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Heavy metal in cosmetics and its risk to future generation in remote area of Azad Jammu and Kashmir Trarkhel District Sudhnoti

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The widespread use of cosmetic products has raised global concerns regarding their potential toxicity, particularly the heavy metals content. While cosmetics serve economic and aesthetic purposes, their health implications, especially in underdeveloped regions, are becoming increasingly evident. This study investigates the level of toxic heavy metals in both branded and local cosmetic products available in the remote area of Trarkhel, District Sudhnoti, Azad Jammu and Kashmir (AJK), Pakistan, where specific data on cosmetic contamination with heavy metals and associated health risks are lacking. The presence of these metals, whether as intentional additives or impurities from raw materials, is particularly pronounced in unregulated, locally produced, and potentially counterfeit imported cosmetics, posing significant public health challenges. A total of 30 cosmetic samples, comprising lipsticks, foundations, eye shadows, nail polishes, and others, were analyzed using Atomic Absorption Spectroscopy (AAS-700) to determine the levels of lead (Pb), cadmium (Cd), copper (Cu), cobalt (Co), silver (Ag), nickel (Ni), Arsenic (As), manganese (Mn) and mercury (Hg). On comparative basis, different brands of lipsticks contain the highest mean concentrations (mg/kg) of Ni (89.3 ± 0.39), Mn (79.8 ± 0.03), Cu (62.1 ± 0.04), Pb (23.3 ± 0.05), Co (13.8 ± 0.03), Cd (1.35 ± 0.01) and Ag (0.73 ± 0.01), whereas branded and local creams had elevated level of Hg (358.53 ± 0.02) followed by Zn (1181 ± 0.04), Co (28.9 ± 0.04), Ni (11.0 ± 0.04), Pb (6.21 ± 0.06) Cu (3.52 ± 0.01), As (1.56 ± 0.01), and Cd (1.35 ± 0.01) mg/Kg, with least concentration in Mn and Ag. The level of heavy metals was lower in nail polishes compared to lipsticks and creams. Multivariate analysis suggested a strong correlation among Pb, Cu, Ni, Cd, and Mn, while Cd showed a negative correlation with Co, Ag, and As, and Mn, indicating disparity in distribution and sources of contamination. Health risk assessment further revealed that Margin of Safety (MoS), Hazard Quotient (HQ), and Hazard Index (HI) values fell above the permissible boundaries for most of the lipsticks, creams, and nail polishes. Regarding carcinogenicity, LCR values surpassed the established threshold in all cosmetic products with the exception of lipsticks. The findings emphasise the urgent need for routine monitoring and enforcing strict quality assurance protocols to safeguard the safety of cosmetics, particularly in vulnerable and underdeveloped areas like Trarkhel. This study not only fills a crucial research gap but also provides a foundation for future studies on cosmetic toxicity and public health awareness in rural regions.

Keywords Cosmetics impurities, Heavy metals, Health risk assessment, future generation at risk in trarkhel, AJ&K

Cosmetics, originating from the Greek word "kosmtikos"[1–3], are widely used by both men and women to enhance appearance and mask imperfections. These products encompass a broad spectrum, including creams, lipsticks, powders, fragrances, hair dyes, and baby products[4]. The cosmetics industry has recorded an average annual

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Sample nature	Available standards	Pb	Cd	Cu	Co	Fe	Cr	Ni	Ag	Zn	Mn	AS	Hg	Reference
*Drinking water	WHO	0.01	0.003	2	2	0.3	0.05	0.020		3	0.5	0.01	$0.001, 0.006_{(IM)}$	
	USEPA	0.015	0.005	1.3	-	0.3	0.1	-		5	0.05	0.01	0.002	
	NEQS-Pakistan	< 0.05	0.01	2	-		< 0.05	< 0.02		3	< 0.5	< 0.05	< 0.001	
***Daily dietary intake	-	7-230 (adult)	18.9	**1-1.5	-	**45	25–224	< 1		**5.2–16.2	-	50	-	[1,2]
Cosmetics	USFDA	*20	*3	200	< 170		50	10		-	-	*3	*1	
	*WHO	2	1	-	-	-	-	-		-	-	0.01	3	
	Canada	10	3	-	-	-	1	-		-	-	3	1	
	Germany	0.5	0.1	-	-	-	-	-	-	-	-		0.1	
	EU	-	-	-	-	-	-	10	-	-	-	0.5	-	[3]

Table 1. International standard guidelines showing the maximum heavy metal content (mg/Kg) for some metals. Values are in, *mg/L, **mg/day, ***µg/day, $^{!!}$ng/kg, $^{!!!}$The value in the soil is mg/kg this may increase due to the use of pesticides, ‡µg/ m3, ‡‡mg/m3, USEPA (United State Environmental Protection Agency), WHO (World Health Organization), USFDA (United States Food and Drug Administration), FAO (Food Additive Organization), OSHA (Occupational Safety and Health Administration), WHO (World Health Organization), NEQS (National Environmental Quality Standards) M/MM/IM (Organic mercury/metallic mercury/Inorganic mercury).

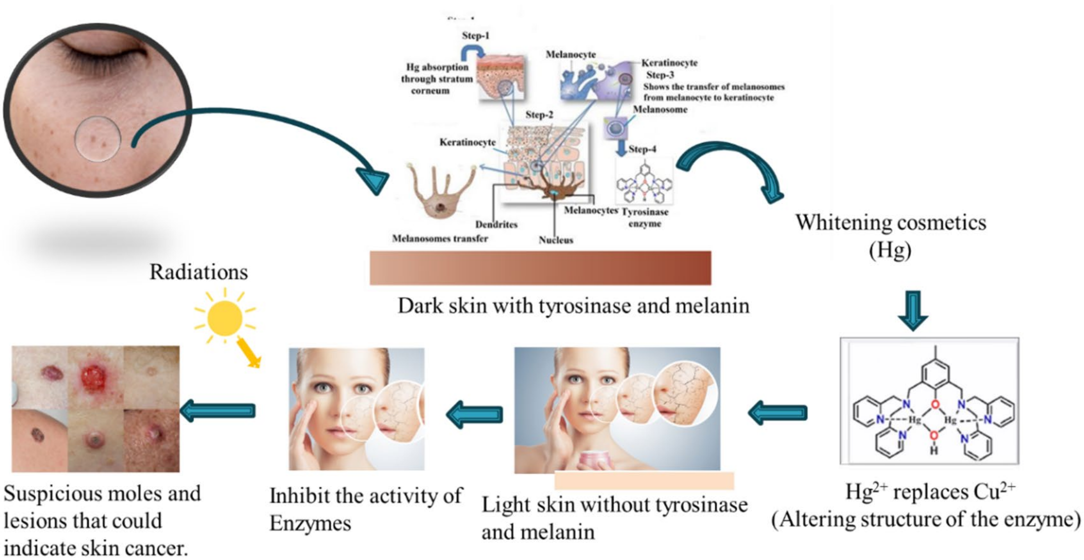

Fig. 1. Prposed mechanism of Depigmentation: Absorption of mercury in the stratum, Melanosomal arrangement. Facilitation of the movement of melanosomes by dendrites, the depigmentation process created by the author based on conceptual representation.

growth of about 4.5% over the past two decades, due to rising global demand[5–7]. However, concerns persist regarding the safety of cosmetic ingredients and their potential health impacts[3], especially as many products are applied to highly sensitive and absorbent skin regions. Heavy metals, present as impurities or intentional additives for colour, UV protection, or other functions[8], can accumulate in the body with daily use and pose significant health risks[9], particularly where regulations are weak. Metals such as lead (Pb), cadmium (Cd), copper (Cu), cobalt (Co), iron (Fe), chromium (Cr), nickel (Ni), silver (Ag), zinc (Zn), manganese (Mn), arsenic (As), mercury (Hg), gold (Au), platinum (Pt), palladium (Pd), beryllium (Be), titanium (Ti), and aluminum (Al) can be toxic at concentrations exceeding permissible limits, as shown in Table 1, while trace elements like Fe, Zn, Mo, Cu, and Se are beneficial only within safe limits[10,11].

Heavy metals, in the form of inorganic mercury compounds are used in whitening creams to inhibit melanin production, thereby disrupting metalloenzyme function and displacing essential metals. This can potentially inhibit enzymes such as tyrosinase (Fig. 1) and interact with cellular macromolecules[12–14].

Although the EU has banned certain compounds in cosmetics, adverse health effects persist, often exacerbated by inadequate labelling[15,16]. Women in regions such as Iran, the Arab world, India, Pakistan, and Turkey are particularly at risk due to higher cosmetic usage[17]. Therefore, strict monitoring and regulation of heavy metal contents in cosmetics are crucial to ensure consumer health and environmental safety[18].

Cosmetic products contain over 10,000 chemical ingredients, with more than 100 banned due to their toxic properties[19]. Prolonged use can lead to serious health issues, as these chemicals are both lipophilic and hydrophilic[20]. Many dermatologists consider cosmetics more harmful than beneficial, with some components linked to cancer, congenital disabilities, and neurological and reproductive disorders[12]. The USFDA has prohibited nine harmful ingredients, including formaldehyde, coal tar, parabens, phthalates, Pb, and Hg[2]. The chemical content varies by product type, brand, and colour, with lipstick being the most widely used and containing various dyes[21,22]. Lead and tin dyes stabilise paraffin and enhance red hues in skincare products[15]. Sunscreens and whitening products often contain metals and metal oxides of Cd, Cr, Cu, Hg, and Pb[23,24]. Nails, containing 10–30% water, readily absorb pigments and heavy metals such as Pb, Cd, and Cr from nail polishes, and pose health risks upon accumulation[25]. Transition metals like titanium dioxide, chromium-coated mica, and iron oxide provide pearlescence in lipsticks[26]. Kohl (Kajal/Surma), containing compounds such as galena (PbS), talc, and zincite (ZnO), which are banned by the USFDA due to high Pb content but still widely used in Asia, the Middle East, and Africa for cultural and medicinal purposes[27]. Despite regulatory bans, these products are easily accessible in countries like Pakistan and Iran, often due to traditional beliefs. While trace heavy metals are essential for metabolism, excessive levels in cosmetics cause physiological harm. Studies link Pb-containing cosmetics to elevated lead in breast milk[28], and improper eye products correlate with conditions like posterior blepharitis[29]. Health Canada reported that over 90% of analysed cosmetics contained Pb or Be, and nearly all had Ni impurities, often exceeding the permissible limits by 20 to 500 µg/g or more[12].

Heavy metals such as arsenic have long been recognised for their toxic effects. Historically, arsenic was employed as a chemical weapon and as a poison for murder during the First World War. Its pervasive presence in the environment has facilitated its entry into consumer products, including cosmetics[1,2,12,30,31].

In cosmetics, heavy metals may be intentionally added for colour or stability or may contaminate products through raw materials, water, or manufacturing equipment, especially in the absence of strict regulations[5,21,32–34]. Metals like Al, Cu, Ag, and Au are used for metallic effects, while Pb, Cd, As, Zn, Cr, Fe, Mn, and Ni serve as colourants or to enhance shelf life[1,32]. Nanomaterials, including metal oxides such as TiO_2, ZnO, and Al_2O_3, are now common in cosmetics for UV protection, antimicrobial action, and improved product performance[35,36]. However, these nanoparticles possess the capability to penetrate the skin barrier due to their small size, and get access to the underlying tissues (Fig. S1), and may induce cellular damage or carcinogenic effects[12,37,38]. Regulatory agencies like IARC and USEPA classify Cd and Pb as human carcinogens, and even essential metals such as Zn, Cu, and Fe are toxic at high concentrations[39]. Cosmetics can expose users to toxic metals through the skin or ingestion. Sweet poison or sweet kiss, often referred to as poison kiss, is associated with lip products containing Pb, Cr, and other heavy metals that are absorbed or ingested when lips coated with/or wear lipsticks are licked or kissed (Fig. S2), and ultimately transfer to the fetus during pregnancy[40]. Despite the risks, international regulations and data on the toxicity of metals like Ni, Cr, and Co in cosmetics remain insufficient[28].

Lead is a highly toxic metal for which no safe level of exposure has been established, accumulating in organs and tissues and disrupting cellular metabolism and inducing oxidative stress[9]. Even minimal Pb exposure is neurotoxic, linked to developmental delays, hormonal disorders, infertility, and cognitive deficits, especially in children[12]. Pb is frequently detected in lipsticks and other cosmetics at levels exceeding safety limits set by agencies such as the USFDA (10 µg/g) and NHPD Canada (20 µg/g), and poses risks of miscarriage and anaemia[28]. Cadmium, classified as a human carcinogen by NIOSH, is toxic even at low levels, causing kidney damage, hypertension, anaemia, and reproductive toxicity[24]. It is found in hair products, eyeliners, and lip glosses, with a biological half-life ranging from 10 to 35 years, and can accumulate in the placenta, affecting fetal development[12]. Regulatory limits for Cd in cosmetics are 3 µg/g in Canada and 5 µg/g in Germany. Copper plays a vital role in enzymatic activities and pigmentation, but can become toxic at elevated concentrations. Such toxicity can result in hepatic and neurological damage, immune system impairment, and green discolouration of hair[41]. In cosmetics, copper is commonly employed as a colourant and biocide, with regulatory limits of 50 µg/g. Prolonged or chronic exposure beyond these limits should be avoided to prevent accumulation and associated adverse effects[42]. Cobalt, a component of vitamin B_{12}, is necessary in trace amounts, but excessive exposure can cause dermatitis, allergies, asthma, and organ toxicity[41,43]. Iron is vital for haemoglobin and cellular processes, but overexposure from cosmetics can cause oxidative stress, organ damage, and genetic conditions like hemochromatosis. Chromium exists in multiple oxidation states and is used as a colourant in cosmetics. The Cr^{3+} is recognised as an essential nutrient involved in metabolic processes, whereas Cr^{6+} is known for its genotoxic and carcinogenic properties[9]. The FDA has not set limits for Cr in cosmetics. Nickel, required only in trace amounts, is a common allergen in cosmetic products, capable of inducing dermatitis and allergic reactions even at concentrations as low as 1 ppm[24,44]. At elevated concentrations, nickel exposure can induce DNA damage, promote carcinogenesis, and cause toxicity to multiple organ systems. Regulatory guidelines in Europe have set a recommended level of nickel below 5 ppm to minimise health risks. Zinc, though vital for biological functions, can provoke gastrointestinal discomfort, dermal irritation, and metabolic disturbances in excessive use through cosmetic products[45]. Zinc is extensively utilised in sunscreens for its UV-reflective properties and in toothpaste formulations; however, elevated concentrations may pose health hazards[46,47]. Although manganese is essential for enzymatic functions and normal physiological development, excessive exposure is associated with neurotoxicity and affects bone integrity. The recommended daily intake of manganese ranges from 2.0 to 8.8 mg/day, yet certain cosmetic products have been reported to contain higher levels, thereby raising concerns regarding potential chronic health implications. Arsenic is a toxic element commonly detected in eyeliners and other cosmetic products, where it can be absorbed dermally, ingested, or inhaled. Exposure to arsenic is associated with adverse developmental effects, organomegaly, neurotoxicity, and an increased risk of carcinogenesis[48]. Inorganic arsenic, especially in the + 3 oxidation state, is far more toxic than its + 5 form[49]. Chronic exposure disrupts cellular processes and enzyme function, causing skin lesions, pigmentation changes, and cancers. Regulatory limits for arsenic are set at 3 ppm in some colourants (FDA)[48]. Mercury is among the most toxic and bioaccumulative metals, commonly found in skin-lightening creams, soaps, and some colour cosmetics[48,50]. Even in trace amounts, mercury is hazardous, easily absorbed through the skin, and can cause neurological, renal, and cardiovascular damage. Chronic exposure can lead to mood changes, behavioural disorders, hypertension, and organ toxicity[51]. International guidelines limit for mercury in cosmetics is 1 ppm (USFDA) and 3 ppm (Health Canada)[48].

In Pakistan, especially in remote and underserved areas like Trarkhel in District Sudhnoti, Azad Jammu and Kashmir (AJ & K), the risk is compounded by limited regulatory enforcement, lack of consumer awareness, and the prevalence of non-branded or counterfeit cosmetic products, which are more likely to be contaminated with hazardous metals. The unique socioeconomic and geographic challenges faced by residents of Trarkhel further intensify their vulnerability to the adverse effects of contaminated cosmetics. The absence of systematic monitoring and the widespread availability of potentially contaminated, non-branded cosmetic products in Trarkhel pose a significant yet underexplored public health threat to the current and future generations residing in this remote area.

Despite the growing global literature on heavy metal contamination in cosmetics, there is a notable lack of region-specific data for remote areas of AJ&K, Pakistan, particularly regarding the exposure risks faced by future generations in communities such as Trarkhel. Most research focuses on urban markets or branded products with higher vulnerability due to poor healthcare access and economic constraints, and thus, leaving a critical gap in understanding the extent and impact of heavy metal toxicity in rural and marginalised populations. Additionally, the cumulative effects of multi-metal exposure from cosmetics remain understudied, especially in regions with concurrent environmental contamination. There is also insufficient investigation into the socio-cultural factors driving cosmetic use in these areas, hindering effective intervention strategies. Based on the above discussions, this study aims to assess the potential health risks associated with the use of these cosmetic products, particularly among women. Furthermore, it seeks to compare the detected heavy metal concentrations with national and international safety standards to provide evidence-based recommendations for regulatory authorities and to raise awareness among local consumers about the hazards posed by contaminated cosmetics.

Materials and methods

Materials

In this study, for the sample preparation, analytical grade acids (nitric acid and perchloric acid) were purchased from Sigma Aldrich. The standard solution of known concentrations for the desired metal solution was prepared in distilled water (dH_2O) from a certified stock solution (1000 ppm) in the range of 0.02 to 10 mg/Kg for all experimental work. A dilution factor was applied for the sample, either diluted or pre-concentrated, during sample preparation[2]. A total of 30 cosmetics products of various brands were collected from the local markets of Trarkhel, District Sudhnoti, in 2023. The different types of cosmetic products and the number are presented in Table 2. Briefly, lipsticks (n = 10), beauty cream (n = 10), and nail polish products (n = 10) were collected. These markets offer a diverse selection of personal care items, including products made locally by unregistered companies as well as those imported from developed and developing countries. Consequently, there is a rising apprehension regarding the potential toxicity of these metals on human beings. Keeping in view their regular usage and the potential health consequences, the samples were shipped to the lab, coded, and kept at 4 °C until analysis[52]. The concentrations of metals in all samples were measured using AAS-700 (Perkin Elmer 700, USA). The limits of detection (LOD) and limits of quantification (LOQ) for all elements were determined using the AAS-700 technique. Calibration was conducted using standard stock solutions prepared at concentrations of 0.02 to 10 mg/Kg. To evaluate matrix effects, these standards were spiked (i.e. standard addition method) into 10 mL of blank samples, mixed for one minute, and analysed using the AAS technique to eliminate the matrix effects[53]. Calibration equations and correlation coefficients were established, demonstrating strong linearity ($R^2 \geq 0.98$) and high precision, with relative standard deviations (RSD) below 5.8%. The LOD and LOQ were calculated based on signal-to-noise ratios of 3 and 10, respectively (Table S1). The batch number of the brand has not been disclosed due to legal considerations. We have only provided the names of the product studies in this research work.

Sample preparation

In the preliminary stages of the research, all the apparatus was first rinsed with 5% HNO_3 solution and finally washed with deionised water. A total amount of 4 g of each sample was weighed and transferred into a 100 mL beaker for wet digestion. A 4:1 mixture of concentrated nitric acid (65%) and perchloric acid (70–72%) was added, and digestion was carried out on a hot plate in a fume hood. The temperature was gradually increased from 10 to 110 °C in controlled increments (e.g., 5–10 °C every 10–15 min). This reaction was continued until the sample reached near dryness. This slow heating prevented sudden combustion caused by the exothermic reaction of oily compounds. If a brown or black colour appeared, additional acid mixture was added, and the process was repeated with controlled heating until white fumes appeared, indicating complete digestion and a residual volume of approximately 2 mL. The digested samples were then cooled, filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask, and diluted to the mark with deionised water[2].

Sample analysis and quantification of HMs

Precise determination of heavy metal contents in cosmetic products is vital because the margin of safety is very narrow between an appropriate amount and overconsumption. Currently, there are several methods used for the analysis of heavy metals in cosmetics. These include sector field inductively coupled plasma mass spectrometry (SF-ICP MS), the plasma fission spectrograph, inductively coupled plasma optical emission spectrometry, and inductively coupled plasma mass spectrometer (ICP-MS)[2] etc. However, the atomic absorption spectrophotometer (AAS) and graphite furnace atomic absorption spectrometry (GFAAS) are the most widely used analytical techniques for analysing heavy metal concentrations in cosmetic items[54]. Thus, AAS (Perkin Elmer 700) was used to monitor Pb, Cd, Cu, Co, Ag, Ni, Zn, As, Mn, and Hg in this research project. The measurement was taken in triplicate using the standard deviation of the mean value. Rounding of data was applied whenever needed for the results.

Statistical analysis

A Statistical software, IBM SPSS Statistics version 26.0.1, was used to assess the statistical significance of each analysis. The result of the heavy metal analysis was reported as an average of all the values taken in triplicate with standard deviation (i.e., Mean ± SD), with BD below the detection limit.

Health risk assessment

Carcinogenic and non-carcinogenic health risks were assessed based on guidelines provided by the United States Environmental Protection Agency (USEPA). The estimated risk values were compared with USEPA threshold limits to evaluate potential health hazards for consumers. The primary route of exposure contributing to these risks is dermal absorption of heavy metals present in cosmetic products. There are many parameters like systematic exposure dose *(SED)* for non-cancer (non-carcinogens) risk assessment (SED_{nca}), Margin of safety (MoS), Hazard Quotient (HQ), and Hazard Index (HI), systematic exposure dose *(SED)* for cancer (carcinogens) risk assessment carcinogens (SED_{ca}), as well as Lifetime cancer risk (LCR) and total cancer risk (TCR for carcinogenic metals concentrations like Pb, Cd, and Cr, As, and Hg, etc.,[55,56],

Margin of safety (MoS)

Human exposure to target analytes may occur via ingestion, inhalation through the respiratory tract, or absorption through the skin. Among these, dermal absorption is the predominant route of exposure relevant to skin care products when evaluating potential health risks from cosmetic ingredients. The health risk associated with heavy metals in cosmetics can be quantitatively expressed as the margin of safety (MoS), defined as the ratio of the no-observed-adverse-effect level (NOAEL) to the systemic exposure dosage (SED). A MoS value equal to or greater than 100 indicates that the chemical is considered sufficiently safe for human exposure[57].

$$MoS = \frac{NOAEL}{SED} \tag{1}$$

A no-observed-adverse-effect level (NOAEL) defines the exposure concentration at which no harmful effects are detected. As reported by Arshad et al., 2020[26], the NOAEL was derived from dermal reference doses (RfDs) using the following equation:

$$NOAEL = Rfd \times UF \times MF(\frac{mg}{kg}.d^{-1}) \tag{2}$$

where the uncertainty factor (UF) accounts for the overall confidence in the various data sets, while MF is the modifying factor (based on the scientific judgment). Default values for MF and UF are set at 1 and 100, respectively. Dermal reference doses (RfDs), expressed in mg kg^{-1} day^{-1}, represent accepted exposure levels for various metals. According to the USA, the risk-based concentration of dermal reference doses for individual elements, Pb, Cd, Cu, Co, Ag, Ni, Zn, As, Mn, and Hg are 0.42, 0.005, 0.04, 0.06, 0, 0.0054, 0.3, 0.0003, 0.00184, and 0.003 mg kg^{-1} day^{-1}, respectively[26,58–60]. The World Health Organisation (WHO) considers a margin of safety (MoS) value up to 100 as acceptable but closely evaluated (threshold); MoS values below 100 indicate potential risks, whereas values above 100 are considered safe for use (safe). The Scientific Committee on Consumer Safety (SCCS) notes that conventional MoS calculations often assume 100% oral bioavailability if oral absorption data are not available.

The systemic exposure dosage (SED) represents the expected quantity of chemicals absorbed into the bloodstream and thus becomes systemically available through various exposure routes. Because the majority of cosmetic formulations are applied topically, the systemic bioavailability predominantly depends on the topical absorption efficiency of each ingredient. The SED is calculated considering the metal concentration present in the cosmetic product under study, the daily amount of product applied on the skin surface, and the average body weight of the individual[55].

$$SED_{dermal}\left(\frac{mg}{Kg}\right).d^{-1} = \frac{Cs\left(\frac{mg}{Kg}\right) \times SAA\left(cm^2\right) \times AA\left(\frac{g}{cm^2}\right) \times F \times RF \times BF\left(\frac{mg}{Kg}\right)}{BW\ (Kg)} \times 10^{-3} \tag{3}$$

In the equation, Cs [mg/kg] represents the concentration of metal detected in the sample, SSA corresponds to the exposed skin surface area [cm^2] in contact with contaminants from the cosmetic product, and AA denotes the amount of product applied per unit skin area [g/cm^2]. F indicates the frequency of application per day, while RF is the retention factor, representing the proportion of product remaining on the skin after application. BF (kg/mg) stands for the bioaccessibility factor, accounting for the fraction of the metal accessible for absorption, and 10^{-3} [mg/kg] is the unit conversion factor. The body weight (BW) assumed in this study is 70 kg[57]. The standard values established by SCCS for various parameters of cosmetic products for SSA, for lipstick, beauty cream, sunblock, and nail polishes used were, 4.8, 565,1425, 580 (hair dyes), respectively. The values of AA for lipstick, beauty cream, sunblock, and nail polishes were 0.05, 1.54, 3.7, and 3.5 quantity applied [g/cm^2], respectively. Whereas the values for F for lipstick, beauty cream, and sunblock were 1[26]. For nail polishes, it was taken as 0.1 (hair dyes). Similarly, the values of Rf were 2 for both lipsticks, beauty cream, and sunblock[26], and for nail

Nature	Code	Products name	Pb	Cd	Cu	Co	Ag	Ni	Zn	As	Mn	Hg	Techniques	
Lipsticks products														
Branded lipsticks	**BL1**	Swiss miss/B	**62.2** ± 0.1	**2.8** ± 0.00	**316** ± 0.29	**53.8** ± 0.02	**3.86** ±0.00	118 ± 0.21	BDL	BDL	**395** ±0.15	BDL	GAAS	Present Research
	BL3	Rivaj UK/ B	26.7 ± 0.03	0.86 ± 0.01	11.3 ± 0.01	10.23 ± 0.03	BDL	30.0 ± 0.2	BDL	BDL	141 ±0.08	BDL		
	BL5	Miss Rose/ B	18.9 ± 0.08	1.08 ± 0.03	0.83 ± 0.00	9.03 ± 0.06	0.32 ±0.00	1.35 ± 0.1	BDL	BDL	23.7 ±0.03	BDL		
	BL8	Matte lipstick/B	0.84 ± 0.00	1.13 ± 0.00	0.66 ± 0.01	7.16 ± 0.07	0.16 ±0.00	0.68 ± 0.02	BDL	BDL	0.75 ±0.00	BDL		
	BL9	Loreal/ B	5.12 ± 0.03	1.1 ± 0.01	0.37 ± 0.01	14.3 ±0.09	0.08 ±0.00	0.25 ±0.06	BDL	BDL	**0.262** ±0.00	BDL		
Mean (*n* = 5)			**22.774**	**1.39**	**58.26**	**18.92**	**0.886**	**30.2**	BDL	BDL	BDL	BDL		
Local lipsticks	LL2	Huxia Beauty/L	14.6 ± 0.04	1.28 ± 0.01	258 ± 0.15	8.7 ± 0.01	1.65±0.01	**731** ± 3.18	BDL	BDL	3.81 ±0.00	BDL		
	LL4	Colour Ingtitute/L	25.0 ± 0.06	1.02 ± 0.00	15.1 ± 0.00	12.4 ± 0.07	0.737±0.00	4.13 ± 0.02	BDL	BDL	12.6 ±0.01	BDL		
	LL6	Huxia/ L	49.6 ± 0.1	0.98 ± 0.02	11.3 ± 0.01	9.23 ± 0.01	0.1±0.00	2.13 ± 0.10	BDL	BDL	30.9 ±0.01	BDL		
	LL7	Matte/ L	20.7 ± 0.1	1.1 ± 0.01	1.03 ± 0.01	6.32 ± 0.02	0.162±0.00	2.18 ± 0.05	BDL	BDL	0.9 ±0.013	BDL		
	LL10	Lipstick/ L	9.43 ± 0.01	2.18 ± 0.01	5.16 ± 0.01	7.16 ±0.01	0.25±0.00	3.27 ± 0.05	BDL	BDL	189 ±0.03	BDL		
Mean (*n* = 5)		-	**23.9**	**1.31**	**66.00**	**8.76**	**0.579**	**148**	BDL	BDL	BDL	BDL		
Overall mean (*n*= 10)			**23.3**	**1.35**	**62.1**	**13.8**	**0.733**	**89.3**	BDL	BDL	BDL	BDL		
Min-Max			**0.85-62.22**	**0.75-2.8**	**0.375-316.87**	**7.16-53.8**	**1.09-3.86**	**0.25-731**	BDL	BDL	BDL	BDL		
Literature of lipstick products														
Mni-Max		-	**0.0006-429.1**	**0.001-68.2**	**<0.02 -135**	**0.0001-19.9**	**<0.01-5**	**<0.012-174**	**<0.03-123**	**0.012-14.1**	**0.28-151**	**0.075-80**	GAAS	[1]
Beauty Cream Products														
Continued														

Nature	Code	Products name	Pb	Cd	Cu	Co	Ag	Ni	Zn	As	Mn	Hg	Techniques	
Branded beauty cream	BBC11	Sandal beauty cream/B	11.6 ± 0.02	1.31 ± 0.01	**30.9** ± 0.01	**243.5**	**0.53** ± 0.00	**103** ± 0.05	400 ±0.01	2.68 ± 0.03	0.15±0.01	3047±0.05	GAAS	Present Research
	BBC14	Sunblock/B	11.0 ± 0.05	1.23 ± 0.00	0.287 ± 0.01	10.9 ± 0.06	0.18 ± 0.00	0.32 ± 0.01	14.3 ±0.01	BDL	0.15±0.00	18.2 ±0.02		
	BBC15	Lady dania Sun block /B	9.51 ± 0.1	1.28 ± 0.01	0.275 ± 0.01	BDL	0.45 ± 0.00	0.67 ± 0.06	4.12 ±0.01	BDL	0.125±0.00	2.5 ±0.01		
	BBC17	Rivaj sunblock/B	BDL	1.2 ± 0.01	0.5 ± 0.01	BDL	0.43 ± 0.00	0.66 ± 0.02	BDL	BDL	0.025±0.00	BDL		
	BBC19	Johnson cream/B	9.2 ± 0.1	1.55 ± 0.00	0.312 ± 0.00	6.37 ± 0.06	0.28 ± 0.00	0.31 ± 0.03	BDL	BDL	0.075±0.00	BDL		
	BBC20	Himalaya cream/B	BDL	1.23 ± 0.02	0.237 ± 0.00	4.62 ± 0.03	0.25 ± 0.00	0.88 ± 0.1	BDL	0.43 ±0.01	0.105±0.00	BDL		
Mean (*n* = 5)			**6.902**	**1.30**	**5.41**	**44.2**	**0.358**	**17.64**	**69.8**	**0.520**	**0.105**	**511.37**		
Local beauty cream	LBC12	Face fresh beauty cream/L	7.1 ± 0.1	2.67 ± 0.02	0.512 ± 0.01	15.1 ± 0.02	0.325 ± 0.00	1.91 ± 0.01	996 ±0.05	BDL	0.175 ±0.00	344 ±0.01		
	LBC13	Marvi Beauty cream/L	4.52 ± 0.1	1.02 ± 0.01	0.787 ± 0.01	9.17 ± 0.02	0.57 ± 0.00	2.75 ± 0.03	49.3 ±0.02	BDL	0.075 ±0.00	167 ±0.03		
	LBC16	Snow cream/L	9.0 ± 0.08	0.95 ± 0.01	0.287 ± 0.00	0.05 ± 0.02	0.187 ± 0.00	0.037 ± 0.06	5.62 ±0.21	BDL	0.062 ±0.00	BDL		
	LBC18	Chiltan pure acene cream/L	BDL	1.05 ± 0.02	1.12 ± 0.01	BDL	0.387 ± 0.01	0.262 ± 0.1	1.62 ±0.03	BDL	0.1 ±0.00	5.25 ±0.01		
Mean (*n* = 5)		-	**5.15**	**1.42**	**0.678**	**6.10**	**0.368**	**1.240**	**263**	BDL	BDL	**129**		
Overall mean (*n* = 10)			**6.21**	**1.35**	**3.52**	**28.9**	**0.362**	**11.0**	**166**	**1.56**	**0.105**	**358**		
Min-max			**BDL-11.6**	**0.95-0-2.67**	**0.019-2.47**	**BDL-1.21**	**0.125-0.537**	**0.021-8.241**	**BDL-400**	**0.43-2.68**	**0.025-0.175**	**BDL - 3047**		
Literature of beauty cream products														
Min-max			**0.005-1266**	**0.005-466**	**0.016-65.3**	**<0.02-40.25**	**<0.01-100**	**0.016-41.5**	**0.006-12.14**	**0.005-466.7**	**0.005-466.7**	**0.0045-14,507**		[1]
Nail polishes														
Continued														

Nature	Code	Products name	Pb	Cd	Cu	Co	Ag	Ni	Zn	As	Mn	Hg	Techniques	
Branded Nail Polish	BNP26	Xuncai/B	BDL	1.42 ± 0.01	0.56 ± 0.01	5.91 ±0.04	0.33 ±0.00	BDL	BDL	BDL	0.187± 0.00	BDL	**GFAAS**	**Present research**
	BNP27	Colorist/B	BDL	1.51 ± 0.01	0.45 ± 0.01	4.46 ±0.08	0.25 ±0.00	BDL	BDL	BDL	**11**± 0.03	BDL		
	BNP28	Sweet touch London/B	BDL	1.58 ± 0.00	0.25 ± 0.01	4.82 ±0.02	0.3 ±0.010	BDL	BDL	BDL	0.225± 0.00	BDL		
	BNP29	Face cover/B	BDL	1.66 ± 0.01	0.46 ± 0.00	7.98 ±0.01	0.27 ±0.01	BDL	BDL	BDL	0.25± 0.01	BDL		
	BNP30	Xuancai/B	**2.97** ± 0.08	1.51 ± 0.04	**0.25** ± 0.00	0.4 ±0.02	0.35 ±0.00	BDL	BDL	BDL	BDL± 0.00	BDL		
Mean (n =5)			**0.59**	**1.54**	**0.395**	**4.71**	**0.302**	**BDL**	**BDL**	**BDL**	**2.3324**	**BDL**		
Local Nail Polish	LNP21	HD Romantic collars/L	BDL	1.28 ± 0.01	0.62 ± 0.01	11.4 ±0.09	**0.37** ±0.00	**0.712** ± 0.1	BDL	BDL	0.62 ± 0.01	BDL		
	LNP22	Mode love/L	BDL	1.56 ± 0.01	**46.3** ± 0.73	5.61 ±0.04	0.23 ±0.00	0.212 ± 0.04	BDL	BDL	0.05± 0.00	BDL		
	LNP23	Christin/L	BDL	1.28 ± 0.02	0.27 ± 0.00	1.52 ±0.02	0.25 ±0.00	BDL	BDL	BDL	0.025± 0.00	BDL		
	LNP24	AIR Woman/L	1.4 ± 0.01	1.55 ± 0.02	0.37 ± 0.01	6.92 ±0.03	0.25 ±0.00	BDL	BDL	BDL	0.337± 0.002	BDL		
	LNP25	Mendon nail polish/L	2.97 ± 0.01	1.52 ± 0.00	0.41 ± 0.00	**12.7** ±0.02	0.3 ±0.011	BDL	BDL	BDL	1.02± 0.01	BDL		
Mean (n = 5)		-	**0.87**	**1.44**	**9.61**	**7.65**	**0.282**	**0.185**	**BDL**	**BDL**	**0.410**	BDL		
Overall Mean (n =10)			**0.43**	**1.49**	**5.00**	**6.18**	**0.292**	**0.092**	BDL	BDL		BDL		
Min-Max			**BDL -2.97**	**1.28 -1.66**	**0.25-46.3**	**0.4-1.12.7**	**0.237-0.375**	**BDL -0.712**	BDL	BDL	**BDL-11**	BDL		
Literature of Nail Polish Product														
Min-Max			**<0.1-42**	**0.01-8.12**	**0.5-30**	**<0.01-1**	**0.1-5**	**1.88-4.22**	-	-	**0.76-6.32**	-		[1]

Table 2. Heavy metals (mg/kg) in cosmetic products reported from Trarkhel, Azad Jammu and Kashmir, Pakistan and compared with the literature. *BDL* Below detection limit.

polishes (hair dyes), it was 1/week (20 min). It is generally accepted to assume that no more than 50% of an orally administered dose becomes systemically available[26].

Hazardous quotient (HQ) and hazard index (HI)
The hazard quotient (HQ) is a metric used to quantify the non-carcinogenic risk associated with metals and metalloids present in cosmetic samples. It is defined as the ratio of the systemic exposure dosage (SED) to the dermal reference dose (RfD) of each toxicant, both expressed in mg kg^{-1} day^{-1}. An HQ value below 1 indicates that exposure remains within safe limits, posing no significant health risk. Conversely, an HQ exceeding 1 signifies that exposure surpasses the safety threshold and may result in adverse health effects.

$$Noncarcinogenic\,risk; HQ = \frac{SED_{nca}}{Rfd} \tag{4}$$

The hazard index (HI) quantifies the cumulative health risk resulting from exposure to several metal(loid)s. It is calculated as the sum of the individual hazard quotients (HQ) for all metal(loid) species under consideration. An HI value exceeding 1 suggests a potential health risk due to combined exposure to several hazardous substances. The HI was calculated using the following equation, as reported in previous studies[57].

$$\mathrm{HI} = \mathrm{HQPb} + \mathrm{HQCd} + \mathrm{HQCu} + \mathrm{HQCo} + \mathrm{HQAg} + \mathrm{HQNi} + \mathrm{HQZn} + \mathrm{HQAs} + \mathrm{HQMn} + \mathrm{HQHg} = \sum\nolimits_{i=1}^{n} HQ_i \tag{5}$$

Lifetime cancer risk (LCR)
Carcinogenic risk refers to the probability that an individual may get cancer over time due to exposure to a chemical agent. The carcinogenic risk was calculated using Eq. (6) [57]

$$\text{Carcinogenic risk} = \mathrm{SED} \times \mathrm{SF} \tag{6}$$

where SF represents the carcinogenicity slope factor (mg kg^{-1}. d^{-1}), and it approximates the cancer risk per unit intake dose of an agent to cause cancer over an average lifetime. The reported slope factors for Pb, Cd, Cu, Co, Ag, Ni, Zn, As, Mn, Hg are 0.0085, 6.7, 1.5, NA (not available), NA, 0.3, 0.91, NA, 3.6, and 0.3 (ingestion) (mg kg^{-1} d^{-1}), respectively[26,58]. The total cumulative cancer risk (TCR) can be calculated from Eq. (7).

$$TCR = \sum\nolimits_{i}^{k} CDI_K \times SF \tag{7}$$

Results and discussion
Characterizations
An atomic absorption spectrometer (AA 700) was used to analyse all ten heavy metals, as summarised in Table 2. The calibration curves showed linear responses over a concentration range from 0.02 to 10 mg/kg, following the standard requirements. This linearity confirms the accuracy and reliability of the analyte quantification across all tested samples. Analysis of heavy metals in cosmetics contributes important information about the risk these metals pose to human health. Results showed concentrations and presence of numerous heavy metals such as Pb, Cd, Cu, Co, Ag, Ni, Zn, As, Mn, and Hg among various product categories. These findings are especially important since some of these metals are known for being toxic at trace-level concentrations, and their presence may exceed the permissible limits established by regulatory authorities. The data were systematically analysed to determine cosmetic sample compliance with established safety standards. Potential health risks associated with their use were assessed in comparison with heavy metal concentrations to guidelines from international regulatory bodies such as the European Commission on Health and Food Safety. Sources of contamination, mechanisms of toxicity, and implications for consumer safety are discussed. It is further demonstrated that variability observed within product types and brands and thus needs monitoring and regulation.

Levels of heavy metals in all cosmetic products
The number of selected cosmetics products was 30, 10 each for lipsticks, creams, and nail polishes. An analysis was performed for 10 elements in the lipsticks, creams, and nail polishes from the districts of Sudhnoti, Azad Jammu and Kashmir. The sample and literature data are reported in Table 2 and further supported by Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12, and show a marked difference from each other and vary from sample to sample. Comparison of results within each category reveals that the concentrations of heavy metals measured in the 30 samples differ significantly among the various brands (Table 2). The comparative average concentration of heavy metal contents in the cosmetic products is summarised in Table S2.

Lead (Pb) concentration
The concentration of lead (Pb) detected in lipsticks, creams, and nail polishes ranged from 0.85 to 62.22 mg/kg, BDL (Below Detection Limit) to 11.62 mg/kg, and BDL to 2.97 mg/kg, respectively. The mean Pb concentration in local lipstick samples was 23.90 mg/kg, with the highest value observed in LL8 (49.67 ± 0.095 mg/kg). In branded lipsticks, the mean Pb content was 22.774 mg/kg, reaching a maximum of 62.22 ± 0.09 mg/kg in sample LB1. For creams, the overall mean was 6.902 mg/kg, with the highest concentration measured at 11.62 ± 0.02 mg/kg; local cream brands averaged 6.21 mg/kg, with a peak value of 9.0 ± 0.08 mg/kg in sample CL16. Branded and local nail polishes showed mean Pb concentrations of 0.59 mg/kg and 0.87 mg/kg, respectively, with the greatest value of 2.97 ± 0.08 mg/kg identified in both NPB30 (branded) and NPL25 (local). As indicated in Fig. 2; Table 2. The Pb concentrations found in most lipstick samples exceeded the recommended limits set by Health

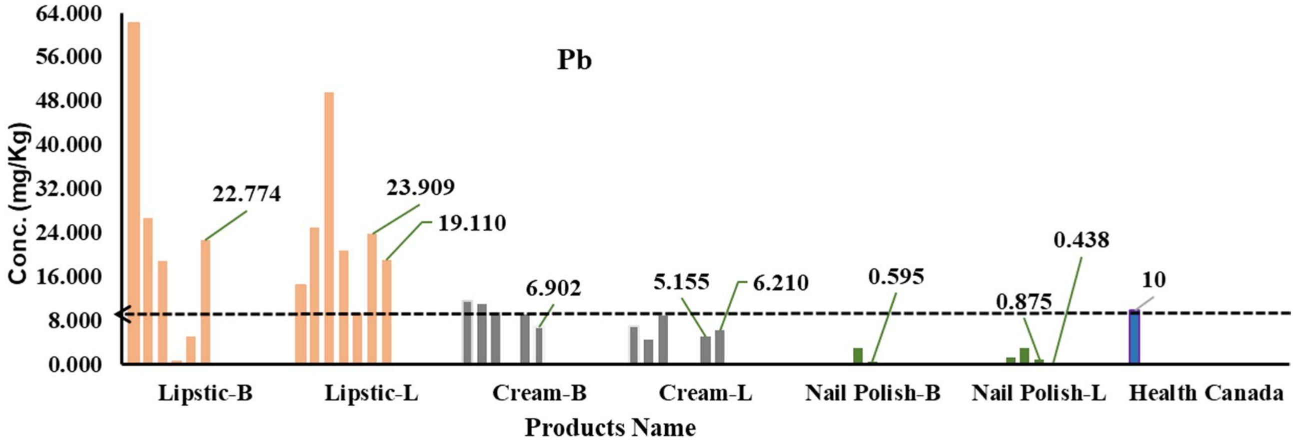

Fig. 2. Level of Pb in cosmetics products compared with the standard value according to Health Germany guidelines.

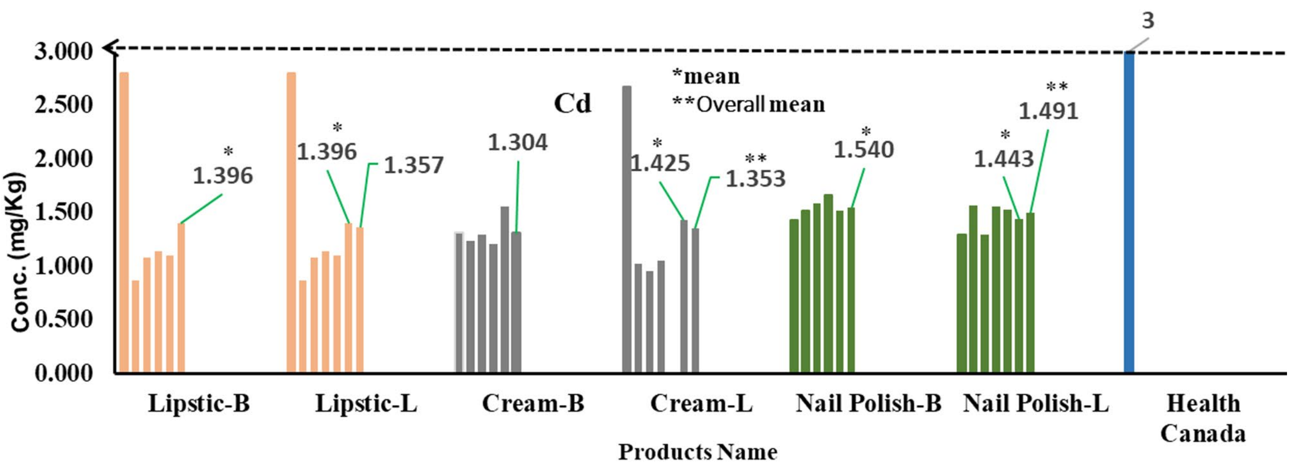

Fig. 3. Concentration of Cd in cosmetics products compared with the standard value according to Health Germany guidelines.

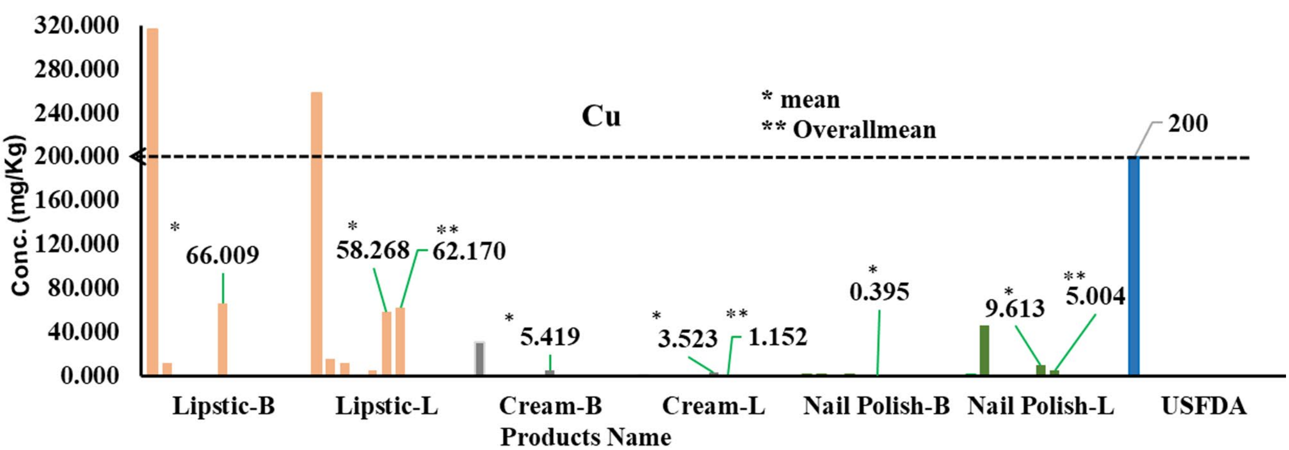

Fig. 4. Mean and overall mean concentration of Cu in cosmetic products compared with daily dietary intake guidelines.

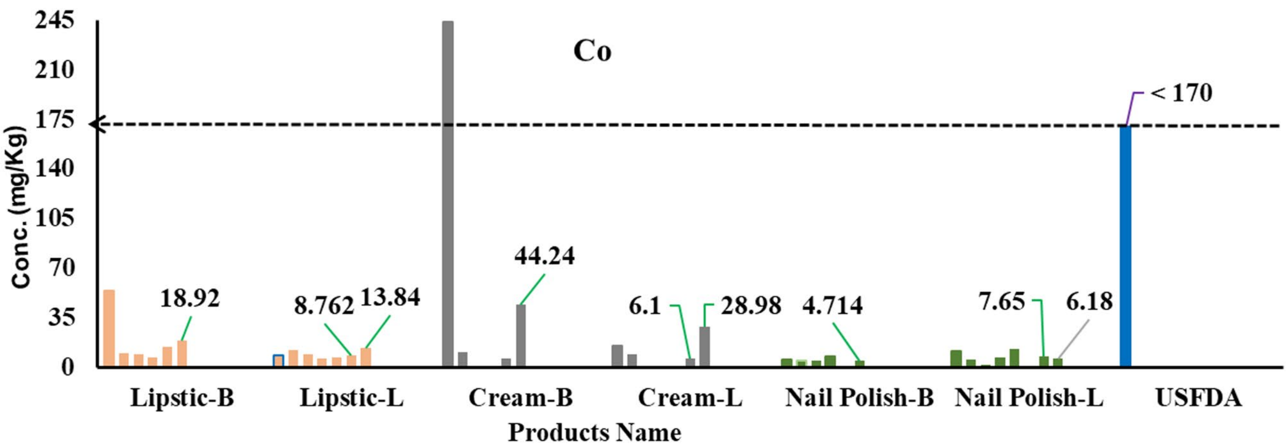

Fig. 5. Mean and overall mean of Co in cosmetics products compared with Health Canada guidelines.

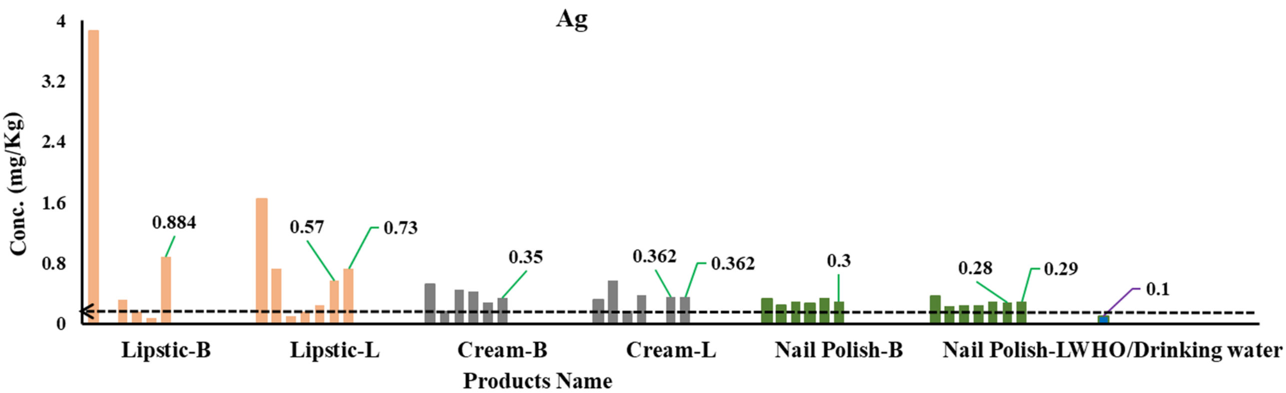

Fig. 6. Concentration of silver in different cosmetic products compared with the WHO.

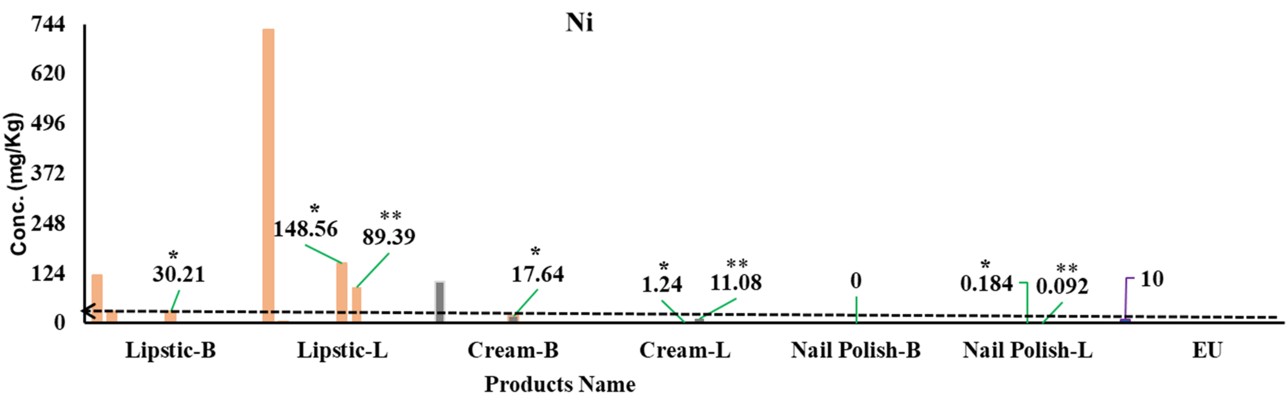

Fig. 7. Concentration of Nickel in different cosmetic products compared with German health guidelines.

Canada[48], while levels in creams and nail polishes were comparatively lower and generally within permissible guidelines.

Cadmium (Cd) concentration

Among different brands, Cd was highest in concentration (2.81 ± 0.09) mg/kg in LB1 (branded lipsticks), followed by 2.18 ± 0.01 mg/kg in local lipsticks brand (LL5), whereas the lowest values (0.86 ± 0.01) were found for BL3 in branded lipsticks, as shown in Fig. 3. However, none of the analyzed samples exceeded their respective permissible limits of 3 mg/kg set by the Canadian authority in cosmetic products[48].

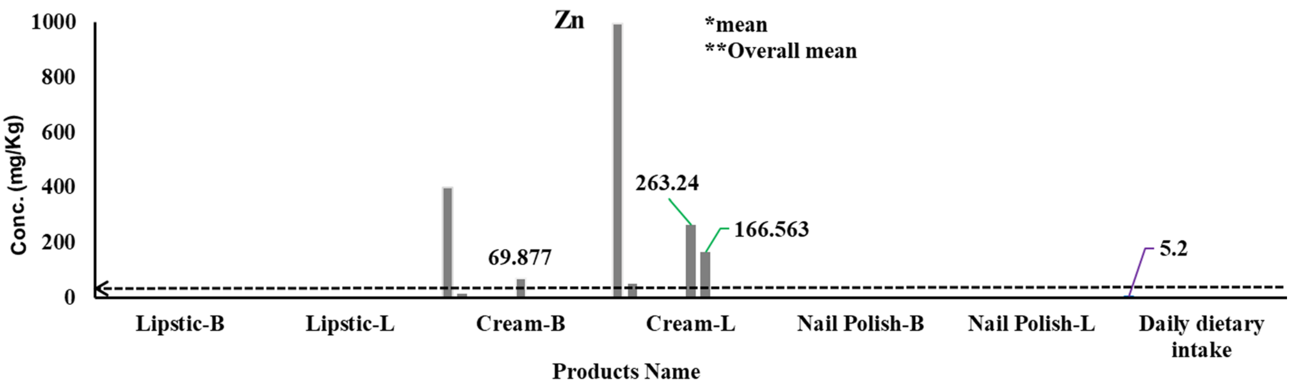

Fig. 8. Concentration of Zinc in different cosmetic products compared with daily dietary intake (ug/day).

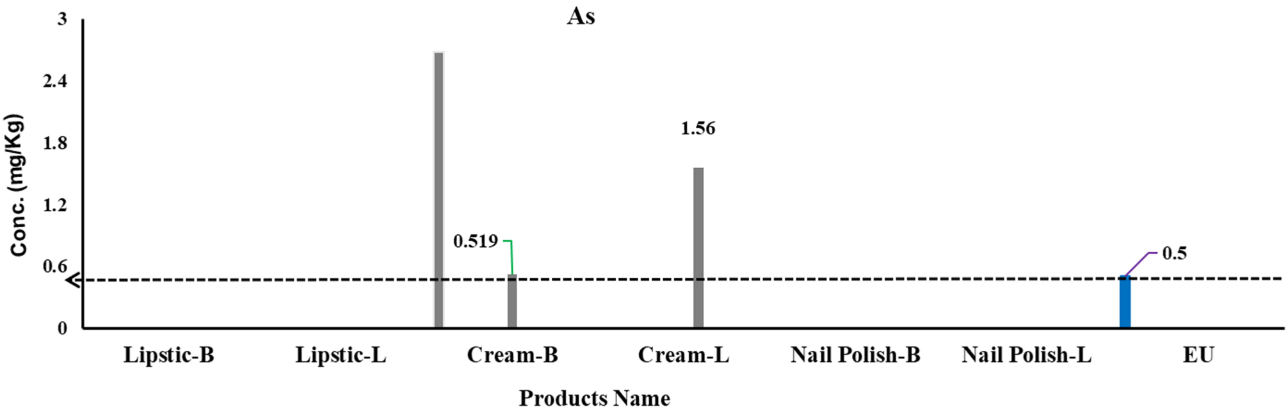

Fig. 9. Concentration of Arsenic in different cosmetic products compared with the WHO.

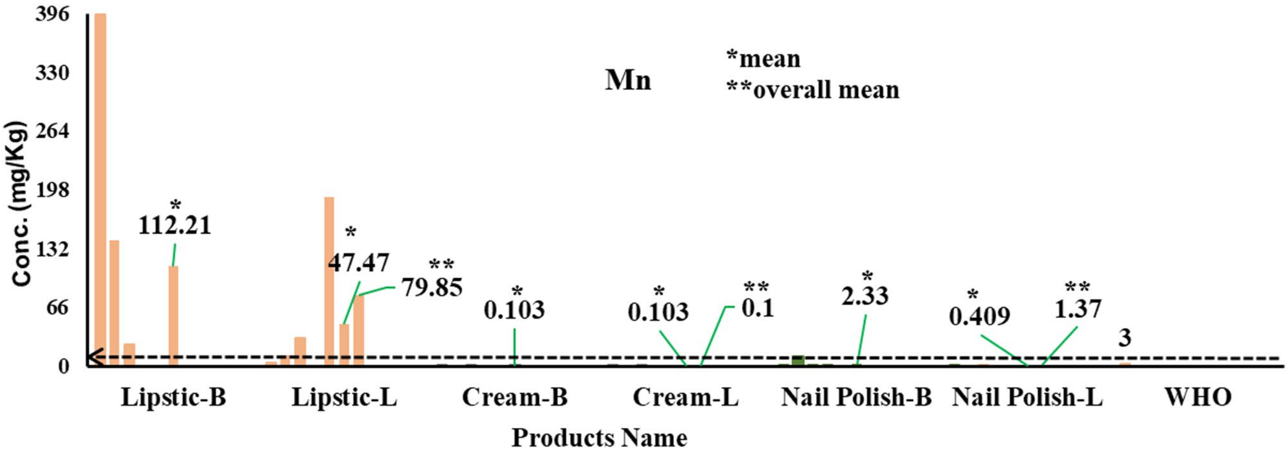

Fig. 10. Concentration of Nickel in different cosmetic products compared with German health guidelines.

Copper (Cu) concentration

The mean values of Cu (mg/kg) in cosmetic products are in the order of local lipsticks (66.00) > branded lipsticks (58.26) > local nail polish (9.61) > branded beauty (5.418) > local beauty cream (3.52) > branded nail polish (0.395) Maximum concentration of Cu (316 mg/Kg) in BL1 was found higher than all of the studies conducted for cosmetics products and the values recommended (200 mg/Kg) by USFDA[48] as shown in Table 1; Fig. 4. Copper (Cu) is primarily used as a colorant and preservative in cosmetic formulations. Certain products incorporate Cu-peptides due to their potential anti-ageing benefits. As an essential trace element, copper supports protein synthesis and stability, which are crucial for maintaining healthy skin. However, excessive exposure to copper

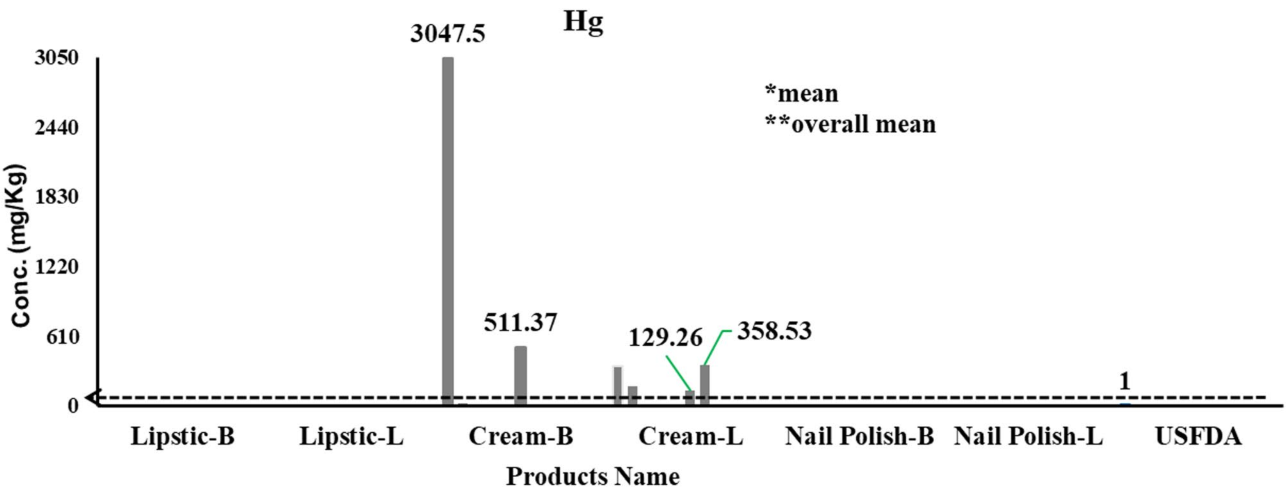

Fig. 11. Concentration of Mercury in different cosmetic products compared with the USFDA Health guidelines.

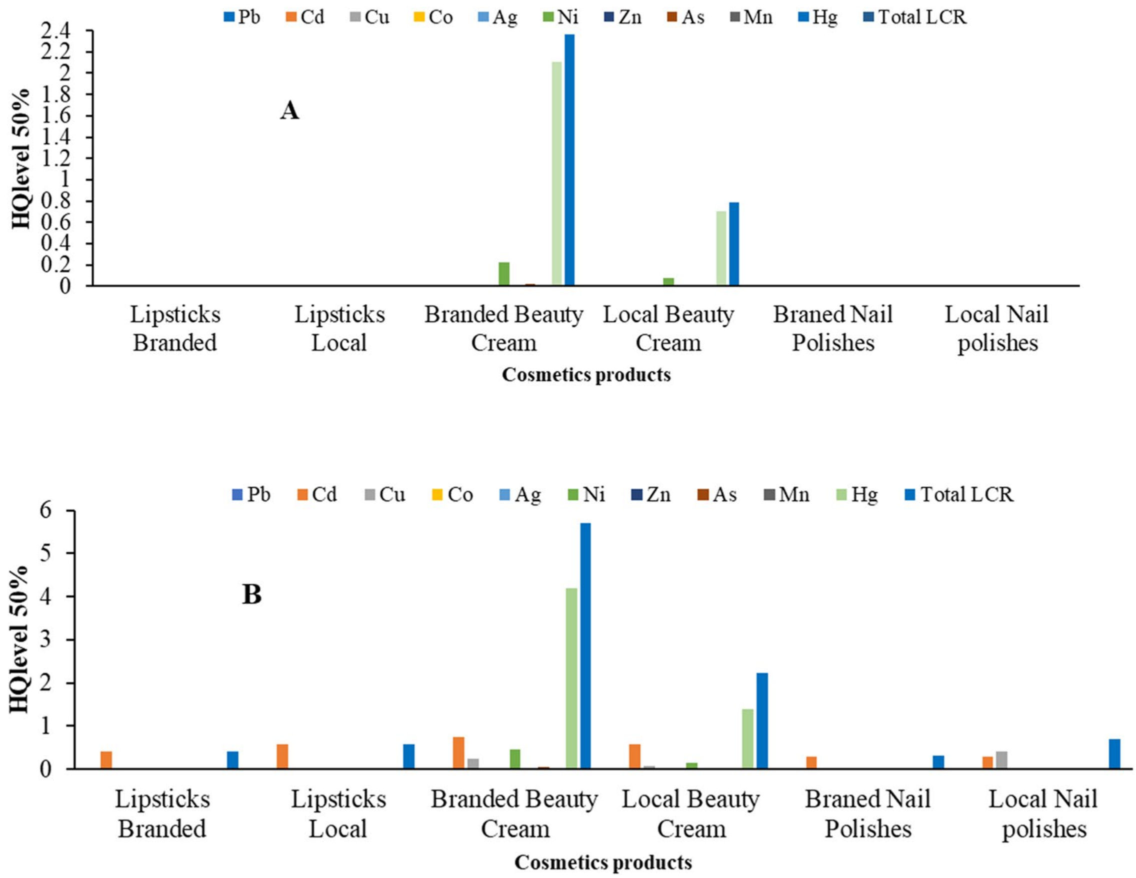

Fig. 12. Health risk assessment based on LCR of cosmetic products at 50% (**A**) and 100% (**B**) bio-accessibility levels.

in cosmetics can be hazardous. Prolonged or excessive use may lead to copper toxicity, with dermal absorption contributing to increased systemic copper levels and potential adverse health effects[58].

Cobalt (Co) concentration

The maximum values including mean of Co in mg/kg in cosmetic products for branded beauty cream in BBC1, 243.5 ± 0.01 (44.241) > branded lipsticks LB1 of 53.8 ± 0.02 (18.92) > local beauty cream in LBC1, 15.18 ± 0.02

(6.10) > local lipsticks LL2 of 12.4 ± 0.07 (8.762) > branded nail polish, BNP4 7.98 ± 0.01 (4.717). The maximum concentration of Co (243.5 ± 0.005 mg/Kg) in BBC1 was found to be higher than all of the studies conducted so far for cosmetics products and the values recommended (< 170 mg/Kg) by USFDA[48], as shown in Table 1; Fig. 5. The presence of Co in most of the cosmetics is not added intentionally. However, excessive exposure to cobalt can lead to various health issues, including neurological disturbances, cardiovascular effects, and respiratory complications. Although external skin contact with cobalt seldom results in substantial systemic absorption, percutaneous uptake can still occur, potentially causing systemic toxicity[58].

Silver (Ag) concentration

The mean values (mg/kg) of Ag in cosmetic products in the decreasing pattern from highest to lowest are: branded lipsticks (0.8868) > local lipsticks (0.579) > local beauty Cream (0.368) > branded beauty cream (0.358) > branded nail polish (0.302) > local nail polish (0.282), as shown in Table 2. A previous study reported by Ullah et al., 2023 indicated that the cosmetic goods (lipsticks, cream and nail polishes) from several beauty stores had concentrations of Ag ranges as; <0.01-5 mg/kg for lipsticks, 0.125–0.537 mg/Kg for creams and 0.1-5 mg/Kg for nail polishes[48], and these findings of Ag are higher than the results of the present study except branded and local lipsticks as shown in Table 2. The permissible limit of silver (Ag) in cosmetic products is not explicitly defined by major international organisations like the WHO, FAO, USFDA, or the EU Cosmetics Regulation. However, silver is often regulated in its various forms (metallic silver or silver nanoparticles) due to concerns about its potential toxicity and bioaccumulation. They provide limits for silver in drinking water, with a tolerable level of 0.1 mg/L for long-term exposure, which can be used as a reference for product safety. Fig, 6 shows the comparison of the present study with the maximum level of Ag in drinking water.

Nickel (Ni) concentration

The concentration of nickel with the highest concentration (731.1 ± 3.18) was observed in LL1 for a local lipstick with a mean value of 148.56 mg/kg, followed by BL1 (118.71 ± 0.21) in branded lipsticks and BBC1 (103.012 ± 0.05) in branded beauty cream. The minimum concentration of nickel was observed in both local and branded nail polishes (Fig. 7). However, the values of nickel reported in the literature for lipsticks, cream, and nail polishes were (< 0.012–174.8), (0.016–41.5), and (1.88–4.22) mg/Kg, respectively, and were found to be smaller than the present study. However, the data observed here exceeded the permissible limit (10 mg/Kg) according to global standards suggested by the European Union (EU). Nickel (Ni) is commonly present in a variety of cosmetic products, mostly as a trace element found in colourants and preservatives or as a contaminant in raw materials and pigments. It is present in cosmetics such as hair dyes, lipsticks, and eye makeup formulations[58].

Zinc (Zn) concentration

The mean concentrations (mg/kg) of Zn in cosmetic products were found in the following order: local cream (263.25) > branded cream (69.876) and can be seen in Fig. 8. The highest concentration in of Zn was found in local cream LBC1 (996.37 ± 0.05) followed by branded beauty cream BBC1 (400.77 ± 0.012), and found higher than found by Ullah et al.,2023 (0.006–12.14) and lower from different samples collected and analyzed in the range (1.4–8909 mg/kg) in Qatar[58]. Although the acceptable limits for zinc (Zn) in cosmetic products are not clearly established, the high concentration observed in the sample is noteworthy. Zinc oxide, a common and generally recognised as safe ingredient in sunscreens, serves to protect the skin by reflecting and scattering ultraviolet (UV) radiation. However, excessive zinc intake, whether from cosmetic sources or other exposures, can induce adverse effects such as gastrointestinal discomfort and compromised immune function. The maximum tolerable daily intake of zinc through diet ranges from 5.2 to 16.2 μg/day[59].

Arsenic (As) concentration

The concentrations (mg/kg) of As in the cosmetic samples in branded beauty cream BBC1 (2.68 ± 0.03) BBC6 (0.43 ± 0.01) with an overall mean concentration (n = 10) of 1.56 and a concentration range of 0.43–2.68. The concentrations of As in the lipsticks and nail polishes were below the detection limit, and this is lower than the content of As found in literature (0.005–466.7) [2]. A study conducted in Botswana reported arsenic (As) concentrations in facial and body creams and lotions from different beauty shops in the range of 1.95–4.52 mg/kg[58], which is almost similar to the present investigation. Chronic exposure to arsenic is associated with adverse health effects, including skin lesions, various cancers, cardiovascular diseases, and neurological disorders. Although many countries have prohibited arsenic use in cosmetic products, its occurrence remains a concern due to potential contamination during manufacturing processes. Continuous quality control and regulatory enforcement are imperative to mitigate risks linked to arsenic exposure from cosmetics. Regulatory limits for arsenic in cosmetics vary by jurisdiction: the FDA allows up to 3.0 mg/kg for colourants, while the EU, GCC, ASEAN, China, and Korea restrict levels to 0.5, 3.0, 5.0, 2.0, and 10 mg/kg, respectively[12,58]. The higher value of As in the present study than EU (0.5) is alarming, as shown in Fig. 9; however, based on the other guidelines, it can be compromised, but constant use of cosmetics containing As is detrimental.

Manganese (Mn) concentration

The mean concentrations (mg/kg) of Mn were found in the following order: local lipsticks (112.21) > branded lipsticks (47.47), branded nail polishes (2.33) > local nail polishes (0.412) > branded beauty cream (0.105) ≈ local beauty cream (0.1031), as shown in Fig. 10 and Table S2. The highest concentration of Mn detected in branded lipsticks (BL1) was found to be 395.12 ±0.14 mg/kg, exceeding the value reported in the literature (0.28–151). A study from Ghana documented Mn in lipsticks at 154 mg/kg[59], which is less than the concentration observed in this study, The overall mean concentrations across cosmetic types were found to be in the range of 79.85 mg/kg, 0.105 mg/kg, and 1.37 mg/kg in lipstick products, beauty cream products, and nail polish products, respectively. Mn is a vital metal for numerous metabolic functions in biological systems.

Nevertheless, Mn contamination is a significant concern in cosmetics due to its potential health hazards. Pigments in lipsticks may contain Mn compounds for colouration, whereas lotions may incorporate manganese-based substances in emulsifiers and thickeners, leading to contamination.

Additionally, massage creams and scrub products could introduce Mn contents because of Mn-containing oils or abrasive materials, underscoring the broad range of cosmetics susceptible to such contamination. Despite the lack of well-defined acceptable limits for Mn in cosmetics[59], the elevated levels in samples BL1 and BL3 raise significant safety concerns.

Mercury (Hg) concentration

The mean concentrations (mg/kg) of Hg were only estimated in branded and local beauty creams and were below the detection limit in the rest of the samples. The mean concentration of Hg in branded and local beauty cream was 511.37 and 129.26, respectively, with overall mean concentration and range of 358.53 and BDL – 3047.5, respectively. The concentration of Hg in branded beauty cream is in the order: BBC1 (3047.5 ± 0.05) > BBC14 (18.25 ± 0.02) > BBC3 (2.5 ± 0.01) and local beauty cream LBC1 (344.12 ±0.01) > LBC2 (167.7 ±0.03) mg/Kg as shown in Fig. 11. The present study recorded mercury (Hg) concentrations higher than those reported in samples from Qatar[61], and lower than the results documented by Ullah et al., 2023, in the range (0.0045-14,507.74). Previous research in Pakistan indicated mean Hg levels of 0.49 mg/kg, 1.21 mg/kg, and 5.42 mg/kg in foundation products[58], which are lower than the mercury content detected in beauty creams in this investigation. Mercury is frequently found in cosmetics, especially skin-lightening creams and facial depigmentation products, as well as sunscreens. It may enter cosmetics either as a contaminant during production or added for preservative or for skin-lightening purposes. Prolonged exposure to Hg is associated with neurological impairments, including cognitive dysfunction and disrupted nerve function[62]. Regulatory agencies, including the FDA, EU, GCC, ASEAN, China, Canada, and Korea, set limits on mercury concentrations in cosmetics, with thresholds ranging from 0.1 to 1 mg/kg, and a specific limit of 1 mg/kg mercury in colourants used in cosmetics[58].

Statistical analysis

Statistical calculations were made on the obtained data to determine the hazardous nature of the creams. Calculations were done with IBM SPSS Statistics version 26.0.1 software. This data includes maximum and minimum concentrations, mean, standard deviation (SD), and Pearson's correlation coefficient. Results of correlation analysis in Table S3 demonstrate that there were highly significant ($p < 0.01$) positive associations between Pb-Cu ($r = 0.915$), Pb-Ag ($r = 0.898$), and Pb-Ni ($r = 0.959$), etc., in different brands of lipsticks. In local lipsticks, Cd was significantly correlated at $p < 0.01$ with Mn ($r = 0.939$), Cu has a strong correlation with Ag ($r = 0.933$), Ni (0.999), Ag also has a strong correlation with Ni ($r = 0.923$), while Pb showed strong negative associations with Cd (r = -0.657) at $p < 0.05$. In the branded beauty cream, a significant positive relationship was found between Pb-Mn ($r = 0.713$), Cu-Co, Cu-Ni, Cu-Zn, Cu-As, and Cu-Hg ($r = 0.999$, $r = 1$, $r = 1$, $r = 0.986$, $r = 1$), respectively. Other correlations were either weak or moderate. In branded beauty cream there were also a significant positive relationships between Cd-Co ($r = 0.8233$), Cd-Zn ($r = 1.00$), Cd-Mn ($r = 0.998$), Cd-Hg ($r = 0.9981$), Cd-Hg ($r = 0.891$), Cu-Ni ($r = 0.962$), Co-Ag ($r = 0.824$), Co-Mn ($r = 0.858$), Co-Hg ($r = 0.991$), Ag-Ni ($r = 0.927$), Zn-Mn ($r = 0.998$), Zn- Hg ($r = 0.892$), Mn-Hg ($r = 0.918$). A strong negative correlation was observed for Pb-Cu (r = -1.00), Pb-Ag (r = -0.997), Pb-Ni (r = -0.954), whereas a weak negative correlation existed between Pb-Co (r = -0.526), Pb-Hg (r = -0.409) in local beauty cream. In Nail polish products (branded nail polishes), there was no correlation found at $p < 0.01$; however, a moderate positive correlation at $p < 0.05$ was found between Pb-Ag, Cd-Co, Cu and Co ($r = 0.635$, $r = 0.397$ and $r = 0.675$, respectively). A moderate negative correlation at $p < 0.05$ was found between Pb-Cu, Cu-Ag and Ag-Mn (r = -0.582, r = -0.517, and r = -0.713), respectively. Similarly, a weak negative correlation was observed in Pb-Cd, Pb-Mn, Cd-Cu, Cd-Mn, Cu-Ag, and Co-Mn (r = -0.172, r = -0.269, r = -0.309, r = -0.493, r = -0.269, r = -0.232, and r = -0.032), respectively, indicating that these metals are rarely found together in high concentrations. In local nail polishes, there is no significant positive or negative relationship except Co and Mn ($r = 0.927$), Ag-Ni ($r = 0.800$), and Pb-Mn ($r = 0.773$), which depicted a highly significant positive correlation ($p < 0.01$), followed by Co-Ag ($r = 0.731$) and Pb-Cd ($r = 0.527$), Pb-Co ($r = 0.585$), Cd-Cu ($r = 0.471$), Co-Ni ($r = 0.409$), and Ag-Mn ($r = 0.644$) at $p < 0.05$.

Human health risk assessment

Non-carcinogenic risk assessment and margin of safety

Systemic exposure to cosmetic products estimates the quantity of chemicals entering the human body via various exposure pathways. The systemic exposure dosage (SED) values, calculated at 50% and 100% bio-accessibility for selected heavy metals in different cosmetic products, are presented in Table S4. It was noted that SED at 50% accessibility, the highest mean values of metals in branded and local lipsticks were found in the pattern Cd (3.13E-02 mg $kg^{-1}.day^{-1}$) > Mn (4.39E-04 mg $kg^{-1}.day^{-1}$) > Cu (2.59E-04 mg $kg^{-1}.day^{-1}$) > Ni (1.18E-04 mg $kg^{-1}.day^{-1}$) > Pb (8.90E-05 mg $kg^{-1}.day^{-1}$) > Co (7.40E-05 mg $kg^{-1}.day^{-1}$) > Ag (3.47E-06 mg $kg^{-1}.day^{-1}$); and Cd (4.39E-02 mg $kg^{-1}.day^{-1}$) > Ni (5.80E-04 mg $kg^{-1}.day^{-1}$) > Cu (2.28E-04 mg $kg^{-1}.day^{-1}$) > Mn (1.86E-04 mg $kg^{-1}.day^{-1}$) > Pb (9.35E-05 mg $kg^{-1}.day^{-1}$) > Co (3.43E-05 mg $kg^{-1}.day^{-1}$) > Ag (2.27E-06 mg $kg^{-1}.day^{-1}$), respectively. Likewise, SED levels at 100% bio-accessibility for Pb, Cd, Cu, Co, Ag, Ni, Mn, for branded and local lipsticks were 1.78E-04, 6.26E-02, 5.17E-04, 1.48E-04, 1.29E-05, 5.72E-03, 2.98E-05, and 1.87E-04, 8.77E-02, 4.55E-04, 6.85E-05, 5.74E-06, 6.99E-04, 6.24E-04, respectively. The highest values at 50% and 100% SED were observed for Cd, followed by Mn ≈ Cu, and Pb, and Cd, followed by Ni, Cu, Co, Mn, and Pb, respectively. The calculated SED values at 50% bio-accessibility for various heavy metals (HMs) in local beauty creams, Ni and Hg, exhibited notably high SEDs, ranging from 2.41E + 1 to 7.03E + 00 mg $kg^{-1}.day^{-1}$, with Pb, Co, and Ag also showing elevated levels (3.05E-01, 7.00E-01, and 2.52E-01 mg $kg^{-1}.day^{-1}$, respectively). Minor but detectable levels were recorded for Cd, Cu, As, Mn, and Zn, which were below detection or negligible. In branded creams, SED values were significantly lower. Pb, Cd, and Co ranged from 6.90E-02 to 8.10E-02 mg $kg^{-1}.day^{-1}$, while Hg and Ni showed a maximum SED of 1.72E + 0 mg $kg^{-1}.day^{-1}$ to 3.50 E + 0. Arsenic and zinc remained undetectable or negligible across samples. At 100% bio-accessibility, the trend continued with higher systemic exposure from local creams. For local creams, Hg and Ni showed markedly high SEDs of 1.40E + 01 and 3.44E + 00 mg kg-1.day^{-1}, respectively. Co and Pb were also present at elevated levels (1.62E-1 and 1.38E-01 mg $kg^{-1}.day^{-1}$). Branded creams, on the other hand, exhibited substantially lower SEDs for all metals, with high values around 3.99 E-3 mg $kg^{-1}.day^{-1}$, except for Hg (1.40E + 00 mg $kg^{-1}.day^{-1}$) and As (1.30 E-2 mg $kg^{-1}.day^{-1}$). At 50% bio-accessibility, local nail polishes showed elevated SED levels for several metals compared to branded products. Notably, Mn (6.50 E-1 mg $kg^{-1}.day^{-1}$) and Cu (1.39 E-1 mg $kg^{-1}.day^{-1}$) were significantly higher in local brands, whereas branded polishes exhibited comparatively lower values for Mn (3.38E-2 mg $kg^{-1}.day^{-1}$) and Cu (5.75E-3 mg $kg^{-1}.day^{-1}$). While Pb, Zn, As, and Hg were undetectable or negligible in both groups, Cd, Co, and Ni were consistently present, with higher values observed in local polishes. For instance, Cd ranged from 2.24E-2 (branded) to 2.09E-2 mg $kg^{-1}.day^{-1}$ (local), and Co from 6.85E-2 to 1.11E-1[1] mg $kg^{-1}.day^{-1}$, respectively. At 100% bio-accessibility, the SED values nearly doubled in both product types. Local nail polishes again demonstrated higher exposure values for Mn (1.30E + 0 mg $kg^{-1}.day^{-1}$), Cu (2.78E-1), and Co (2.22E-1 mg $kg^{-1}.day^{-1}$). In contrast, branded samples showed maximum Mn and Co levels of 6.76E-2 and 1.37E-1 mg $kg^{-1}.day^{-1}$, respectively. Cd, Ni, and Ag also followed similar trends with higher systemic exposure in local brands. The calculated values of SED were found to be more or less similar to SED levels observed in the previous study[26,58] in different cosmetic products, but the value of Pb, Cd, and Hg, in particular, reported in this study was found to be higher than the study conducted by Arshad et al. (2020)[26].

The methodology developed by the SCCS for testing and evaluating the safety of cosmetic elements served as the foundation for the development of the MoS[28]. The MoS (Table S5) evaluation in this current study was based on the dermal bioavailability of the cosmetic product at 50% and 100% of the identified metal(loid) content. The calculated MoS values for heavy metals (HMs) in branded and local lipsticks at 50% and 100% bio-accessibility are compared with previously reported data. As per regulatory risk assessment frameworks, MoS > 100 is generally considered indicative of acceptable safety for consumer exposure to cosmetic products. At 50% bio-accessibility, the present study revealed that the highest MoS values in branded lipsticks followed the trend: Pb (1.18E + 05) > Co (2.03E + 04) > Cu (3.87E + 03) > Ni (1.14E + 03) > Mn (1.05E + 02) > Cd (3.99E + 00). Similarly, for local lipsticks, the MoS hierarchy was: Pb (1.12E + 05) > Co (4.38E + 04) > Cu (4.40E + 03) > Mn (2.47E + 02) > Ni (2.33E + 02) > Cd (2.85E + 00). These findings indicate that Pb and Co exhibited the highest MoS values across both product types, suggesting a lower health risk due to relatively lower exposure compared to their acceptable exposure limits. However, Cd consistently showed low MoS values (below 100) in both branded and local samples, which is a safety concern due to its cumulative toxicity even at trace levels. Arshad et al. (2020) reported MoS values for Pb and Cd in lipsticks as 2.39E + 06 and 8.55E + 05 at 50% and 1.20E + 06 and 4.27E + 05 at 100% bio-accessibility, respectively. It was significantly higher in the literature than in the present study, indicating much lower exposure levels in these samples. On the other hand, extremely high MoS values for Cd, Pb, Cu, Ni, Zn, Mn, and Hg, e.g., Pb (3.73E + 05), Cd (1.54E + 07), Ni (1.19E + 07), were reported previously[28], again pointing to considerably safer exposure margins than those found in the current study for Cd, Cu, and Mn. At 100% bio-accessibility, the MoS values in local lipsticks remained in the same pattern but with reduced safety margins due to increased exposure. The MoS values were: Pb (1.12E + 05), Co (4.38E + 04), Cu (4.40E + 03), Mn (2.47E + 02), Ni (2.33E + 02), Cd (2.85E + 00), again, indicating sufficient safety for most of the metals except Cd, which continues to present a potential health concern under worst-case exposure assumptions. The findings align partially with the literature-based conclusion that MoS > 100 indicates safety. As noted in previous studies, most cosmetic products, including lipsticks, were deemed safe when their MoS exceeded 100. However, the current data shows that although Pb, Ni, Co, Cu, and Mn generally meet these threshold guidelines, Cd consistently falls below the safety margin, especially in both branded and local samples. This suggests the need for stringent monitoring and possible reformulation to reduce cadmium content in lipstick products.

At 50% Bio-accessibility, in branded beauty cream, Pb (3.45E + 01), Cd (2.23E + 00), Co (2.14E + 00), Ni (5.61E-03), As (1.15E + 00), and Hg (7.57E-03) show MoS values far below 100, indicating potential health concerns, particularly for Cd, Ni, and Hg due to their high toxicity even at trace levels. The values of Cu (1.20E + 01) and Mn (9.28E + 00) also fall below the safety threshold, suggesting moderate risk. Similarly, Zn (2.41E + 01) shows slightly higher safety but is still insufficient. Overall, none of the elements in the branded cream reach the safe MoS margin of 100. In local cream, Pb (1.52E + 02) and Cu (1.11E + 02) are the only two metals that exceed the proposed minimum MoS threshold value of 100, set by WHO[57], indicating adequate safety. Other elements, including Cd (6.60E + 00), Co (1.85E + 01), Ni (3.86E-02), Mn (3.57E + 01), Hg (1.07E-03), and Zn (3.51E + 00), fall below the acceptable limit (100) set by WHO[57]. As (2.31E + 00) was also detected and far below the MoS margin, this is unfavourable and has health concerns.

At 100% Bio-accessibility in branded cream, the MoS values increase slightly due to recalculated exposure, Pb (6.90E + 01), and Cu (2.41E + 01) still fail to meet the MoS > 100 threshold. Other metals, including Cd (4.46E + 00), Co (4.29E + 00), Ni (1.12E-02), Mn (1.86E + 01), Zn (1.09E + 01), and Hg (1.30E-02), remain well below the safe margin. Overall, none of the metals in the branded cream meet regulatory safety levels at 100% exposure either. Local cream Pb (3.04E + 02) and Cu (2.22E + 02) continue to exceed MoS > 100, affirming safer use. Cd (1.32E + 01), Co (3.70E + 01), Ni (7.71E-02), and Mn (7.13E + 01) show improvement but still do not reach the acceptable MoS. Hg (2.14E-03) remains extremely low. Notably, zinc levels are elevated, and arsenic is also present in higher concentration (1.15 E + 01).

The derived MoS values for Pb, Cd, Cu, Co, Ag, Ni, Zn, As, Mn, and Hg in both branded and local lipsticks at 50% bioaccessibility show marked variation across metal type and product origin. For branded lipsticks, MoS values for most metals, including Pb and Ni, either meet or considerably exceed the WHO-recommended minimum of 100, with the notable exception of Ag and Mn values, which are significantly below this threshold. Local lipsticks, conversely, exhibit higher MoS for Pb (826.772) but notably lower MoS for Cd (5.981), Cu (7.194), and Co (13.514), all falling short of the minimum acceptable margin and indicating a heightened concern for these metals in local formulations. Both products show undetectable values for As and Hg, which is consistent with a favourable risk profile for these particular elements in the branded samples. At 100% bioaccessibility, the MoS for branded nail polishes remains moderate for Pb (1.12E + 01) and Cu (3.48E + 02), with Ag (1.01E + 02) just at the safety cut-off, while Co and Ni maintain values well above the benchmark, suggesting comparatively reduced risk from these metals in branded products. Local nail polishes, on the other hand, display relatively lower MoS values across most metals, including Pb (1.20E + 01) and Co (1.44E + 01), underscoring a potential safety deficit for these locally manufactured items. Notably, values for As and Hg are again absent, supporting the low exposure likelihood for these elements within this subset.

In comparison with literature values reported by Ullah et al., 2023 , where the MoS ranges for Pb, Cd, Cu, Co, Ag, Ni, and Mn extend from as high as 7.5E + 12 to as low as 1.5E + 06 across different cosmetic categories. The MoS values established in the present study are lower by several orders of magnitude for nearly all studied metals, particularly in local products. These observations highlight a tangible disparity between current findings and earlier published data, signalling either enhanced levels of metal contamination in locally produced cosmetics or differences in underlying assessment parameters. Such discrepancies call for heightened vigilance in exposure assessment and reflect the need for strict quality control in the cosmetic sector, particularly in unregulated local markets.

The HQ and HI values of the cosmetic products at 100% bio-accessibility (Table S6) indicated that HQ and HI values for several cosmetic products particularly beauty creams (both branded and local) were markedly elevated and, in nearly all cases, far exceed unity (1) for multiple metals, including Cd, Co, Ni, Zn, As, Mn, and Hg. For instance, branded beauty cream displays extremely high HQs at 100% bioavailability for Ni (1.05E + 01), As (7.26 E + 00), Cd (2.54E + 01), and Hg (2.08 E + 03), and a cumulative HI of 2.15 E + 03, all of which signal a pronounced health risk through cosmetic use. Similar trends were observed for local beauty creams with cumulative and nail polishes, with local nail polishes showing high HQs for Cd (8.37E + 00), Cu (6.96E + 00), and Mn (6.51E + 00), and substantial HI values (2.82E + 01). In contrast, HQ and HI values for lipsticks, both branded and local, are generally low HQ (HQ < 1), except for isolated cases like Cd in local lipsticks (HQ 1.75E + 01), suggesting most lipstick samples fall within a safer exposure margin.

Lifetime cancer risk (LCR)

Lead (Pb), arsenic (As), as well as cadmium (Cd), nickel (Ni), and mercury (Hg) are classified as probable carcinogens declared by the International Agency for Research on Cancer (IARC, 2012)[63]. The presence of Pb and AS even at low levels poses a potential lifetime cancer risk, particularly due to their cumulative toxicity and long biological half-lives[64–66]. The primary routes for HM entry into the human body are ingestion and dermal absorption. Due to their non-biodegradable nature, these metals tend to accumulate in the body over extended periods. This accumulation disrupts cellular functions and interferes with intracellular mechanisms[26]. Consequently, such contaminants contribute to increased cancer risk by inducing oxidative stress, damaging DNA, and causing cell death[2,3]. Lifetime Cancer Risk (LCR) estimates the potential cancer risk associated with exposure to HMs found in cosmetic products. According to USEPA guidelines, the acceptable LCR range is between 1E-6 $\times 10^{-6}$ and 1E-4[26]. In this study, as shown in Table S7, the LCR was calculated for carcinogenic metals (Pb, Cd, Ni, As, and Hg) at 50% and 100% bioaccessibility levels (Fig. 12). Among the analysed HMs, the estimated lifetime cancer risk exceeded the permissible limit for most cosmetic products, indicating a possible cancer risk with continued use, except for lipsticks. The comparatively lower risk associated with lipsticks is likely due to their application over a smaller area and in smaller quantities. Nevertheless, the elevated risk highlighted here is concerning, as prolonged use of these products could increase cancer incidence among consumers. Previous studies have reported LCR values below 10^{-6} for various facial cosmetic products, including lipsticks[66].

Conclusion

Overall, elevated concentrations of heavy metals in beauty cream formulation were predominantly detected in the following decreasing order: Hg > Zn > Co > Ni > Pb > Cu > As > Cd > Ag > Mn, whereas Pb, Cd, Co, and Ni reached maximal levels in various brands of lipsticks and nail polishes, respectively. The calculated systemic exposure dosage (SED) values for all branded and local cosmetic products ranged from 2.27E-06 to 2.41E + 01 mg $kg^{-1} \cdot day^{-1}$, with cadmium (Cd), nickel (Ni), mercury (Hg), and manganese (Mn) exhibiting notably elevated exposures, while other metals generally remained within permissible safety limits. Correspondingly, the Margin of Safety (MoS) values ranged broadly from 7.71E-02 to 3.73E + 05, where lead (Pb) and cobalt (Co) typically demonstrated higher safety margins, whereas Cd, Ni, Mn, and Hg consistently fell below the recommended MoS threshold of 100, indicating potential health risks. Overall, branded cosmetics manifested relatively safer profiles compared to local formulations, which showed reduced safety margins for several metals. Further risk assessment using Hazard Quotient (HQ) and Hazard Index (HI) at 100% bio-accessibility were significantly elevated in beauty creams and local nail polishes, with cadmium (Cd), nickel (Ni), arsenic (As), manganese (Mn), and mercury (Hg) contributing most substantially to the health risk, whereas lipsticks generally exhibited HQ values below 1, except for cadmium in local samples, indicating comparatively lower exposure risk. Multivariate analysis demonstrated a strong correlation among Pb, Cu, Ni, Ag, Hg, and Cd, alongside a noticeable divergence for Cd and Cu, Co, Ag, Ni, and Mn, signifying convergent and divergent pathways of contamination across different cosmetic matrices. Regarding carcinogenicity, LCR values surpassed the established threshold in all cosmetic products with the exception of lipsticks. This study highlights the significant presence of heavy metals in various cosmetic products available in District Sudhnoti, Azad Jammu and Kashmir, with lead and cadmium showing particularly high concentrations in lipsticks and beauty creams. Nail polishes generally exhibited lower metal levels. Both imported cosmetics, especially those with counterfeit labels, and locally produced items were found to contain concerning amounts of heavy metals. Although the concentrations measured were mostly within regulatory limits, the potential for bioaccumulation through repeated dermal exposure raises serious health concerns, including an increased risk of skin cancer and other chronic diseases. This upsurge in heavy metal content within cosmetic products can largely be traced to the origin and composition of raw materials, manufacturing methodologies, storage conditions, and transportation practices. Therefore, it is essential to implement stricter regulatory standards and ensure rigorous quality control to limit heavy metal contamination in cosmetics. Additionally, continuous monitoring and surveillance programs are needed to safeguard consumer health. Further research should focus on identifying the specific chemical forms of these metals in cosmetic products and assessing their toxicological impacts to better understand the risks associated with their use. This information can assist manufacturers and consumers in making informed decisions about cosmetic safety.

Data availability
All data related to this work have been provided in the manuscript.

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Author contributions
H.B and H.U. authored the project and designed the study; H.U. planned and supervised experimental work, which was done by H.B.; S.A. and T.U. contributed to the study design and discussed the data; A.B.M.I., M.K.,

and M.A.H. performed the statistical analysis; Z.G. B. I., S.A.U. revised the data; H.U. wrote the original draft of the paper; all authors contributed to the manuscript's final form and approved the version to be submitted. H.U–90%, H.B.–10%.

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Declarations

Competing interests
The authors declare no competing interests.

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