certain metals: 5 parts per million (ppm) for arsenic (As), 5 ppm for lead (Pb), and 20 ppm for other heavy metals [116]. The World Health Organization (WHO) has also set limits: 10 ppm for lead (Pb), 0.3 ppm for cadmium (Cd), and 1 ppm for mercury (Hg). Within the European Union (EU), the limits are set at 0.5 ppm for lead (Pb), 0.5 ppm for cadmium (Cd), and 1.0 ppm for chromium. Similarly, Canadian authorities have established limits: 10 ppm for lead (Pb), 3 ppm for cadmium (Cd), and 3 ppm for mercury (Hg) [117].

## The presence of typical heavy metals in cosmetics and their effects

### Lead

Lead, one of the extensively researched heavy metals, is often examined due to its detrimental implications. Rather than being employed for its potential attributes, lead is typically considered a contaminant with severe impacts on human well-being. Its interaction with vital organs can induce neurotoxic, nephrotoxic, and hepatotoxic responses [118,119], along with potential effects on the reproductive system [120]. Additionally, lead exposure can influence fetal development as it crosses the placental barrier [121,122]. Certain studies have implicated lead as a potential human carcinogen [123]. Notably, individuals who use eye cosmetics have been found to possess blood lead levels three times higher than non-users [124]. Sources of lead exposure encompass industrial emissions, car exhaust, industrial chemicals like aged paints and pesticides, and combustion of fossil fuels. Such sources can lead to food contamination as well. Regulatory bodies globally are persistently grappling with defining acceptable lead limits. The World Health Organization has instituted a limit of 10 parts per million (ppm) [125]. Alternatively, another reference suggests an allowable level of 0.1 milligrams per liter (mg/l) [126]. For cosmetics, the FDA has set a maximum permissible content of 10 ppm for lead in color additives, governed by Good Manufacturing Practices [116]. However, for color additives, the lead content must not surpass 20 ppm [127]. Notably, within the EU, lead and its salts are explicitly prohibited in any cosmetic product [111]. Health Canada has established a threshold of 10 ppm for lead content in cosmetic products [117].

### Cadmium

Cadmium, recognized for its array of colored salts spanning from deep yellow to orange, has found usage in cosmetics [108]. However, it has been linked to various toxicities in humans, largely stemming from its absorption upon the topical application of several cosmetic products, albeit at a low rate (0.5%) [121,128,129]. Topical use can lead to irritant dermatitis [130]. The primary concern with cadmium lies in its propensity to accumulate within human tissues, subsequently releasing slowly into the bloodstream. It typically binds to keratin. On a systemic level, it notably impacts the skeletal, reproductive, metabolic, respiratory, and renal systems [131,132,133]. Osteoporosis, diabetes, lung cancer, and kidney damage have been associated with cadmium exposure [134]. Furthermore, it contributes to skin aging by inducing oxidative stress [135]. Despite its inclusion in cosmetics, cadmium can be found in various sources such as industrial waste, agrochemicals (pesticides and fertilizers), and batteries.

According to the World Health Organization (WHO), the permissible cadmium limit is 0.3 parts per million (ppm) [125]. Alternatively, another reference cites an allowable level of 0.06 milligrams per liter (mg/l) [126]. The US Pharmacopeia (USP) sets an oral limit for cadmium in nutritional supplements, ranging from 0.09 micrograms per kilogram (µg/kg) to 3 ppm. Importantly, the European Union (EU) strictly prohibits the presence of cadmium and its salts in any cosmetic product [111]. Health Canada has stipulated a threshold of 3 ppm for cadmium content in cosmetic products [117].

**Nickel**

Nickel stands out as a prevalent metal impurity often found in various natural ingredients incorporated into cosmetic products. Many nickel-containing salts exhibit a green hue, rendering them potentially suitable as colorants. However, nickel's role extends beyond coloration, as it is recognized as a contact allergen that can induce dermal sensitization, allergies, and dermatitis [136], primarily through direct and extended contact. Instances of nickel allergies have arisen due to its presence in topical cosmetics and jewelry, leading to diagnoses [137]. Moreover, nickel's impact can extend to the respiratory system, potentially resulting in nasal and lung cancers [133]. Despite cosmetics' intent to rejuvenate skin, the presence of nickel may instead lead to oxidative stress, thereby contributing to skin aging [135]. This could be attributed to the elevated expression of collagenases in the skin, leading to the degradation of the skin matrix and subsequent loss of elasticity [138].

The International Agency for Research on Cancer (IARC) has categorized metallic nickel as a potential human carcinogen (Group 2B), while its compounds are classified as carcinogenic (Group 1) [139]. Naturally, nickel can occur in soil and volcanic dust, and industrial activities also contribute to its presence in dust and fumes. Due to the potential for skin sensitization, proposed limits for nickel content in products have emerged. Recommended limits of 5 ppm [131] and 1 ppm [140] have been suggested for specific household products and detergents, respectively. Similarly, limits for nickel presence in cosmetics have been proposed, particularly targeting individuals sensitized to nickel. Many "nickel-free" products on the market contain less than 1 ppm of nickel [141,142,143]. For oral consumption, the permissible level of nickel is indicated as 0.20 ppm according to [144]. Within the European Union (EU), the presence of nickel and several of its salts is expressly prohibited in any cosmetic product [111]. These restricted compounds include nickel monoxide, dinickel trioxide, nickel dioxide, trinickel disulphide, tetracarbonynickel, nickel sulphide, nickel dihydroxide, nickel carbonate, and nickel sulphate.

## Mercury

Mercury is among the heavy metals frequently incorporated into cosmetic formulations. While mercury is generally recognized for its characteristic silvery, shiny, and dense liquid state, it exists in diverse forms encompassing both inorganic and organic compounds. In its inorganic state, like ammoniated mercury, it is utilized for its skin lightening properties. Conversely, organic forms such as phenyl mercuric and ethyl mercuric salts are employed as preservatives in mascaras and eye makeup cleansing products [145,146]. Following application to the skin, mercury, often abbreviated as Hg, permeates through the skin via sweat glands and hair follicles [130,147]. During this process, a portion of Hg transforms into its metallic form, accumulating in the skin tissue. The compound effectively obstructs the function of tyrosinase, an enzyme crucial for melanin production [148], making it a sought-after ingredient in skin-lightening creams [75]. It's worth noting that labels of certain products, such as creams bearing the abbreviation 'precip blanc,' can hint at the inclusion of mercury [149].

Systemically, exposure to mercury can result in an array of symptoms encompassing vomiting, nausea, kidney impairment, and central nervous system effects like irritability, tremors, weakness, nervousness, fatigue, and memory decline. Moreover, sensory functions such as hearing, taste, and vision can also be adversely affected. In more severe cases, elevated mercury content can lead to fatality [150,151]. Notably, following dermal absorption and subsequent systemic distribution, mercury might prompt autoimmune glomerulonephritis. Research underscores the substantial accumulation of mercury in various organs and bodily fluids, including hair (22.5 ppm, double the levels observed in non-cosmetic users), blood (up to 233 nmol/l, over four times higher than non-cosmetic users), and urine (up to 2531 nmol/day, fifty times higher than non-cosmetic users) [152,153,154,155].

Mercury is a metallic element that is naturally occurring in the environment and its compounds are the most common form that exists naturally in the environment. Due to its ubiquity, several authorities issued limitations for Hg use. For instance, the FDA restricts its use and is regulated in cosmetic products. The FDA allows a maximum level of 1 ppm of Hg in mercury-contaminated lead acetate when used as a colour in cosmetics [116]. Within the European Union, mercury and its compounds are not allowed in cosmetics, whereas phenyl mercuric salts are only allowed as preservatives in eye care products at a maximum allowable level of 70 ppm [111] whereas in the US it is allowed up to a level of 65 ppm by weight [116]. Health Canada allows a maximum Hg content of 1 ppm in cosmetics [117]

## Arsenic

Arsenic, a metalloid, is widely distributed as a significant environmental contaminant. While it may lack redox activity, it targets sulfhydryl groups on proteins, potentially leading to the depletion of glutathione [156], a vital amino acid-derived antioxidant responsible for safeguarding cellular components against damage from radicals and heavy metals. Prolonged dermal exposure to arsenic can result in localized effects such as hyperpigmentation and keratosis. However, at a systemic level, it poses risks of carcinogenesis and vascular disorders [156,157]. Despite arsenic being considered a less prevalent contaminant in cosmetics compared to other heavy metals, regulatory bodies have endeavored to set limits on its presence in cosmetic products, driven by concerns of prolonged exposure.

The challenge with arsenic contamination extends beyond legally approved cosmetic products available in the market. Notably, significant quantities of arsenic have been detected in cosmetics from illicit underground markets [158]. Similar to mercury, the FDA has established a threshold of acceptability for arsenic (up to 3 ppm) in the context of lead acetate, a colorant prone to contamination with this metalloid [116]. This maximum permissible limit aligns with the broader constraints outlined by Health Canada for all cosmetic products [117]. Within the European Union, arsenic and its salts are strictly prohibited in any cosmetic formulation [111].

  

## Pre-existing vulnerabilities and cumulative impacts

Beauty products encompass an array of compounds, including formaldehyde, phthalates, parabens, lead, mercury, triclosan, and benzophenone, which possess the potential to detrimentally affect well-being [159,160,161]. Exposure to even one of these constituents has been associated with disturbances in the endocrine system, cancer, harm to reproductive function, and hindered neurodevelopment, especially in children [162,163,164,165]. Particularly, women aged 18–34 are inclined to be "heavy buyers," purchasing more than 10 different types of products annually. This demographic and their offspring might face heightened susceptibility to toxic environmental agents if these products are used during critical developmental stages like preconception or pregnancy [166]. The impact of these chemicals may be more pronounced within low-income and racially/ethnically diverse communities, as these groups are subjected to more frequent exposures to various environmental and social risk factors, consequently leading to inferior health outcomes [167].

National data encompassing women of reproductive age in the United States point to heightened levels of certain endocrine-disrupting compounds, such as phthalates and parabens, within women of color compared to their white counterparts. Importantly, these racial and ethnic disparities are not solely attributed to socioeconomic status [168,169,170,171]. Moreover, individuals employed within the beauty industry, predominantly women of color and immigrant women, encounter potential occupational health hazards due to the presence of chemicals within professional cosmetic products and a lack of standardized workplace safety protocols [172,173,174]. Previous assessments evaluating cumulative environmental risks among marginalized groups have generally prioritized pollution sources rooted in specific locations, like industrial emissions or areas with high traffic volume [175,176]. Nevertheless, it is worth noting that exposure to beauty products might be elevated within communities that are simultaneously subjected to excessive exposures from place-based pollution [177,178].

### Conclusion

This comprehensive examination underscores the critical importance of addressing heavy metal contamination in both food and cosmetic products due to its profound impact on human health and well-being. The escalating presence of heavy metals in the environment, coupled with their various sources, poses a significant threat to food security and safety. It is imperative to recognize the complexity of heavy metal transfer in soil-crop systems and the necessity for robust epidemiological research to truly understand the health risks involved. Moreover, the study highlights the urgency of accurate soil pollution mapping and advocates for innovative, eco-friendly remediation strategies to mitigate contamination.

Within the realm of cosmetics, this investigation reveals notable variations in heavy metal concentrations across different product types. This underscores the need for stringent quality control measures and continuous monitoring to ensure the safety of consumers. Health risk assessments bring to light potential risks, particularly the heightened risk of skin cancer, underscoring the urgency for revisiting safety limits.

Additionally, the review introduces a valuable screening tool for assessing heavy metal risks in food, shedding light on reference values and background exposure levels. While acknowledging the influence of geographical and cultural factors, it stresses the importance of evolving regulations and assessment methods to keep pace with emerging science, changing health endpoints, and shifts in food consumption trends.

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