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# Metals Behind the Make-Up: Health Risks, Detection Methods and Regulatory Landscape of Heavy Metals in Cosmetic

Bilimoriya Disha[1], Patel Payal[2], Pathan Mahek[3], Rathod Aayushi[4], Bhavna Chandnani[5], Vikram Pandya[6]
[1,2,3,4]B.Pharm Scholar, Tathya Pharmacy College, Chikhli(396521), Gujarat, India
[5]Department of Quality assurance, Tathya Pharmacy College, Chikhli(396521), Gujarat, India
[6]Department of Pharmaceutics, Tathya Pharmacy College, Chikhli(396521), Gujarat, India

***Abstract***—*Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), and others have been detected in various cosmetics (lipsticks, eyeliners, skin lightening creams, powders, hair dyes). These contaminants may originate from raw materials, pigments, manufacturing equipment, adulteration, and environmental deposition. Chronic dermal exposure can lead to local effects (contact dermatitis, pigmentation changes) and systemic effects (neurotoxicity, nephrotoxicity, reproductive toxicity, carcinogenicity) depending on the metal, dose, and duration. Modern analytical methods — sample digestion followed by AAS, ICP-OES, ICP-MS, and XRF — enable sensitive quantification, with ICP MS offering the lowest limits of detection suitable for regulatory surveillance. International regulatory frameworks differ: the EU and UK have stringent bans and limits for several metals, the US FDA provides guidance but fewer explicit limits, and many low- and middle-income countries rely on older legislation or inconsistent enforcement.*

***Keywords***— *Heavy metals, cosmetics, lead, mercury, cadmium, analytical methods, ICP-MS, regulation, dermal exposure, risk assessment.*

## I. INTRODUCTION AND SCOPE

Cosmetics and personal care products are applied to intact or slightly damaged skin, mucous membranes, hair and nails and include a large variety of formulations — creams, lotions, powders, lip products, eyeliners, hair dyes, and deodorants. Because use is frequent and often chronic, even small concentrations of toxic contaminants may contribute to cumulative exposure. For pharmacy students, understanding the presence of heavy metals in cosmetics is important because pharmacists are trusted sources of consumer health information, play roles in product selection and pharmacovigilance, and may collaborate in surveillance studies. This review focuses on commonly reported heavy metals, detection methods used in regulatory and research settings, health implications, and practical recommendations for monitoring and mitigation.

Cosmetic products are composed of different organic and inorganic materials including hydrophilic and hydrophobic sub stances. The use of mineral pigments in the production of color cosmetics frequently results in the contamination of cosmetic products with heavy metals (HMs), including copper, nickel, cobalt, lead, chromium, cadmium, and other substances.

These HMs become a part of 11 cosmetic product intentionally in the form of pigments, preservatives, UV filters as well as antiperspirant, antifungal and antibac- terial agents. It has been reported that human exposure to UV radiations can cause chronic as well as acute health effects on human skin, eye and immune system. Therefore, UV filters are a crucial component of sunscreens and other popular cosmetic items that are used everyday by cosmetic companies.

It is used by both males and females for beautification that improve the features and smell of the body and hide the blemishes of the skin. These items include; Skin-care creams, lipsticks, lotions, fragrances, sprays, talcum and face powders, kajal, sindoor, fingernail polishes, permanent waves, bindi, eye and facial makeup, hair colours, hair oil, hair dyes, bubble baths, bath oils, infant product The investigated fairness creams were varied in their metal levels, and the estimated amounts of lead, cadmium, and chromium were shown to be higher than the respective maximum allowable levels, according to the WHO standard.(2)

Heavy metals are considered to be one of the main sources of pollution in the environment, because of their significant effects on the ecological quality .The main sources of heavy metal pollution in the environment are man-made effects, including 13 combustion of fossil fuels, mining activities, wastewater discharges of manufacturing industries, and waste disposal(2)

According to the World Health Organization (WHO), heavy metals concentration of herbal medicines must definitely be controlled But WHO is silent regarding the maximum permissible limits of heavy metals in herbal cosmetics. In this case, Health Canada has taken the initiative and implemented a few measures to control heavy metal concentration in cosmetics International Science Congress Association and determined the maximum acceptable limits i.e Lead (10ppm), Arsenic (3ppm), Mercury (3ppm), Cadmium (3ppm) and Antimony (5ppm)(1)

Recent studies revealed that the use of cosmetic products (e.g. moisturizing creams, lipsticks, powders, sunscreen creams, eye cosmetics, etc.) represent an important way of skin exposure not only to organic chemicals.(8)



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*Definitions and classification of heavy metals in cosmetics:*

*Definition of heavy metals*

The term "heavy metals" does not have a universally agreed scientific definition, but in cosmetic toxicology it typically refers to metallic elements and metalloids that have

- Relatively high atomic weight and density (>5 g/cm³)
- Environmental persistence and bioaccumulation potential
- Documented toxicological or ecotoxicological hazards

*Key Metals of Concern:* Lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), cobalt (Co), and aluminum (Al).

*Classification approaches:*

*(A) Based on intentionality of presence*

1. Intentionally added (rare, often illegal): o Mercury salts in skin-lightening creams (banned but still detected in some markets) o Lead-based pigments historically in kohl/surma
2. Unintentionally present (contaminants/impurities): o Lead, cadmium, arsenic, nickel as natural impurities in mineral pigments and clays o Chromium, cobalt from pigments and raw materials

*(B) Based on toxicological profile*

1. Carcinogenic metals: Arsenic, cadmium, hexavalent chromium (Cr VI), nickel (IARC classified)
2. Neurotoxic metals: Lead, mercury
3. Nephrotoxic metals: Cadmium, mercury, lead
4. Dermatotoxic/sensitizers: Nickel, cobalt, chromium

*(C) Based on chemical speciation (oxidation state/chemical form)*

- Chromium: Cr(III) (nutritional trace element, relatively less toxic) vs Cr(VI) (highly toxic, allergenic, carcinogenic)
- Mercury: inorganic salts (skin-lightening), elemental mercury (rare in cosmetics), organic methylmercury (not common in cosmetics but toxicologically relevant)

*(D) Based on source of contamination*

1. Raw material-derived: Pigments (iron oxides, ultramarine, clays, mica)
2. Process-related: Contamination from manufacturing vessels, water, or equipment
3. Intentional adulteration: Addition of mercury salts for bleaching effect, or lead for dark pigmentation
4. Environmental: Deposition during raw material harvesting ((soil, water contamination)

*Sources and Pathways of Contamination*:

- Mineral-Based Contaminants: A primary source of heavy metals is the geological origin of raw materials. Mineral pigments and fillers like iron oxides, titanium dioxide, mica, talc, and clays naturally contain impurities such as lead, arsenic, cadmium, and chromium.
- Botanical and Herbal Sources: Plants used for extracts can bioaccumulate heavy metals from the soil and irrigation water. This is a significant risk for herbal-based cosmetics, including Ayurvedic creams and hair oils.
- Water Quality in Production: Contaminated process water is a major vector. Heavy metals like lead, arsenic, or nickel can enter formulations via old plumbing systems or inadequate water purification during the manufacturing process.
- Manufacturing Equipment Leaching: Physical contact with factory infrastructure can introduce toxins. Unlined or corroded metal vessels, pipelines, and stirrers can leach heavy metals directly into the product batches.
- Processing Residuals: Cross-contamination between batches in shared facilities and the use of metal-based catalysts (e.g., zinc or chromium salts) in chemical synthesis can leave traces if the final purification is incomplete.
- Packaging Risks: Contamination can occur after production through low-quality packaging. This includes leaching from lead solder in metallic containers, decorative coatings, or the use of recycled plastics and glass containing impurities.
- Environmental Deposition: Heavy metals can enter the supply chain through airborne industrial emissions, which settle on raw materials during harvesting, transport, or storage.
- Intentional Adulteration: Despite bans, some manufacturers deliberately add toxic metals for specific effects. Notable examples include mercury salts for skin bleaching and lead-based pigments in traditional eye cosmetics like kohl and surma.
- Supply Chain Vulnerabilities: The globalized nature of sourcing makes quality control difficult. Procuring materials from artisanal or small-scale suppliers who lack strict testing protocols increases the risk of contamination.

*Health Risks and Toxicological Impact:*

*General Mechanisms of Toxicity:*

Heavy metals do not easily leave the body; instead, they build up over time through bioaccumulation, particularly in the liver, kidneys, and brain. They damage the body through:

- Oxidative Stress: Creating reactive molecules that damage DNA and proteins.
- Enzyme Inhibition: Binding to essential enzymes and "turning them off."
- Endocrine Disruption: Mimicking or blocking natural hormones.

*Metal-Specific Health Effects*

Lead (Pb): Acts as a calcium mimetic that accumulates in bones; causes neurological impairment (learning disabilities), inhibits blood production (anemia), and triggers skin pigmentation changes.

Mercury (Hg): Organic forms cross the blood-brain barrier (neurotoxicity), while inorganic forms from lightening creams cause kidney failure (nephrotoxicity); symptoms include tremors and memory loss.

Cadmium (Cd): Remains in the kidneys for over 20 years; leads to bone demineralization (osteoporosis) and is a Group 1 carcinogen.

Arsenic (As): Causes visible skin changes like keratoses and pigment patches; long-term exposure is linked to bladder, lung, and skin cancers due to DNA repair interference.



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Nickel (Ni): A major allergen responsible for allergic contact dermatitis, characterized by itching, redness, and chronic skin rashes.

Chromium (Cr): Hexavalent Cr(VI) is highly corrosive, causing "chrome ulcers" (skin ulceration) and serious respiratory issues.

Aluminum (Al): Primarily used in antiperspirants; associated with localized skin irritation and ongoing scientific debate regarding a link to Alzheimer's disease.

*. Exposure Routes:*

- Dermal: Slow absorption through skin (creams/powders).
- Oral: Direct ingestion (lipsticks/lip gloss) or hand-to-mouth transfer.
- Inhalation: Direct delivery to lungs via sprays and loose powders.

## II. Analytical Methodologies

*Sampling and sample preparation:*

- Representative sampling: Ensuring that cosmetic samples (lipsticks, powders, creams) are homogenized before analysis.
- Pre-treatment: Removal of moisture, grinding solid samples, and homogenization of creams and gels.

*Digestion techniques:*

- Open vessel acid digestion: Involves nitric acid or aqua regia heating in beakers; simple but risk of contamination and analyte loss.
- Microwave-assisted digestion: Closed vessels with controlled pressure and temperature; provides rapid, complete digestion with minimal analyte loss.
- Dry ashing/fusion methods: High temperature treatment with flux (e.g., lithium borate) for refractory samples like pigments; used when acids are insufficient.

*Simple and Accessible Methods*

These methods are often used for preliminary screening due to their low cost and ease of use:

- Colorimetry: Uses chemical reagents (like dithizone for lead) to create a color change. It is inexpensive and visual but lacks high sensitivity and can be obscured by cosmetic dyes.
- UV-Visible Spectrophotometry: Measures light absorbance of metal complexes at specific wavelengths. It provides more quantitative data than simple colorimetry but requires clear, pigment-free solutions.
- Flame Photometry: Detects alkali metals (like sodium or calcium) by measuring the light they emit in a flame. While rapid, it is ineffective for heavy metals like lead or mercury.

*Advanced Instrumental Techniques:*

For precise safety monitoring and regulatory compliance, advanced tools are required:

- Atomic Absorption Spectroscopy (AAS): A reliable standard for detecting lead, cadmium, and arsenic. It is highly sensitive but generally tests for only one element at a time.
- ICP-OES: Uses plasma to excite atoms for multi-element detection. It is faster than AAS and ideal for large-scale laboratory monitoring.
- ICP-MS (The Gold Standard): This technique offers ultra-trace sensitivity, measuring concentrations as low as parts per trillion (ppt). It is the most powerful tool available but is costly and requires expert operation.
- X-Ray Fluorescence (XRF): A non-destructive and portable method. Because it doesn't damage the sample, it is frequently used by customs officials for rapid field screening of imported cosmetics.

*Regulatory Guidelines and Standards:*

Global regulatory frameworks are essential for ensuring consumer safety by establishing strict limits on heavy metal contaminants that arise from unavoidable manufacturing processes. Organizations like the World Health Organization (WHO) and the International Cooperation on Cosmetics Regulation (ICCR) provide the foundational guidance for these standards, aiming for international harmonization to protect public health and facilitate fair trade. While specific limits vary by region, the overarching goal across all jurisdictions is to ensure that toxic metals are not intentionally added and that trace impurities are kept to the absolute technical minimum.

In the United States, the FDA monitors compliance under the Federal Food, Drug, and Cosmetic Act, specifically recommending that lead levels in lipsticks do not exceed 10 ppm (parts per million). The European Union maintains even stricter oversight through Regulation (EC) No. 1223/2009, which explicitly prohibits the intentional use of lead, cadmium, mercury, arsenic, and antimony, allowing only technically unavoidable traces (e.g., lead $\leq$ 20 ppm). Similarly, India regulates these substances through the BIS and CDSCO, which strictly prohibit mercury compounds (limit $\leq$ 1 ppm) and cap lead content at 20 ppm. Other regions, such as Canada with its "Hotlist" and Japan with its outright prohibitions, follow similar paths, while ASEAN nations have moved toward harmonizing their guidelines with the rigorous standards set by the EU.

*Risk Assessment And Management:*

Risk assessment is a systematic process used to determine if the heavy metals in a product pose a real threat to the user. It begins with hazard identification to find which metals are present, followed by a dose-response assessment to understand how much of that metal causes harm. Finally, an exposure assessment looks at how often a consumer uses the product. By combining these factors, regulators can estimate the overall risk to the public.

To manage these risks, manufacturers must implement Good Manufacturing Practices (GMP) and perform rigorous batch-wise testing. This ensures that even if trace impurities are present, they stay below the Toxicological Reference Values, such as the Tolerable Daily Intake (TDI), which defines the safe limit for daily exposure over a lifetime.

*Exposure Factors:*

- Product Form: Lipsticks carry ingestion risks, while



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powders pose inhalation risks.

- Usage Habits: How much is applied and how many times per day.
- User Sensitivity: Children and pregnant women have a much lower tolerance for exposure.

*Management Strategies:*

- Source Control: Auditing suppliers and screening raw minerals/herbs before production.
- Quality Monitoring: Testing finished batches to ensure they meet FDA, EU, or BIS standards.
- Consumer Education: Warning the public about the dangers of "unregulated" or "counterfeit" cosmetics.

*Safety Benchmarks:*

- ADI/TDI: The scientific "red line" for safety (e.g., WHO limits lead to 3.6 µg per kg of body weight daily).
- Compliance: Strict adherence to international regulatory ceilings (ppm limits).

*Herbal Innovations and Organic Cosmetics:*

The shift toward herbal and organic cosmetics is primarily driven by rising consumer awareness of heavy metal toxicity and a demand for eco-friendly, synthetic-free alternatives. By replacing mineral-based pigments with plant dyes like henna and beetroot, and synthetic preservatives with natural extracts like neem or rosemary, manufacturers can significantly reduce the risk of heavy metal contamination. These botanical ingredients offer multifunctional benefits—such as UV protection from green tea and anti-aging properties from plant stem cells—often enhanced by modern technologies like nanotechnology and green extraction methods to ensure high purity and stability.

However, the "natural" label does not automatically guarantee safety; a major challenge remains the bioaccumulation of heavy metals in plants grown in polluted soil, which necessitates strict adherence to global organic certification standards like USDA, COSMOS, or India's NPOP. Beyond environmental risks, the industry faces hurdles in standardizing active ingredients and managing the higher costs associated with organic production. Despite these challenges, the integration of traditional Ayurvedic knowledge with modern AI-driven personalization and biodegradable packaging represents the future of the industry, offering safer and more sustainable beauty solutions.

## III. FUTURE PERSPECTIVES

- Next-Gen Detection: Development of "Point-of-Care" kits and "Lab-on-a-chip" devices will allow manufacturers and regulators to detect lead and mercury instantly on-site.
- AI & Sustainability: AI will be used to predict contamination risks before production begins, while "Green Chemistry" will focus on plant-derived ingredients and closed- loop manufacturing to keep external toxins out.
- Strict Policy: There is a global push to harmonize metal limits across all countries, making it harder for contaminated products to cross borders.
- Education & Advocacy: Pharmacy students will receive more training in cosmetic toxicology, and digital platforms will allow consumers to verify safety certificates via their smartphones.

## IV. CONCLUSION:

Heavy metals in cosmetics are a persistent global health threat because they accumulate in the body over time. While advanced analytical tools like ICP-MS and AAS are essential for monitoring safety, they must be paired with Good Manufacturing Practices (GMP) and strict raw material screening.

The industry is at a turning point: the shift toward herbal and organic cosmetics offers a safer path, but only if sourcing is tightly controlled to avoid polluted soil. By combining innovative technology (like AI and nanotechnology) with global regulatory harmony and consumer education, the next generation of cosmetics can achieve a higher standard of safety and sustainability.

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