iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: V Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.83076

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Heavy Metals in Cosmetics

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Abstract: This analysis examines five heavy metals that are frequently present in cosmetics, exposing a knowledge gap between manufacturers and regulations governing permissible metal concentrations. Cadmium functions as both a colorant and a pollutant, whereas lead and arsenic are recognized as contaminants. Notably, compared to other products, lipsticks, eye shadows, face paints, makeup foundations, and skin-lightening lotions show higher quantities of heavy metals. The results demand that producers and regulators regularly check for these elements in cosmetics. Despite being rare, significant quantities of mercury have been identified in skin-lightening treatments. To investigate the connections between the five metals and find variations among sixteen categories of skin care and cosmetic formulations, a multi-variate meta-analysis was carried out.
Keywords: arsenic, lead, cadmium, nickel, mercury, metallokinetics, metallodynamics

I. INTRODUCTION

A cosmetic product is one that is meant to be applied superficially to improve look without changing the physiological processes of the body. Cosmetics have been used since ancient times, and their formulation and manufacturing techniques have changed dramatically throughout time, moving from small-scale to large-scale industrial production [3]. In the past, natural components made up the majority of cosmetics, but the usage of petrochemicals has significantly increased. Organic formulations have recently become more popular due to customer demand for more natural ingredients [5]. Regulatory scrutiny has resulted from the expansion of varied cosmetic goods, which have created health and safety concerns. Regulations in the European Union, for example, emphasize that cosmetics should not be used for medical treatment or diagnosis and separate cosmetics from topical medications [10,11]. Cosmetics are not thoroughly tested before being released into the market, unlike pharmaceuticals, yet makers are nonetheless responsible for the goods' safety. Cosmetic formulas have limited limitations for some dangerous components, especially heavy metals, which reflects persistent worries about possible contamination even in "natural" goods [14]. For instance, different health organizations, such as the FDA and WHO, have established permissible criteria for some metals, such lead, cadmium, and mercury, or they are completely prohibited. However, regional variations cause regulatory confusion [9,11]. Cosmetics are now widely used and an essential component of contemporary beauty regimens [5]. However, the concealed existence of heavy metals in cosmetics and their possible harmful effects on skin health have raised increasing worries [1]. Lead, mercury, cadmium, arsenic, chromium, nickel, and other heavy metals can be purposefully added to cosmetic compositions or contaminated during manufacturing [12,13]. This article examines the ways in which extended exposure to these harmful substances can cause skin irritation, allergic reactions, skin barrier disruption, early aging, hyperpigmentation, and even systemic toxicity as a result of bioaccumulation [14]. These dangerous compounds continue to exist in a variety of cosmetic products despite current regulatory limits due to loopholes in safety standards and insufficient quality control [16]. In order to reduce the risk of heavy metal exposure and safeguard skin health, the article highlights the significance of consumer awareness, safe cosmetic options, and stricter regulatory procedures. Assessing the frequency of heavy metals in cosmetics and comprehending their effects on human health are the goals of the continuing research. Cosmetics are intended to improve, nourish, and beautify our look [18,19]. However, what happens if the very items that are supposed to protect and perfect your skin can pose invisible risks? Many cosmetic products may contain dangerous heavy metals hidden behind their seductive hues, smooth textures, and seductive scents. These silent invaders can affect your skin as well as your general health [20].

II. HEAVY METALS

Lead, cadmium, nickel, mercury, and arsenic are examples of heavy metals, which are distinguished by their metallic characteristics and abundance in the d and p-blocks of the periodic table. Because of their pervasiveness in a variety of settings, including both living and non-living matrices, these metals are cause for concern [22]. Heavy metals can interfere with the way helpful metals operate in biological systems, which may have negative physiological impacts on people, mammals, insects, and other creatures as well as plants. The frequent use of cosmetic goods that may include these dangerous elements, like lipsticks, eye shadows, and face powders, is a major source of heavy metal accumulation in living organisms [11,17].

III. METALLOKINETICS AND METALLODYNAMICS WITHIN THE BODY

The body's processes for absorbing, distributing, metabolizing, excreting, and interacting with heavy metals are intricate, especially when it comes to their existence in cosmetics. Heavy metal dynamics are impacted by the different application durations of cosmetic products [16]. Heavy metals can have both local (such as allergic contact dermatitis) and systemic effects after entering the body primarily by topical or dermal application [17]. Even after quitting use, local buildup might result in metal reservoirs that cause long-term exposure [18]. Nickel is one of the metals that can pierce epidermal layers and enter the bloodstream, frequently in combination with other metals that cause harm [19]. Hand-to-mouth transfer or lip products can potentially result in oral intake [20]. According to research, users' blood and organs have higher levels of heavy metals than those of non-users, with porous facial skin enabling more significant absorption [23]. Heavy metals have the ability to attach to proteins and nucleic acids, interfering with vital biological processes and perhaps causing cancer. The review focuses on the harmful effects of lead, cadmium, nickel, mercury, and arsenic at the cellular and molecular levels, highlighting these elements as major and sometimes overlooked dangers in cosmetic items [24].

IV. THE PRESENCE OF TYPICAL HEAVY METALS IN COSMETICS AND THEIR EFFECTS

A. Lead

Lead is a major environmental pollutant that has been shown to have negative effects on human health, including neurotoxicity, nephrotoxicity, and hepatotoxicity, as well as affects on fetal development and reproduction [21]. Lead exposure can be caused by industrial emissions, vehicle emissions, paint and pesticide chemicals, and contaminated food [22]. The European Union forbids lead and its salts in cosmetics completely, whereas the FDA and the World Health Organization set restrictions of 10 parts per million in cosmetic items [23]. Lead content in cosmetics, especially lipsticks, has been extensively investigated, according to research, and the results show a range of lead concentration, some of which exceeds allowed limits [24]. Although most results are inside the FDA's 20 ppm guideline, studies show notable lead levels in lipsticks ranging from 73.1 to 3760 ppm [26]. While eyebrow pencils and mascaras usually stay under the limit, eyeshadows exhibit varying levels of lead, with some cases above regulatory limitations [27,28]. In general, the continuous investigation of lead in cosmetics highlights the significance of oversight and control to safeguard consumer health [28].

B. Cadmium

Despite its modest absorption rate (0.5%), cadmium, a metal used in cosmetics for its colorful salts, has caused health concerns because of certain toxicities associated with topical use [29]. It mainly affects the human skeletal, reproductive, metabolic, respiratory, and renal systems; it is linked to lung cancer, osteoporosis, diabetes, and kidney damage [30,31]. In human tissues, cadmium can build up and cause oxidative stress that ages the skin and has systemic effects [25]. The WHO has set a tolerable limit for cadmium in cosmetics at 0.3 ppm, while the EU forbids its use completely, despite the fact that it can be found in a variety of sources, including industrial waste and agrochemicals [27]. Cadmium levels in goods vary, according to reports; some lipsticks contain levels as high as 60.20 parts per million, while others have levels that are undetectable [28]. Comparative research indicates that cheaper lipsticks had greater levels of cadmium (0.89 ppm) than more expensive ones (0.34 ppm). Although some greatly exceed, eye shadows often report levels below 3 ppm [29,30]. Other cosmetics, such mascaras and eyebrow pencils, usually include modest quantities of cadmium—up to 0.034 ppm and 1.12 ppm, respectively [31]. Shampoos and hair dyes have very little cadmium, whereas face paints have an average of 0.6 ppm. Cadmium levels are also kept low by the majority of toothpastes and body cosmetics. As a result, the presence of cadmium in cosmetics is frequently perceived as a contaminant rather than a purposeful component [28].

C. Nickel

Many natural substances in cosmetic goods contain nickel, a metal contaminant that can cause allergic responses and even cancer. Because of the possibility of nickel-induced skin sensitization and oxidative stress, which can cause skin aging and respiratory problems, its presence, especially in topical cosmetics like lipsticks and eye creams, raises concerns [14]. Metallic nickel and its derivatives have been designated as possible carcinogens by the IARC. Although many "nickel-free" goods contain less than 1 ppm, proposed limits for nickel in cosmetic items suggest a tolerable threshold of 0.20 ppm [15]. According to studies, the nickel level of lipsticks varies from 1.61 to 22.8 ppm, and continuous use poses a risk to consumers [16,19]. According to research, toothpaste also contains nickel in concentrations ranging from 0.02 to 18.535 parts per million. Numerous studies have examined eye cosmetics for exceeding the 1 ppm safety threshold, with differing findings [20]. Generally speaking, hair products have lower nickel levels, which is less concerning [21]. In general, many cosmetics exhibit nickel levels that warrant additional research in light of safety guidelines put forward by the FDA and other organizations, despite the existence of regulation restrictions [22,23].

D. Mercury

Both inorganic and organic molecules contain mercury, a heavy metal that is often used in cosmetic formulas [1,2]. While organic forms like phenyl mercuric and ethyl mercuric salts function as preservatives in cosmetics like mascara and eye makeup removers, inorganic forms like ammoniated mercury are used to lighten skin [2]. Mercury is added to skin-lightening lotions because, when applied topically, it can collect and obstruct the tyrosinase enzyme, preventing the synthesis of melanin [4]. Mercury exposure can have a number of detrimental impacts on the body, such as gastrointestinal distress, changes to the central nervous system, and even death [6,7]. Studies have shown that compared to non-users, cosmetic users had much higher levels of mercury in their hair, blood, and urine [10]. The FDA and other regulatory agencies limit the amount of mercury that can be present in cosmetics to a maximum of 1 ppm [11]. On the other hand, phenyl mercuric salts are only allowed in eye care products at a maximum of 70 parts per million, whereas mercury and its compounds are completely prohibited in cosmetics by the European Union [9]. Health Canada permits up to 1 ppm in accordance with the FDA [13,15]. Numerous studies that concentrate on skin-lightening products frequently find mercury levels that are higher above the safety threshold of 3 ppm, with some products showing levels as high as 126,000 ppm [16]. Other types of cosmetics have different concentrations of mercury, such as small amounts in sunblocks and face creams, and some toothpaste and hair products also have measurable levels of mercury [17]. Overall, mercury is nevertheless common in skin-lightening formulas even though it is one of the least common heavy metals found in cosmetics [18].

E. Arsenic

Sulfydryl groups in proteins are the main target of arsenic, a common environmental pollutant that may deplete glutathione, an essential antioxidant. Long-term exposure can lead to vascular disorders, skin problems, and cancer [9]. Despite being a tiny contaminant in cosmetics compared to other heavy metals, regulatory agencies have imposed restrictions on its presence because of health concerns; the FDA permits lead acetate colorants to contain up to 3 parts per million [18,19]. Arsenic and its salts are completely prohibited in cosmetics in the EU. Kohl presents serious concerns with concentrations as high as 1630 ppm, even though the majority of cosmetic items have arsenic levels below this threshold [20]. Concerns regarding long-term use have also been raised by other items that have been found to exceed permitted levels, such as several toothpastes and skin-lightening lotions [21]. Overall, even though arsenic is rarely detected in cosmetics, its existence—particularly in unapproved products—remains concerning [23].

Toxic Metal	**Organ Toxicity**	**Disrupted macromolecules/ Mechanism of action**
Mercury (Hg)	- CNS injuries - Renal dysfuntion - GI ulceration	- Thiol binding (GHS conjugation) - Enzymes inhibition - ROS production
Lead (Pb)	- CNS injury - Lungs dysfunction - hematological changes (Anemia) - GI colic - Liver damage - Reduced pulmonary function - Cardiovascular dysfunction	- Increased inflammatory cytokines - Inhibition of heme biosynthesis
Cadmium (cd)	- Degenerative bone disease - Kidney dysfuntion - Liver damage - GI disorder	- m-RNA EXPRESSION DYSREGULATION - APOPTOSIS

	- Lungs injury - Disorder in the metabolism of Zn and Cu - Cancer	- ENDOPLASMIC RETICULUM STRESS - Dysregulation Of Ca, Zn and Fe homeostasis - Low serum PTH
Arsenic (AS)	- Cardiovascular Dysfunction - Skin and hair changes - CNS injury - GI discomfort - Liver damage	- Damaged capillary endothelium - inhibition of ATP formation alteration in - neurotransmitter homeostasis
Nickel (Ni)	- liver damage - CNS injury - Kidney dysfunction cancer -	- Oxidative stress - Nickel is neurotoxic and - accumulated in the brain Nasal and lungs cancer

Table no. 1: toxic metal its action on organ

V. HEALTH RISK ASSESSMENT

A. *Margin of safety (MoS)*

The Margin of Safety (MoS), which is determined by dividing the No Observed Adverse Effect Level (NOAEL) of the product under study by its systemic exposure dosage (SED) as previously reported, can be used to calculate the health risk to humans resulting from exposure to heavy metal impurities present in cosmetics (SCCS, 2012).MOS = NOAEL/SED (1), where SED is the systemic exposure dosage [µg/kg BW·day−1] and NOAEL is the no observed adverse effect threshold[19].

The amount of substances that enter the human body through different exposure methods is predicted by the SED. It is determined by taking into account the average body weight, the amount of the product applied daily, the frequency of application, the metal concentration in the product under investigation, and the surface area of the skin on which the product is applied (SCCS, 2012). An expression was used to determine the SED value:

SED (mg/kg/d) = Cs × AA × SSA ×F× RF ×BF / BW (2), where Cs is the sample's metal concentration [mg/kg] and AA is the amount applied [g/cm2]. Calculations were performed using the following values [g/cm2]: 0.057 (lipsticks), 0.51 (foundations, creams, masks), and 0.02 (eye shadows, blushes)56[20].

SSA is the skin's surface area [cm2] that the product is applied to. Calculations were performed using the following values: 4.8 for lipsticks, 563 for foundations, creams, and masks, 24 for eye shadows, and 24 for blushes40[21,22].

RF, or retention factor, is 1 for leave-on products and 0.1 for masks; F, or application frequency of a product/day, is 2 for foundations, creams, eye shadows, and blushes and 1 for masks; BF, or bioavailability factor, is 50, 100%, 10–3, or unit conversion factor; BW, or average body weight, is 60 [kg] for all computations [24].

According to (, 2006), NOAEL is a level of exposure at which no negative effects are seen. Its value was determined using dermal reference doses (RfDs) and the following expression:NOAEL = RfD × UF × MF (3) where: RfD – reference dose [µg/kg per day], UF – uncertainty factor, the value used was 100, MF – modifying factor, the value adopted was 1[25].

The RfD values for each element were as follows [mg/kg per day]: Fe 70, Mn 14, Ni 2, Zn 30, Cr3+ 1.5, and Cr6+ 0.3.

where MF is the modifying factor (based on scientific opinion) and UF is the uncertainty factor (reflects overall confidence in the various data sets). MF and UF have default values of 1 and 100, respectively. RfDs stands for dermal reference doses of various metals (µg kg−1d−1). The cutaneous reference doses for Cd, Cr, Fe, Ni, and Pb are 0.005, 0.015, 140, 5.4, and 0.42 µg/kg/d, according to the USA risk-based concentration table [26,27].

The World Health Organization (WHO) states that products with MoS values above 100 are deemed safe for use, while those with values up to 100 are acceptable. The Scientific Committee on Consumer Safety (SCCS) acknowledges that in many traditional MoS calculations, oral bioavailability of an element is taken to be 100% in the absence of oral absorption evidence. Table S2 lists the standard skin surface area (SSA) and amount applied (AA) values for cosmetic products set by SCCS. Nonetheless, it is deemed appropriate to presume that no more than 50% of a dose taken orally is systemically available (SCCS, 2012) [28,29}.

B. Hazardous quotient (HQ) and hazard index (HI)

The ratio of a substance's systemic exposure dosage (SED) to each metal's dermal reference dose (RfD) is known as the hazard quotient (HQ). A HQ value of less than one is regarded as safe, however a number larger than one is dangerous for human health. The following formula was used to determine the HQ level:

HQ = SED/RfD (4)

where:

The reference dose, or RfD, is an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to have no appreciable risk of harmful consequences over the course of a lifetime, with an uncertainty of maybe an order of magnitude [22].

The total of the danger quotients for every metal under investigation is the hazard index (HI). It is calculated to assess the danger to human health posed by exposure to all metallic contaminants. As previously reported, the HI value was computed using the following formula: HI = summation of HQ = HQcd + HQcr + HQni + HQfe + HQpd (5) [23,24].

C. Lifetime Cancer Risk (LCR)

For carcinogenic metals, lifetime cancer risk is typically examined. The following relationship was used in the current study to calculate LCR: LCR is equal to SED × SF (6), where SED is the systemic exposure dosage [µg/kg BW·day−1] and CSF is the coefficient of the slope of carcinogenicity for Cr 0.5 and Ni 0.91 [mg/kg day−1]15[17,20].

The US EPA45,53 permits a cancer risk range of 1·10−6–1·10−4 for regulation purposes.

Using equation VII and the pertinent long-term daily systemic exposure dose, we also determined the lifetime cancer risk:

LCR = SED / HT 25/0.25 (7), where T25 is the dose that induced cancer in 25% of the animals studied, and HT25 is the human equivalent animal dose (T25) [mg/kg/day] [19,21].

For Cr6+ and Ni, the accepted T25 levels were 0.04 and 0.047 mg/kg daily, respectively. The ratio of T25 and human body weight to animal body weight is called HT25[24]. The calculations used an animal (mouse) body weight of 0.025 kg and a human body weight of 60 kg. For human health, HT25 should be less than 1·10−6[25,26].

VI. REGULATIONS FOR COSMETICS INDIA

The Drugs AND Cosmetics Act of 1940 and its 1945 Rules control cosmetics in India, and the Bureau of Indian Standards (BIS) sets standards [13]. The Indian Standards (IS) 6608:2004 and IS 9875:1990 standards for skin creams and lipstick are among the requirements set forth by BIS for cosmetics included in Schedule "S" of the Rules [14]. According to IS 6608:2004, completed goods do not need additional testing for arsenic and heavy metals if raw materials have undergone heavy metal testing and meet criteria [14]. In order to comply with Schedule Q of the Drugs and Cosmetics Act, dyes, colors, and pigments used in cosmetics must follow IS 4707 [15]. The use of cosmetics with pigments and colors that are not approved by BIS and Schedule Q is restricted by Rule 134 [16]. The maximum quantities of permitted synthetic and natural colors are 2 parts per million of arsenic (as arsenic trioxide), 20 parts per million of lead, and 100 parts per million of all other heavy metals that are considered generally safe (GRAS)[18,19]. The 1962 EEC directive specifies limit concentrations in final products as well as extra purity standards. Additionally, Rule 135 restricts the importation of cosmetics containing lead and arsenic compounds, and Rule 145 forbids the use of these compounds in cosmetics for coloring. Furthermore, the production and import of cosmetics containing mercury compounds are forbidden by Rules 145 D and 135 A[20,22].

VII. CONCENTRATIONS OF TOXIC METALS IN COSMETICS

Cosmetics that women frequently use have been linked to heavy metals (Popoola et al. 2013; Ramakant et al. 2014)[9,10]. Long-term dermal absorption of heavy metals can lead to a number of health issues. Table 5 summarizes the trace element contents in the fairness cream as determined by triplicate analysis [7,8]. The results show that the lead content ranged from 14.38 to 50.39 µg/g, with the C-coded [11]. The WHO states that the allowable limit for lead is 10 µg/g (Sukender et al. 2012), and it is found that the lead concentration in every sample is higher than that limit. Cadmium concentrations ranged from 2.40 to 6.27 µg/g in all the samples [12,14]. Cadmium concentrations are highest in sample A and lowest in sample C. Sadly, it was shown that every cosmetic product had cadmium concentrations over the WHO's acceptable limit of 0.3 µg/g (Sukender et al. 2012). Only sample D had chromium levels of 2.82 µg/g among the heavy metals; the other samples had levels below the detection limit, according to data in Table 5[15,16]. The EU states that 1 µg/g of chromium is acceptable (Umar and Caleb 2013). Sample D thus above the allowable limit [16].

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

The amounts of mercury ranged from 0.128 to 0.481 µg/g, with sample C having the highest value and sample B having the lowest. The WHO states that 1 µg/g of mercury is acceptable (Sukender et al. 2012) [18]. Therefore, it may be concluded that all of the samples have mercury levels below what is considered acceptable [19]. Additionally, Health Canada states that the metal concentrations of lead, cadmium, and chromium were under the allowable limit [20]. According to Table 5, the heavy metal concentrations in the cosmetics examined in this study are generally in the following order: Pb > Cd > Cr > Hg, with mean amounts of 28.85 µg/g, 3.23 µg/g, 0.47 µg/g, and 0.25 µg/g, respectively. The recovery study findings were within the allowed range, confirming the validity of the suggested approach for analysis (Table 6) and showing that the suggested method could properly assess any slight change in the drug concentration in the solution [22,23].

VIII. HOW TO PROTECT YOUR SKIN FROM HIDDEN DANGERS

1) Select Trusted Brands: Look for respectable cosmetic companies that carry out thorough safety testing and reveal the source of their ingredients. Seek certifications such as "Heavy Metal Tested" or "Certified Safe Cosmetics" [8].
2) Steer clear of fake goods: When buying skincare and makeup from unlicensed vendors or unfamiliar websites, exercise caution as contaminated and fake goods are more likely to be found there [9].
3) Choose Clean, Natural Beauty Products: In order to reduce the possibility of heavy metal contamination, companies dedicated to clean beauty frequently utilize natural colors and ingredients that have undergone purity testing [10].
4) Conduct Patch Tests: Before using a new product, always do a patch test to check for sensitivity or allergic responses [11].
5) Promote Safer Laws: Encourage companies and groups that advocate for more stringent safety regulations for cosmetics and open labeling [12].

IX. IMPLICATION OF THE CALCULATED CHRONIC DAILY INTAKE AND NON-CARCINOGENIC RISK

A. Chronic Daily Intake

Humans' daily consumption of heavy metals determines how dangerous they are (Ullah et al. 2018). The mean concentration of each of the four metals—lead, cadmium, chromium, and mercury—was used to determine the chronic daily intake (CDI)[17,18]. Table 7 displays the maximum tolerated daily intake (MTDI) and CDI for the metals under study. Lead, cadmium, chromium, and mercury total daily intake was determined to be 4.05E−07, 4.54E−08, 6.61E−09, and 3.49E−09 mg/day, respectively. Every metal's daily intake is lower than the MTDI. The mean CDI values in the cosmetics samples decline in the following order: Pb > Cd > Cr > Hg [20,23].

B. =Non-carcinogenic risk

HQ, or the ratio of a pollutant's measured dosage to a reference dose level, is used to evaluate the health hazards associated with populations using contaminated cosmetics [24]. The exposed population will probably suffer a negative impact if HQ > 1 (Ullah et al. 2017b). Table 8 lists the HQ of the four metals under study for each sample [28,29]. The table shows that the HQ of all the metals obtained for all the beauty cream samples is less than 1, suggesting that dermal adsorption of the examined beauty creams would not pose a serious health danger to Bangladeshi citizens. The cumulative non-carcinogenic effects of several components are expressed by the HI value. HI was less than 1 (Table 8) for the use of the chosen cream, suggesting that consumers are safer [30,31].

X. GENERAL CONSIDERATIONS

The significance of particular metals as pollutants and additives in cosmetic goods is highlighted by the research covered in the preceding sections [1]. Spearman correlation and Principal Component Analysis were used in a multi-variate meta-analysis that considered the maximum levels attained for the various cosmetic formulations in order to identify any specific links between formulations [2,3]. All five metals have a link (r > 0.466) according to Pearson correlation statistics . Together, two latent variables with eigenvalues larger than 1 accounted for 80.54% of the variance [6,7]. The various sets of variables were shown by the factor loadings (Figure 1). Pb, Cd, Ni, and As with lipsticks, eye shadows, face paints, makeup foundation, and skin were all substantially influenced by Factor 1, which was shown on the horizontal axis. high concentrations of these metals in lightning creams [8,9]. These formulas differed significantly from the others [10]. However, skin-lightening creams had higher concentrations of mercury than the other formulations, and F2, which is seen on the vertical axis, weighed heavily on mercury [12]. The results of earlier research are combined in this multivariate study. The findings of such research works are at the disposition of authorities and policy makers for the formulation of high-quality cosmetic products [14].

XI. CONCLUSION

In this investigation, different brands of creams, lipsticks, and lip glosses were tested for arsenic, cadmium, lead, mercury, and nickel [5]. The findings showed that the hazardous elements were present in trace amounts [6]. However, it is thought that long-term use of cosmetics tainted with heavy metals could result in the gradual release of these metals into the human body and have negative consequences for the users [7]. Until the issue is sufficiently resolved, widespread usage of such items should be avoided. The overall findings of the health risk assessment and total concentration show that consumers in Botswana are at risk from imported cosmetics [10]. To guarantee that metal concentrations in facial cosmetics do not surpass legal limits, quality control procedures must to be implemented [11].

XII. ACKNOWLEDGMENT

I would like to express my sincere gratitude to my guide, for their invaluable guidance, constant encouragement, and insightful suggestions throughout this project on "Heavy metal awareness in colour cosmetics: Lead and Mercury in lipstick".

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