Quantitative Evaluation of Lead, Cadmium, and Arsenic in Nepalese Cosmetics: Risk Assessment and Regulatory Insight in 2025

Aavash Subedi[1], Shukra Raj Regmi[1*], Narendra Prakash Shawd[1], Nurul Hoda Khan[1], Dikpal Kumar Shahi[1], Rameshwar Adhikari[2]

[1]Graduate School of Science and Technology, Mid-West University, Birendranagar-21700, Surkhet, Karnali Province, Nepal
[2]Research Centre for Applied Science and Technology (RECAST), Tribhuvan University, Kirtipur, Kathmandu 44618, Nepal

*Corresponding Author: Shukra Raj Regmi, Email: shukra.regmi@mu.edu.np

Abstract

Recognizing the escalating use of cosmetics in Nepal—manufactured under suboptimal conditions or imported from countries with lax regulatory frameworks—this study investigates the prevalence of lead (Pb), cadmium (Cd), and arsenic (As) in 27 cosmetic samples including spanning lipsticks, hair colors, skincare items, powders, and nail polishes. Quantification of heavy metal concentrations was performed using the dithizone method for lead (Pb) and cadmium (Cd), and the molybdenum blue method for arsenic (As). Results revealed alarmingly high lead (Pb) levels with "COLOR STAY MATT 24-HRS" lipstick containing 370.777 mg g^{-1} far exceeding global safety thresholds and cadmium levels peaking at 8.015 mg g^{-1} in "HengFang Sheer Gloss Balm." Arsenic concentrations, while detectable, remained within permissible limits. Integrating data from global health organizations, the study situates Nepal as the second most affected country in Asia and 13th globally in children's blood lead levels. These findings were juxtaposed against international safety standards to reveal significant noncompliance, exacerbating the public health crisis in Nepal. This research underscores immediate policy reforms, stricter import, thorough quality control mechanisms, and comprehensive public education campaigns to mitigate the health and environmental consequences of heavy metal exposure. By addressing these gaps, Nepal can both safeguard public health and contribute to the global discourse on environmental toxicity and regulatory justice.

Keywords: lead (Pb), cadmium (Cd), arsenic (As), cosmetic products, cosmetic metal toxicity, global safety standards, policy intervention.

1. Introduction

Lead is a naturally occurring 36th most abundantly distributed heavy element having crustal abundancy 14 ppm in Earth [1]. It is commonly known as a chalcophile element due to its affinity with sulfur. The most commonly distributed ore of lead is lead galena (PbS), anglesite ($PbSO_4$), cerussite ($PbCO_3$), boulangerite ($Pb_5Sb_4S_{11}$) etc. [2]. Lead contamination occurs in our ecosystem due to natural and anthropogenic activity through volcanic eruption, geochemical activities, cosmetic products, chemical waste, etc. [3]. According to WHO guidelines, the maximum permissible limit of lead is 10µgm/l in water, consumable goods, and cosmetic products (4th edition, 2017). The lead concentration should be less than 5 µg/L in the limnology system, 0.1µg/m^3 in the atmosphere, 100 mg/Kg in the lithosphere, and 4 mg/L in vegetation [4]. Excess consumption may cause a toxic effect on the body such as neurotransmission problems, gastro-intestinal disorders, neuromuscular pain, nephropathy, anemia, kidney damage, skin allergy, and ultimately death [5].

The excess use of lead and lead derivatives in cosmetic products is a matter of great concern for human health. The report has shown that the average distribution of lead in different cosmetic products is greater than 50 ppm in the local market of Iran [6]. Similarly, report from the same country showed that the average distribution of lead is below 7µg/g in the different cosmetic products [7]. In the local market of India, the average distribution is 5µg/gm [8]. In Pakistan, the average distribution of lead in nail police is found 13.6 µg/g [9]. In South Africa, lead concentration in cosmetic products is found below 73.1 ± 5.2 µg/g [10]. A study of lead in children's lip products in China has revealed that the range of its distribution is 0—0.5237 mg/Kg, which is very low as compared to the permissible limit granted by WHO [11]. In the European market, the distribution of lead in the different varieties of the cosmetic product is found 0.55 mg/kg in lipsticks, 0.38 mg/Kg in lip-glosses, which is the below-recommended limit in German 20 mg/Kg [12]. A study of lead in the cosmetic samples in USA, Italy, and China has shown that most of the products from Italy and the USA are under the permissible limit of 20 µg/gm but some samples from Chain have crossed the tolerable limit [13].

Lead is a dication that binds strongly to sulfhydryl groups on proteins, disrupting various bodily functions, particularly in the central nervous system (CNS). It mimics calcium, interferes with enzymes and neuronal signaling, inhibits mitochondrial function, and impairs neurotransmitter release. It affects brain development and synaptogenesis, and behavioral alterations in both lead exposed animals and humans. Lead exposure significantly affects social behavior, not just cognitive function. Studies show a correlation between lead exposure and attention deficits, aggression, and delinquency [14]. Lead shows a significant correlation with crime rates [15]. Lead poisoning in adults can affect the peripheral and central nervous systems, kidneys, and blood pressure. Notably, no safe blood lead level exists; even low concentrations (3.5 µg/dL) can reduce intelligence and cause behavioral issues in children [16]. Approximately 11,325,210 Nepalese children are estimated to suffer from lead exposure, with lead attributable deaths nearly doubling from 3,757 in 2019 to 8,104 in 2021-IHME [17].

Cadmium is a very rare transition metal having an abundance of 0.1 ppm of earth's crust [18]. Many reports have shown that cadmium does not form varieties of ore, most notably its representative ore greenockite (CdS) is found with sphalerite (ZnS). Cadmium extraction takes place from natural sources however; a very low concentration is obtained from the by-product of mining, metallic reduction, zinc spelter, and scrap iron, etc. The high content of cadmium is reported in soil, water, vegetables, tobacco leaf and cosmetics. Cadmium contamination is also reported from mineral sources, rock salt, fly ash, fertilizer, and from specific ore of iron, zinc, copper, and mercury [19]. According to WHO guidelines (4th edition, 2004), the maximum permissible limit of cadmium in drinking water is 0.003 mg/L. Reports on cadmium study show that its concentration should not be above than 0.005 mg/m^3 in the atmosphere, 2 mg/kg in the lithosphere, and 0.001µg/L in the limnology system [20]. Excess concentration in water or inhaling cadmium fume may cause lung cancer, memory loss, fume fever, proteinuria, renal abnormalities, pneumonitis, hormonal misbalance, osteomalacia, and pulmonary edema, etc. [21].

Cadmium is a highly toxic, heavy, and non-essential transition metal. Its industrial uses in PVC products, color pigments, and batteries have led to significant contamination. Even at low levels, cadmium can damage organs, disrupt reproduction, alter gene expression, and cause DNA methylation changes. It also affects the endocrine system, leading to menstrual issues and pregnancy complications, and is linked to osteoporosis and arthritis, posing serious health risks to humans and animals [22]. Arsenic acts as a protoplasmic poison by targeting sulfhydryl groups in cells, disrupting enzymes, cell respiration, and mitosis [23]. It is recognized as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) and is known to cause arsenicosis when present in drinking water. Acute arsenic poisoning can cause severe gastrointestinal and cardiac issues, leading to prostration, stupor, convulsions, paralysis, collapse, and death in coma [24]. Arsenic is another highly toxic 53rd abundantly distributed element having abundancy 1.5 ppm in the earth's crust. The report has shown that its background concentration should be 3 ng/m^3 in air, 100 mg/Kg in soil, 0.4 mg/Kg in vegetation, and 0.15 mg/L in seawater. It is found in a combined state with antimony and bismuth. Arsenopyrite (FeAsS) is a reported ore of arsenic. High arsenic inhalation from water or any contaminated cosmetic products may cause severe toxic effects which is shown by H_3AsO_4 at pH 2, $H_2AsO_4^-$ at pH 2-7, $HAsO_2^{2-}$, at pH 7-11, and AsO_3^{3-} at pH 11 [25].

Chronic exposure results in hair loss, brittle nails, eczema, hyperpigmentation, skin exfoliation, and thickening of the palms and soles [26]. The surge in cosmetics' popularity, driven by advertising, influencers, and beauty pageants, has raised concerns about harmful ingredients that need strict regulation. Rumors about the presence of heavy metals in cosmetics have prompted us to focus on evaluating the safety of various cheap cosmetic brands available in the Nepalese market, many of which are also imported from countries where safety regulations are poorly enforced and with suboptimal manufacturing conditions. The issue of heavy metals in cosmetics is particularly severe in underdeveloped countries like Nepal, where regulatory enforcement is weak. Consumers may lack information about the potential dangers of cosmetics containing heavy metals, and the market is often flooded with low-cost, unregulated products posing significant health risks. The absence of stringent safety standards and limited public awareness exacerbates this problem, leading to widespread exposure to harmful substances. This research aims to analyze cosmetic samples in Nepal for heavy metals using advanced techniques, providing data to inform policy decisions and improve consumer safety.

2. Materials and Methods

2.1. Samples

Samples were collected from various locations within Nepal, with the majority labeled as "Only for Nepal." The collection comprised 27 samples, including 5 lipsticks, 5 hair colors, 6 creams/lotions, 5 powders, and 6 nail polishes, spanning a range of prices. These samples were purchased between February and April 2025 in Nepal and subsequently brought to the Mid-West University, Birendranagar, Surkhet, for the study.

Table 1. Different cosmetic samples with their symbol used in the experiment.

Category	Lipsticks	Lipsticks symbol	Hair colours	Hair colours symbol	Creams/ Lotions	Cream/Lotion symbol	Powders	Powders symbol	Nail polishes	Nail polishes symbol
1	COLOR STAY	L_1	GOOREJ EXPERT	H_1	STRAWBERRY	C_1	JOHNSON	P_1	NHC	N_1
2	ROMANTIC MAy	L_2	BERINA	H_2	LOTUS	C_2	SPINZ	P_2	SONATA	N_2
3	HengFang	L_3	DEXE	H_3	BEAUTI DARBAR	C_3	DERMI COOL	P_3	JAVIRA	N_3
4	BERINA	L_4	ENEGA	H_4	ASSURE	C_4	NARS	P_4	AITRACICN	N_4
5	MATTE	L_5	STREAX	H_5	NEUTROGENA	C_5	POND	P_5	BEAUTY MARK	N_5
6	-	-	-	-	MaMa CARE	C_6	-	-	SPARK	N_6

2.2 Chemicals

All chemicals used in the study were of analytical grade. These included lead nitrate ($Pb(NO_3)_2$, MW = 331.20 g/mol, CAS NO. 10099-74-8, ≈ 99 %) purchased from Fisher Scientific. Similarly, cadmium chloride ($CdCl_2$), and sodium arsenite (Na_2AsO_3, MW = 129.91 g/mol, CAS No. 7784-46-5, 98%,) was purchased from LOBA CHEMIE PVT.LTD. Diphenylthiocarbazone (Dithiozone, $C_{13}H_{12}N_4S$, M.W. 256.33 g/mol, CAS. NO. 60-10-6, ≈ 9 9%) was purchased from CDH (P) Ltd. India. Ammonium molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$, M.W = 1235.9 g/mol, Product No. A-008342, ≈ 98%) was purchased from NIKE CHEMICAL. Chloroform ($CHCl_3$, M.W = 119.38, CAS NO. 67-66-3, ≈ 99.5%) was purchased from Thermo Fisher Scientific India. Ascorbic acid ($C_6H_8O_6$, 176.13 g/mol, CAS NO. 54006 K01, 99.0%) was purchased from SDFCL- s d Fine-CHEM Ltd. Acetone ($(CH_3)_2CO$, M.W. 58.08, CAS No.67-64-1, ≈ 99.5%) was purchased Thermo Fisher Scientific. Hydrogen peroxide (H_2O_2, M.W = 34.01 g/mol, CAS No. CL0C700612, ≥ 6%) was purchased from Merck Life Science Pvt. Ltd. H_2SO_4, sodium hydroxide (NaOH, M.W = 40 g/mol, 97 %) and sulphuric acid (H_2SO_4, M.W. 98.08 g/mol, CAS. NO. DJ3D731684, 95.0-98.0 %, ACS) was purchased from Merck.

2.3. Instrumentation

The quantities of lead (Pb), cadmium (Cd), and arsenic (As) in cosmetic samples were determined by UV-visible spectrophotometer (Labtronics model, LT-2700) . The optical system with a 1200 lines/mm grating having range 190—1100 nm ensures 1nm bandwidth. The silicon photodiode detection contains ±0.1 nm accuracy and repeatability. The photometric accuracy confirms the ± 0.3% T across 0—100% transmittance.

3. Preparation of Chemicals

3.1. Preparation of lead nitrate ($Pb(NO_3)_2$), cadmium chloride ($CdCl_2$)and sodium arsenite (Na_2AsO_3) stock solution

A 1000 ppm ≈ (1000 mg/L), $Pb(NO_3)_2$ solution was prepared at 25^{o}C in distilled water having density 1 gm/L. Then, 10 mL of this solution was diluted to 100 mL to obtain a 100 ppm $Pb(NO_3)_2$ solution. From the 100 ppm solution, 5 mL was diluted to 50 mL to make a 10 ppm $Pb(NO_3)_2$ solution. The 10 ppm solution was then further diluted to obtain solutions with concentrations of 9 ppm, 8 ppm, 7 ppm, 6 ppm, 5 ppm, 4 ppm, 3 ppm, 2 ppm, and 1 ppm to use in the study. The dilution process was repeated to prepared cadmium chloride, and sodium arsenate standard solution for calibration [27].

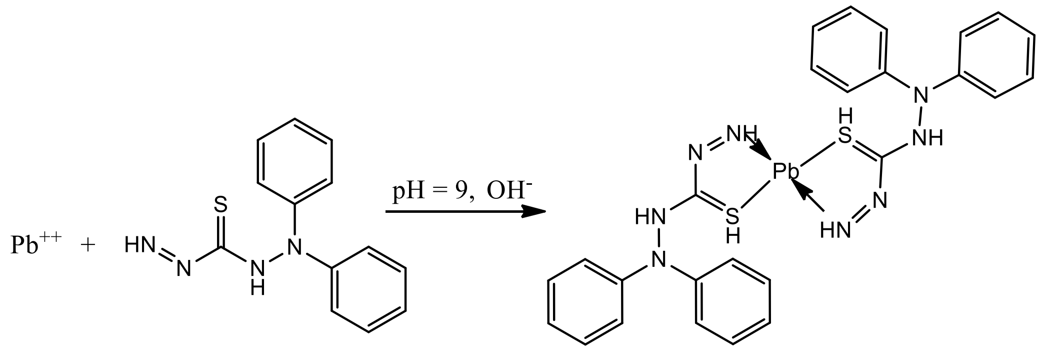
3.2. Sample Digestion

Approximately 1 gram of each cosmetic sample was accurately weighed using an analytical balance. The weighed sample was transferred to a digestion vessel. A mixture of 10 mL concentrated nitric acid and 5 mL hydrogen peroxide was added. The mixture was digested using a microwave digestion system under the following conditions: 180°C for 30 minutes at a ramp time of 10 minutes. After cooling to room temperature, the digestate was filtered through Whatman No. 42 filter paper (Cytiva, Cat. No. 1001-125), and diluted to a final volume of 50 mL with deionized water [7].

3.3. Complexation Reactions

An aliquot of the digested sample (5 mL) was taken. 1 mL of 0.1% dithizone solution in chloroform was added. The mixture was shaken vigorously for 5 minutes in an incubator shaker and allowed to separate. The organic layer containing the lead-dithizone complex was collected for analysis. The process was repeated for the analysis of cadmium. An aliquot of the digested sample (5 mL) was taken. 1 mL of 0.1% dithizone solution in chloroform was added. The mixture was shaken vigorously for 5 minutes and allowed to separate. The organic layer containing the cadmium-dithizone complex was collected for analysis.

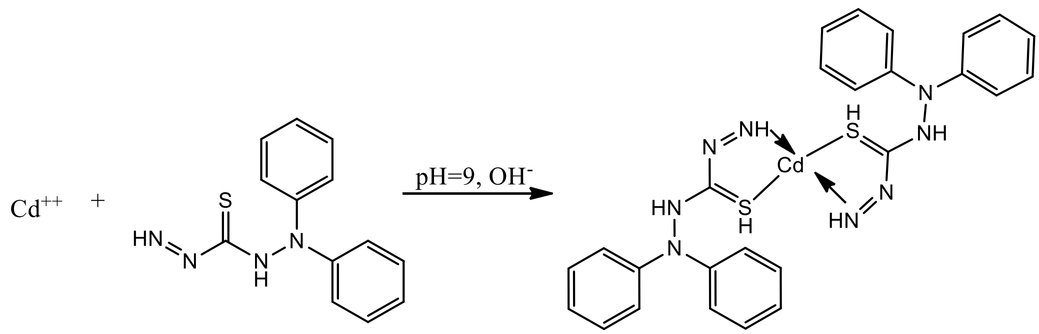
Plausible mechanism 1



Diphenylthiocarbazone

Lead-dithizonate complex 'Red'

Plausible mechanism 2

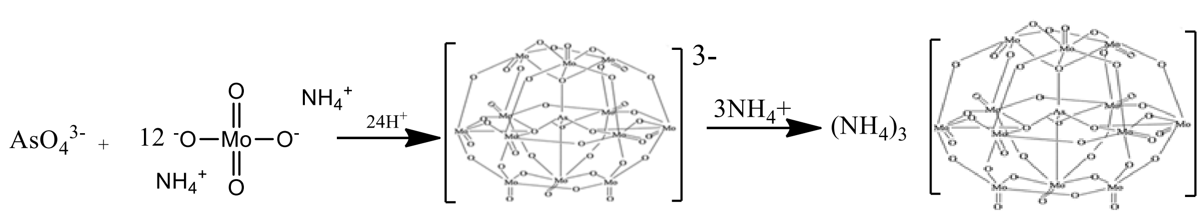


Diphenylthiocarbazone

Cadmium dithizonate complex 'Red'

The test of arsenic was carried out by the molybdenum blue method. An aliquot of the digested sample (5 mL) was taken. 1 mL of 1% potassium iodide (KI) and 1 mL of 1% ascorbic acid were added to reduce arsenic to arsenite (As^{3+}). 2 mL of ammonium molybdate solution (prepared by dissolving 2.5 g of ammonium molybdate in 100 mL of deionized water) was added. 1 mL of 1% hydrazine sulfate solution was added to reduce the molybdenum to form the blue complex. The mixture was allowed to stand for 10 minutes for full color development. The resulting solution was used for analysis.

Plausible mechanism 3



Arsenate anion

Ammonium molybdate

Arsenomolybdic anion 'Yellow'

Ammoniated Arsenomolybdic complex

4. Result and Discussion

4.1. Determination of Maximum Wavelength and Calibration Curve

The absorbance spectra of prepared solutions of lead (Pb), cadmium (Cd), and arsenic (As) were measured across various wavelengths to identify their maximum absorbance wavelengths (λmax). This process ensures the most sensitive and accurate detection for each analyte. Once the λmax was identified, calibration curves were constructed to establish a quantitative relationship between absorbance and concentration for each analyte. For lead (Pb), the maximum wavelength obtained at 520 nm. To establish a calibration curve, absorbance at this wavelength (λmax) was measured for solutions with concentrations ranging from 1 ppm to 9 ppm. A linear regression analysis of the data yielded the equation (Concentration = 9.309 × Absorbance), with a correlation coefficient (r) of 0.998, indicating a strong linear relationship. For cadmium (Cd), the maximum wavelength (λmax) is 500 nm. To establish a calibration curve, absorbance at this wavelength was measured for solutions with concentrations ranging from 1 ppm to 9 ppm. A linear regression analysis of the data yielded the equation (Concentration = 2.960 × Absorbance), with a correlation coefficient (r) of 0.998, indicating a strong linear relationship. Similarly, for arsenic(As), the maximum wavelength (λmax) is 840 nm. To establish a calibration curve, absorbance at this wavelength was measured for solutions with concentrations ranging from 0.1 ppm to 1 ppm. A linear regression analysis of the data yielded the equation (Concentration = 1.193 × Absorbance), with a correlation coefficient (r) of 0.998, indicating a strong linear relationship [27].

4.2. Analysis of the lead, cadmium and arsenic concentration in of lip products

The analysis of various cosmetic products reveals concerning levels of heavy metals, indicating significant health risks. Following Tables detail the concentration of lead (Pb), cadmium (Cd), and arsenic (As) in various cosmetic products, showing that all tested samples contain toxic levels of these metals. Notably, the L_1 (COLOR STAY MATT 24-HRS) lipstick had the highest lead concentration at 370.777 mg g^{-1}, while L_3 (HengFang Sheer Gloss Balm) exhibited the highest cadmium concentration at 8.015 mg g^{-1}.

Table 2. Concentration of Lead, Cadmium, and Arsenic in Lipsticks Products

Samples	Concentration of lead (mg g^{-1})	Concentration of cadmium (mg g^{-1})	Concentration of arsenic (mg g^{-1})	Remarks
L_1	370.777	4.564	0.086	Toxic
L_2	217.607	5.819	0.071	Toxic
L_3	296.696	8.015	0.061	Toxic
L_4	238.310	6.689	0.055	Toxic

L_5	189.158	4.907	0.070	Toxic

Table 2 presents the concentration of lead (Pb), cadmium (Cd), and arsenic (As) in various lip products. All tested lipsticks contained toxic levels of these heavy metals. Notably, the "COLOR STAY MATT 24-HRS" (L_1) product had the highest lead concentration at 370.777 mg g^{-1}. "HengFang Sheer Gloss Balm"(L_3) had the highest cadmium concentration at 8.015 ppm, while "COLOR STAY MATT 24-HRS"(L_1) also showed a notable arsenic concentration at 0.0864 mg g^{-1}. These findings indicate a significant health risk associated with the use of these products due to the high levels of toxic metals.

4.3 Analysis of the lead, Cadmium and Arsenic concentration in Hair colour Products

Table 3. Concentration of Lead, Cadmium, and Arsenic in Hair Products

Samples	Concentration of lead (mg g^{-1})	Concentration of cadmium (mg g^{-1})	Concentration of arsenic (mg g^{-1})	Remarks
H_1	81.267	3.182	0.082	Toxic
H_2	108.021	2.533	0.093	Toxic
H_3	87.467	3.276	0.048	Toxic
H_4	65.603	3.463	0.082	Toxic
H_5	58.45	3.087	0.038	Toxic

As shown in **Table 3,** hair color products also contained significant concentrations of heavy metals. The "BERINA Color VITAMIN"(H_2) product had the highest levels of lead and arsenic, with 108.021 mg g^{-1} and 0.933 mg g^{-1}, respectively. Meanwhile, "ENEGA Crème Hair Colour" (H_4) showed the highest cadmium concentration at 3.463 mg g^{-1}. All products tested were found to be toxic, suggesting potential health hazards for consumers.

3.3. Analysis of the lead, Cadmium and Arsenic concentration in Skincare cream Products

Table 4 details the concentrations of lead, cadmium, and arsenic in various Skincare cream products. "ASSURE Anti Aging Night Cream"(C_4) contained the highest lead concentration at 111.708 mg g^{-1}. "BEAUTI DARBAR Foundation Cream" (C_3) had the highest cadmium concentration at 3.238 mg g^{-1}, while "NEUTROGENA Ultra Sheer Dry Touch" (C_5) showed the highest arsenic level at 0.943 mg g^{-1}. These products pose considerable health risks due to the presence of these toxic metals.

Table 4. Concentration of Lead, Cadmium, and Arsenic in Skincare cream Product

Samples	Concentration of lead (mg g^{-1})	Concentration of cadmium (mg g^{-1})	Concentration of arsenic (mg g^{-1})	Remarks
C_1	18.18	2.666	0.042	Toxic
C_2	49.71	2.764	0.084	Toxic
C_3	102.250	3.238	0.074	Toxic
C_4	111.708	3.170	0.087	Toxic
C_5	54.569	1.636	0.094	Toxic
C_6	79.452	1.764	0.056	Toxic

3.4. Analysis of the lead, Cadmium and Arsenic concentration in Powder Products

Table 5. Concentration of Lead, Cadmium, and Arsenic in Powder Products

Samples	Concentration of lead (mg g^{-1})	Concentration of cadmium (mg g^{-1})	Concentration of arsenic (mg g^{-1})	Remarks
P_1	19.129	1.722	0.094	Toxic
P_2	130.977	1.998	0.054	Toxic
P_3	23.523	2.587	0.014	Toxic
P_4	147.398	1.713	0.015	Toxic
P_5	26.672	1.494	0.025	Toxic

In **Table 5**, the concentrations of heavy metals in powder products are outlined. "NARS Light Reflecting Setting Powder" (P_4) had the highest lead concentration at 147.398 mg g^{-1}. "DERMI COOL Prickly Heat Powder"(P_3) showed the highest cadmium 2.587 mg g^{-1}, and “JOHNSON” (P_1) shows highest arsenic 0.094 mg g^{-1} levels. The findings indicate that all tested powder products are toxic, emphasizing the need for stringent quality control in cosmetic products.

3.5. Analysis of the Lead, Cadmium and Arsenic concentration in Nail Polish Products

Table 6. Concentration of Lead, Cadmium, and Arsenic in Nail polish Products

Samples	Concentration of lead (mg g^{-1})	Concentration of cadmium (mg g^{-1})	Concentration of arsenic (mg g^{-1})	Remarks

N_1	78.363	2.497	0.021	Toxic
N_2	106.010	4.451	0.026	Toxic
N_3	221.620	3.646	0.073	Toxic
N_4	223.416	4.451	0.032	Toxic
N_5	226.234	4.718	0.072	Toxic
N_6	128.768	3.877	0.045	Toxic

Table 6 summarizes the heavy metal concentrations in nail polish products. "BEAUTY MARK Peart Soft Colour Nail Polish" (N_4) had the highest lead concentration at 226.234 mg g^{-1}. Both "SONATA Nail Polish" (N_2) and "AITRACICN the Gel Nail Polish" (N_4) showed the equal cadmium concentration of 4.451 mg g^{-1}, and the highest cadmium concentration was shown by BEAUTY MARK (N_5). "NHC Nail Polish" (N_1) did not report a specific arsenic concentration but still showed toxic levels of cadmium. All products were found to be toxic, highlighting the significant health concerns associated with these nail polishes.

3.6. Graphical Interpretation of Lead, Cadmium and Arsenic concentration

Lead is the most prevalent heavy metal across all cosmetic categories. Nail polish and lip products show particularly high concentrations, with some samples exceeding 200 mg g^{-1}. Powder and skincare products also exhibit significant lead content, often surpassing 100 mg g^{-1}. Cadmium levels are substantially lower compared to lead but are still present in all categories. The highest cadmium concentrations are found in nail polish and lipstick products, typically around 10-15 mg g^{-1}. Skincare and hair products show cadmium concentrations below 10 mg g^{-1}. Arsenic is detected at the lowest concentrations among the three heavy metals. Nail polish and powder products show detectable arsenic levels, generally below 2 mg g^{-1}. Lipstick products also contain arsenic, though at relatively low levels compared to lead and cadmium. The graphs indicate a concerning prevalence of heavy metals in various cosmetic products. Lead is particularly alarming due to its high concentrations across all product types. This underscores the need for enforcement to mitigate health risks associated with heavy metal exposure from cosmetics.

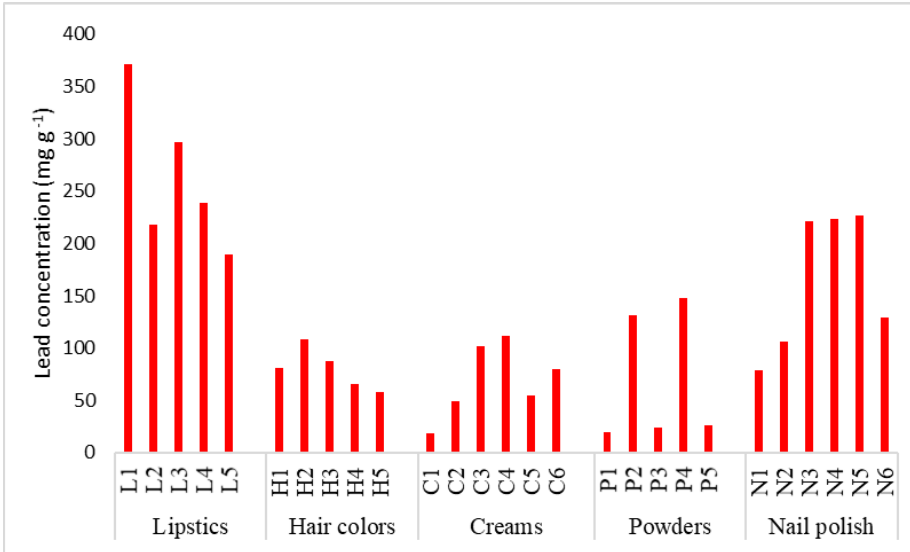


Figure 1. Graphical representations of lead concentration in different cosmetic products.

High levels of lead, cadmium, and arsenic in cosmetics can lead to numerous adverse health effects. Lead exposure is known to cause neurological damage, cognitive impairments, and developmental delays, especially in children. Cadmium is a carcinogen linked to kidney damage and bone demineralization. Arsenic exposure can result in skin lesions, cardiovascular diseases, and an increased risk of cancer. The results of this study indicate a significant presence of heavy metals—specifically lead (Pb) —in various cosmetic products sold in Nepal. This poses a considerable public health risk, particularly given the frequent and widespread use of these products. There are currently no international standards for heavy metal impurities in cosmetics, but limits have been established in specifics countries.

Table 7. Maximum recommended lead, cadmium and arsenic concentration guidelines.

Guidelines	Maximum concentration in ppm (parts per million)		
	Pb	Cd	As
NBSM	10	3.0	3.0
FDA	10	—	3.0
CSAR	10	5.0	2.0
BSI	20	—	2.0

Where, Abbreviations represents, NBSM: Nepal Bureau of Standards & Metrology, FDA: United States Food and Drug Administration, BSI: Bureau of Indian Standards, CSAR: China Cosmetics Supervision and Administration Regulation.

The amount of lead detected in cosmetics was alarmingly high and exceeded the permissible impurity limits set by the Nepal Bureau of Standards & Metrology guidelines. The lack of strict regulatory oversight and enforcement in Nepal contributes to this issue. Furthermore, the absence of standardized international regulations for heavy metal content in cosmetics exacerbates the problem, leading to inconsistent safety standards and potential health risks. In cosmetics, some metals are intentionally included as ingredients, while others are present as contaminants [27]. Notably, lead serves various purposes in different products: lead compounds such as lead tetroxide (red lead) and lead chromate are used to create vibrant red, orange, and yellow shades in lipsticks, hair dyes, and eye makeup [28]. In some Asian and African countries, lead acetate is used in skin-whitening products due to its temporary skin-lightening effects [29]. Lead acetate is also employed in hair dyes to help the dye adhere better to hair strands, resulting in more vibrant and lasting colors [30]. Additionally, lead compounds such as lead oxide, lead sulfate, and lead stearate are used in sunscreens and sun protection products as inorganic UV filters that absorb and scatter UV radiation [31]. Furthermore, lead compounds are used to enhance the stability and shelf-life of cosmetic products, preventing them from degrading over time.

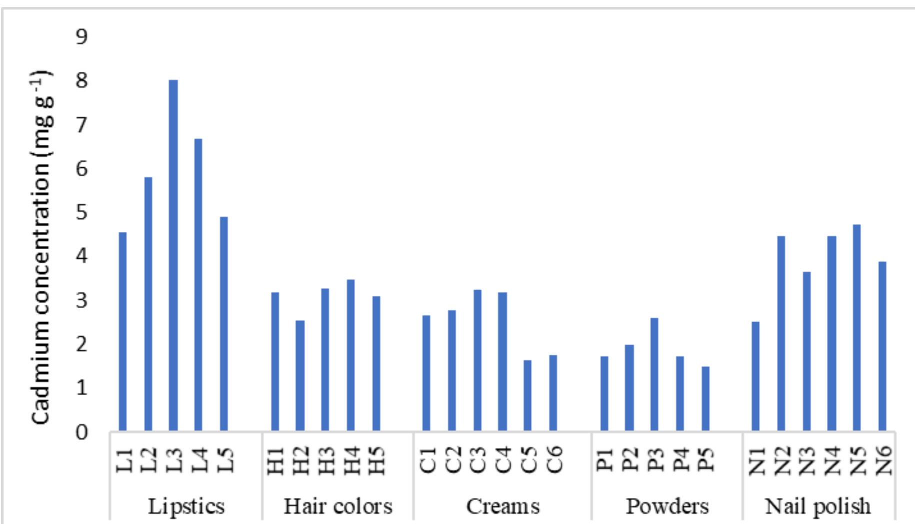


Figure 2. Graphical representations of cadmium concentration in different cosmetic products.

Lead has a long history of use in cosmetics, dating back to ancient civilizations where it was used in various forms for skincare and makeup purposes. Ancient Egyptians used lead-based kohl to darken their eyelids, while Greeks and Romans applied lead-based face powders for a pale complexion. Lead's malleability, ability to create vibrant colors, and perceived medicinal benefits contributed to its widespread use. Despite its toxicity being recognized in historical texts, its cosmetic applications persisted for centuries due to a lack of safer alternatives and the allure of its immediate aesthetic effects. In undeveloped countries, lead can be used in cosmetics due to its affordability as a substitute for high-end ingredients. In regions with lax regulations, manufacturers may prioritize cost over safety, using lead in cosmetics despite known health risks. Additionally, Limited consumer awareness and weak regulation enforcement also contribute to the continued use of lead in cosmetics in some countries.

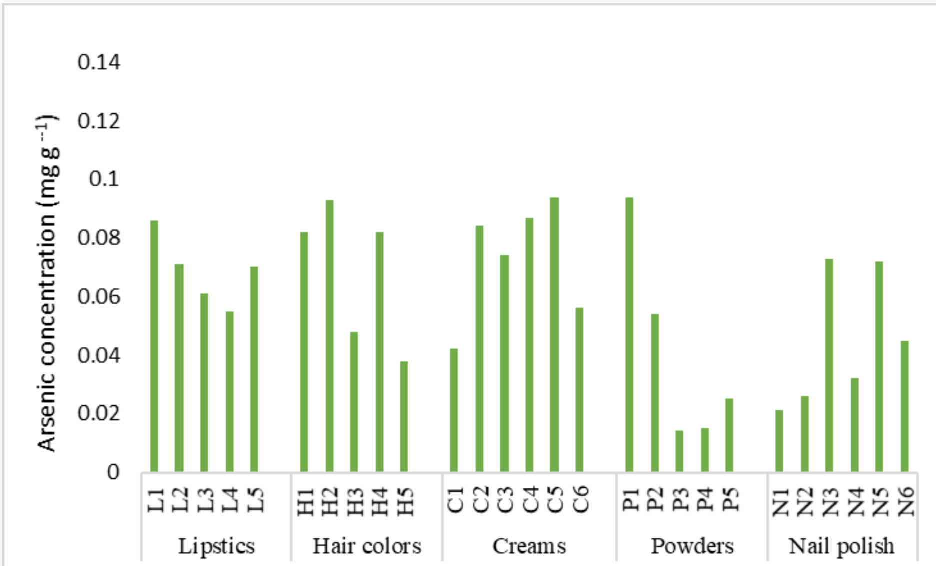


Figure 3. Graphical representations of arsenic concentration in different cosmetic products.

6. Statistical Analysis of lead, cadmium and arsenic in cosmetic samples

6.1. Descriptive Statistics

The statistical analysis revealed that the highest mean lead concentration was found in lipsticks (262±72.24 mg g^{-1}), which is about 13 times higher than FDA limit (2022). The lowest concentration was observed in skincare creams (69.31±35.22 mg g^{-1}), yet still three times higher than the recommended limit. Similarly, nail polishes showed the second-highest lead concentration (164.07±67.32 mg g^{-1}). The highest cadmium concentration was reported in lipsticks (5.99±1.39 mg g^{-1}), whereas the lowest was found in powders. The arsenic concentration, although detected, was below the recommended level and considered almost insignificant.

Table 8. The mean concentration distribution of lead in different cosmetic products.

Products	Lead (mg g^{-1})	Cadmium (mg g^{-1})	Arsenic (mg g^{-1})
Lipsticks	262.51±72.24	5.99±1.39	0.069±0.012
Hair colors	80.16±19.46	3.10±0.35	0.069±0.024
Creams	69.31±35.22	2.54±0.68	0.073±0.020

Powders	69.54±63.90	1.90±0.42	0.040±0.034
Nail polish	164.07±67.32	3.94±0.81	0.045±0.023

6.2. Shapiro-Wilk Test

All the metals and non-metal in the cosmetic products has probability ($p > 0.05$), which indicates the normal distribution of data obeying parametric testing [32].

6.3. One-Way ANOVA Results

The probability ($p < 0.05$) shows that the significant difference in the lead concentration among the tested group. Similarly, for cadmium, significant variation of lead obtained among the group. However, for arsenic ($p > 005$), we obtained no significant differences in arsenic concentration likely due to random chance among the group [33, 34, 35].

Table 9. One-way ANOVA results showing significant for lead and cadmium, and insignificant results for arsenic.

Metals/non-metals	F-ratio	P-value	Significance
Lead	12.00	2.25×10^{-5}	Significant
Cadmium	19.24	6.25×10^{-7}	Significant
Arsenic	2.27	0.095	Non-significant

6.4. Pairwise Independent t-Test (Bonferroni Corrected)

For lead analysis, it was found that lipsticks contain a higher concentration. The value ($p < 0.01$) indicates that the difference in lead concentration is statistically significant at the 1% level. Similarly, result the obtained for cadmium ($p < 0.01$) shows a high concentration. However, no meaningful variation was observed in the concentration of arsenic ($p > 0.05$) [36, 37].

Table 10. Independent t-Test for the categorical concentration of lead, cadmium and arsenic.

Category	Pairwise comparism	Significance level (p value)	Interpretation
Lead	Lipsticks>	P<0.01	High lead concentration
Cadmium	Lipsticks>	P<0.01	High cadmium concentration
Arsenic	No significance difference	P<0.05	Statistically similar

6.5. Chi-Square (χ^2) Association Test

Chi-Square (χ^2) test was obtained to examine whether a significant relationship exists between categorical variations shows that for lead having χ^2 =18.7 and p = 0.0009, and for cadmium, χ^2 = 16.3 and p = 0.0028, showed that the distribution of their respective concentration depends upon the product type. Similarly, for arsenic, χ^2 = 3.5 and p = 0.476, revealed the independent nature of data on product type [38].

Table 11. Chi-Square (χ2) association test for categorical distribution of lead, cadmium and arsenic in the sample.

Category	χ^2	P-value	Conclusion
Lead	18.7	0.0009	Dependent on product type
Cadmium	16.3	0.0028	Dependent on product type
Arsenic	3.5	0.476	Independent on product type

7. Absorption Mechanism of Heavy Metals from Cosmetics

Heavy metals in cosmetics can be absorbed through various routes. The primary route for the penetration of cosmetic ingredients is through the skin dermis, which serves as a protective barrier for sub-dermal and internal body organs [39].

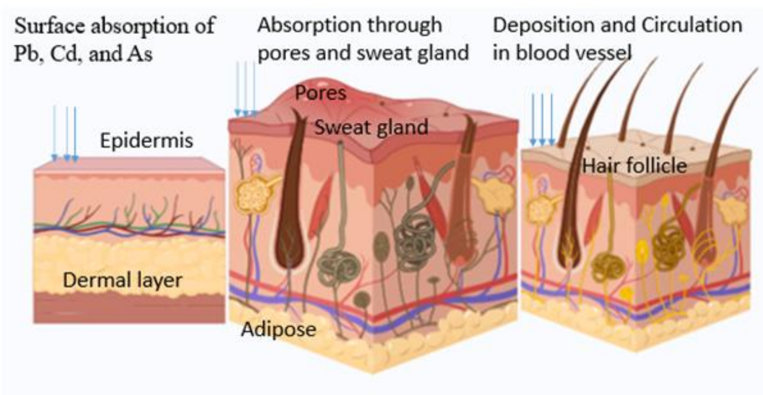


Figure 4. Pathways of Heavy Metal Absorption and Accumulation in Skin (Schematic)

When cosmetics are applied to the skin, their ingredients can penetrate the cell environment via hair follicles, sweat pores, and eventually blood capillaries. Although absorption through the skin is a slow process, prolonged use of cosmetics can lead to increased concentrations of these substances in the body. The presence of heavy metals as contaminants accelerates this accumulation and can cause toxicity, leading to various disorders [39, 40]. **Figure 4** overview shows hair follicles and sweat glands act as channels for deeper penetration of metals into the dermis, by passing the stratum corneum, the outermost layer of the skin. Lead

(Pb) and cadmium (Cd) are absorbed through the skin and enter the bloodstream. Once in the blood, they can be distributed to various organs, potentially causing systemic toxicity. Arsenic (As) binds with keratin in skin and hair, accumulating over time and causing localized effects. mechanisms of toxicity—electrophilic substitution [39]. Heavy metals replace essential elements in biomolecules, disrupting biological functions. For instance, lead can replace calcium in bones, impairing development and neurological functions.

7. The Issue of Lead Contamination in Imported Cosmetic Products

In case of Nepal, several products have been found to contain extremely high levels of lead. A report by the Center for Public Health and Environmental Development (CEPHED) revealed that a paint contained 22,850.17 ppm of lead, which is 254 times higher than Nepal's standard of 90 ppm [41]. Similarly, CEPHED found that lead content in jewelry ranged up to 775,500 ppm, with an average of 198,729.6 ppm, which is 662 times the US standard of 300 ppm for children's jewelry [42]. Studies have revealed that sindoor, vermilion red or orange-red cosmetic powder used in hindu rituals, also contains high levels of lead contamination. The consequences of lead exposure are particularly severe for children, leading to cognitive impairments and other health issues. A global study by UNICEF and pure earth estimated that over 65% of the total child population in Nepal have elevated (BLLs) blood lead levels [43]. The distribution of BLL among children is concerning, with about 26% having BLL between 15-20 µg/dl, 12% having BLL between 20-25 µg/dl, and 4% having BLL exceeding 35 µg/dl [44]. These levels far exceed the safety threshold established by health authorities globally, indicating an urgent public health crisis.

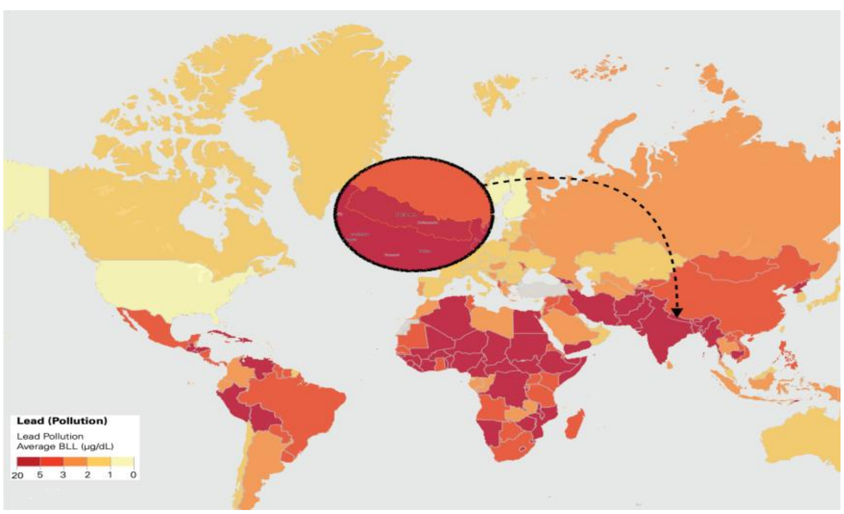


Figure 5. Average Blood Lead Levels by Country (µg/dL)
Source: IHME 2021. (Annex for full list by country, lead exposure and health data is also visualized at www.lead.pollution.org)

Nepal ranks second highest in Asia for average blood lead levels, following Afghanistan, and 13th highest in the world. The health impact is stark, with annual deaths from lead exposure rising sharply from 3,757 in 2019 to 8,104 in 2021-IHME. Additionally, lead exposure has resulted in a significant cognitive toll on the younger population, with the total IQ loss in children estimated at 3,975,210 IQ points, averaging a loss of 6.7 IQ points per child [45].This widespread contamination not only jeopardizes the immediate health and cognitive development of children but also poses a long-term threat to the nation's future productivity and socioeconomic stability. The issue of lead contamination in Nepal is severe, with cosmetics, lead batteries, pottery, ayurvedic medicines, lead solder in food cans, adulterated spices, paints, and jewelry being significant sources of exposure [42, 43]. The findings from various studies highlight the urgent need for stringent regulatory measures and public health interventions to mitigate lead exposure. Protecting children from lead toxicity is imperative for safeguarding their health and ensuring their optimal development. Continued monitoring and research are essential to address this public health challenge and to implement effective strategies for reducing lead exposure in Nepal.

8. Impacts of lead in human body and in environment

Lead exposure has numerous detrimental effects on human health and the environment. Even at low levels, lead can cause hypertension in humans, and it can lead to renal dysfunction, impairing the kidneys' ability to remove waste and maintain chemical balance [46]. In terms of the nervous system, lead exposure more significantly impacts the central nervous system in children, causing conditions such as encephalopathy, which includes symptoms like memory loss, hallucinations, irritability, short attention span, and dullness. In adults, lead more commonly affects the peripheral nervous system. Children, especially young and unborn, are highly susceptible to lead intoxication, showing increased irritability, reduced attention span, and hyperactivity even at low exposure levels. High exposure can result in diminished intelligence, delayed growth, hearing loss, and impaired short-term memory, with extremely high levels potentially leading to permanent brain damage or death. Lead exposure can also cause anemia due to a reduction in red blood cells. In the body, lead is primarily stored in bones, accounting for 40-70% of the lead discharged into the blood [14, 46]. Reproductive health is also adversely affected, with men experiencing decreased sperm count and mobility, reduced libido, abnormal prostatic function, chromosomal damage, testosterone imbalances, and infertility. Women may face miscarriage, pregnancy hypertension, infertility, premature delivery, and preeclampsia due to lead toxicity [14, 41, 46]. Environmentally, lead has historically been used in plumbing materials and solder, leading to contamination of drinking water through the corrosion of these materials. Human activities are responsible for approximately 98% of atmospheric lead. Lead is absorbed by plants through their roots, accumulating mostly in the roots and potentially contaminating the fruits. This not only affects plant health but also biodiversity and soil composition [47].

9. National Law and Standards for Lead and Other Heavy Metals in Cosmetics in Nepal

Until 2019, Nepal lacked specific standards, guidelines, or legislation regulating the presence of lead and other heavy metals in cosmetics. This regulatory gap resulted in no systematic monitoring by either government or private sectors, leaving consumers largely unaware of the potential hazards in cosmetic products [41]. In September 2019, the Nepal Council for Standardization (NCS), in partnership with the Ministry of Industry, Commerce, and Supplies, and the Nepal Bureau of Standards and Metrology (NBSM), introduced the Nepal Standards-2019 for cosmetics. These standards include limits on pH levels, microbial contamination, and heavy metals such as lead, arsenic, mercury, and cadmium. The development of these standards was a collaborative effort involving various stakeholders and aimed to align with international standards from organizations like ISO, SLSI, BIS, and BSTI. Despite the establishment of these standards, there has been no effective implementation. The policy remains unenforced, and the regulatory framework is not yet operational. This negligence could lead to severe consequences, including neurological damage, cancer, and other serious health issues in consumers due to exposure to toxic metals in cosmetics. Additionally, it may result in environmental pollution from the improper disposal of contaminated cosmetics, affecting soil and water quality in the surrounding areas.

10. Conclusion

This study highlights the presence of alarming levels of heavy metals—specifically Lead (Pb), Cadmium (Cd), and Arsenic (As)— in various cosmetic products sold in Nepal, posing significant health risks to consumers. Result showed that the highest lead concentration obtained in lipsticks (370.777 mg g^{-1}) with labelled 'COLOR STAY MATT 24-HRS'. Similarly, highest cadmium concentration showed by 'HengFang Sheer Gloss Balm' lipstics (8.015 mg g^{-1}) and insignificant arsenic concentration in all the samples. There is an urgent need for rigorous regulatory measures and public awareness campaigns to mitigate these risks and ensure the safety of cosmetic products in the market. It is imperative that the Nepal Bureau of Standards & Metrology (NBSM) enforces its existing guidelines and updates them to include stricter permissible limits for heavy metals in cosmetics, as well as enhanced testing and monitoring protocols, to address this critical public health issue.

11. Availability of Data and Materials

The data will be made available at any time when requested at chemistry.gsst@mu.edu.np

12. Funding

No funding was available for this research project.

13. Author Contributions

AS and SRR: raw materials arrangement, preparation, conducting experiments, literature survey and manuscript writing; NPS, NHK & DKS: analyzing and interpretation data and result analysis, RA: manuscript editing and supervision.

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