

Metals in cosmetics: implications for human health

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ABSTRACT: Cosmetics, preparations repeatedly applied directly to the human skin, mucous membranes, hair and nails, should be safe for health, however, recently there has been increasing concern about their safety. Unfortunately, using these products in some cases is related to the occurrence of unfavourable effects resulting from intentional or the accidental presence of chemical substances, including toxic metals. Heavy metals such as lead, mercury, cadmium, arsenic and nickel, as well as aluminium, classified as a light metal, are detected in various types of cosmetics (colour cosmetics, face and body care products, hair cosmetics, herbal cosmetics, etc.). In addition, necessary, but harmful when they occur in excessive amounts, elements such as copper, iron, chromium and cobalt are also present in cosmetic products. Metals occurring in cosmetics may undergo retention and act directly in the skin or be absorbed through the skin into the blood, accumulate in the body and exert toxic effects in various organs. Some cases of topical (mainly allergic contact dermatitis) and systemic effects owing to exposure to metals present in cosmetics have been reported. Literature data show that in commercially available cosmetics toxic metals may be present in amounts creating a danger to human health. Thus, the present review article focused on the problems related to the presence of heavy metals and aluminium in cosmetics, including their sources, concentrations and law regulations as well as danger for the health of these products users. Owing to the growing usage of cosmetics it is necessary to pay special attention to these problems. Copyright © 2015 John Wiley & Sons, Ltd.

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Keywords: heavy metals; aluminium; cosmetics; natural cosmetics; law regulations; metal nanoparticles; concentrations; toxic effects; topical action; systemic action

Introduction

Cosmetics have been commonly used by people all over the world since ancient times in order to clean, improve or change the appearance of the skin, hair, nails and teeth; however, recently a growing popularity of these products, especially natural preparations, has been observed. Cosmetic products include face and body care preparations (creams, lotions, deodorants, soaps, etc.), colour cosmetics (lipsticks, mascaras, eye shadows, nail polishes, etc.), and hair products (shampoos, colours, sprays, gels, etc.). Among them, natural products (henna, various cosmetics containing plant extracts and minerals) as well as preparations containing nanoparticles (especially UV filters) can be distinguished (Sin and Tsang, 2003; Jallad and Espada-Jallad, 2008; Abdel-Fattah and Pingitore, 2009; Atz and Pozebon, 2009; Corazza *et al.*, 2009; Mudholkar, 2012; Raj *et al.*, 2012; Sukender *et al.*, 2012; Ullah *et al.*, 2013; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014).

According to the European cosmetic law described by the Council Directive 93/35/EEC of 14 June 1993 amending for the sixth time Directive 76/768/EEC on the approximation of the laws of the Member States relating to cosmetic products 'a cosmetic product mean any substances or preparations intended to be placed in contact with the various external parts of the human body (...) or with the teeth and mucous membranes of the oral cavity (...) to cleaning them, perfuming them, changing their appearance and/or correcting body odours and/or protecting them or keeping them in good condition' (OJEC, 1993). By definition, all cosmetics permitted for use should be completely safe for users and the final responsibility for ensuring the safety of these

preparations lies with the manufacturers, distributors and importers (OJEU, 2009; Report for International Cooperation on Cosmetic Regulations, 2011).

Unfortunately, the use of cosmetics in some cases is related to the occurrence of unfavourable effects resulting from the presence of chemical substances in these preparations. It has been estimated that in a large number of currently available cosmetic products as many 10 000 chemical substances, including parabens, phthalates, *p*-phenylenediamine, formaldehyde, dioxane, triclosan and numerous metals, are present (Ullah *et al.*, 2013; Darbre and Harvey, 2014). The presence of chemical substances in cosmetics is connected with their intentional use as antioxidants, preservatives, emollients, surfactants, pigments, fragrances, UV absorbers, etc. Moreover, apart from the substances used intentionally, whose presence in cosmetics is allowed and in many countries strictly governed by the relevant legislation, other dangerous chemical substances of accidental origin may also be present in these products (Harada *et al.*, 2001; Lee *et al.*, 2008; Al-Saleh *et al.*, 2009; Oyediji *et al.*, 2011; Adepoju-Bello *et al.*, 2012; Volpe *et al.*, 2012; Khalid *et al.*, 2013; Orisakwe and Otaraku, 2013; Soares and Nascentes, 2013).

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One of the groups of dangerous substances present in cosmetics are heavy metals, including particularly toxic elements such as lead (Pb), cadmium (Cd), nickel (Ni), arsenic (As) and mercury (Hg). Apart from these toxic trace metals, elements such as chromium (Cr), iron (Fe), copper (Cu) and cobalt (Co) – necessary, but dangerous when they occur in excessive amounts – may also be present in cosmetics. In addition, some cosmetics contain aluminium (Al), classified as a light metal. Owing to the harmfulness of metals to human health, their content in cosmetic products is prohibited or restricted by the regulations of some countries, but in many countries there are no regulations in this regard (OJEU, 2009). The European Regulations describe over 1200 various toxic substances whose presence are prohibited in cosmetic products. Among them, there are metals particularly dangerous for human health such as Pb, Cd, As, Ni and Hg. Owing to the lack of uniform legislation regarding toxic metals presence in cosmetics all over the world and the possibility of accidental contamination of cosmetic products with these elements, they are detected in various types of currently commercially available cosmetics (colour cosmetics, face and body care products, hair cosmetics, herbal cosmetics, etc.), in some cases in dangerous concentrations (Amry *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013; Tang *et al.*, 2013). Although absorption of metals from cosmetics through the skin is rather low (Filon *et al.*, 2009), these elements may accumulate in the skin and internal organs, where they can exert toxic effects. Numerous cases of topical (mainly allergic contact dermatitis) and systemic effects caused by exposure to metals present in cosmetics have been reported (Warley *et al.*, 1968; Waldron, 1979; Shaltout *et al.*, 1981; Van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Chan *et al.*, 2001; Saxena *et al.*, 2001; Soo *et al.*, 2003; Guillard *et al.*, 2004; CDC, 2005, 2012a, 2012b; Foulds, 2006; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Li *et al.*, 2010; Amry *et al.*, 2011; Benz *et al.*, 2011; Chakera *et al.*, 2011; Travassos *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013).

Owing to the common pollution of the natural environment by metals in developed countries and their numerous industrial applications people are exposed to them during the lifetime via food, water or air as well as from occupational sources (Fig. 1; Hengstler

et al., 2003; Aguilar *et al.*, 2008; Cao *et al.*, 2010; Zhuang *et al.*, 2014). Herbal medicines and dental amalgams are other sources of exposure to toxic metals (Başgel and Erdemoğlu, 2006; Jallad and Espada-Jallad, 2008; Gasser *et al.*, 2009; Sukender *et al.*, 2012; Oliveira *et al.*, 2014). An important source of exposure to toxic metals is also cigarette smoking (Galazyn-Sidorczuk *et al.*, 2008; Ashraf, 2012). The repeated use of cosmetics containing toxic metals is an additional source of exposure to these elements (Fig. 1), and the available literature provides evidence that in some cases cosmetic preparations may be a source of excessive amounts of metals creating a danger for human health (Warley *et al.*, 1968; Chan *et al.*, 2001; Soo *et al.*, 2003; Guillard *et al.*, 2004; CDC, 2005, 2012a, 2013a; Özkaya *et al.*, 2009; Li *et al.*, 2010; Al-Dayel *et al.*, 2011; Benz *et al.*, 2011; Chakera *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013; Tang *et al.*, 2013).

Taking into account the growing use of cosmetics as well as the reports on the presence of dangerous metals in the cosmetic products currently available worldwide and the cases of unfavourable health effects due to their presence in cosmetics, it was warranted to pay special attention to problems related to metals occurrence in these products. Thus, the present paper focused on this matter including the sources, concentrations and allowed limits of metals content in various types of cosmetics, as well as the danger for human health caused by these elements. This paper is a critical review of worldwide literature concerning this issue and it draws attention to the fact that cosmetics usage may be an additional source of exposure to toxic metals, and that adverse effects sometimes noted after the application of cosmetics may be related to the presence of metals in these products. The harmfulness of heavy metals and Al for humans is well known and widely reported and numerous data show that these metals may create a risk for health even at low exposure (Guillard *et al.*, 2004; Gump *et al.*, 2011; Karagas *et al.*, 2012; Sommar *et al.*, 2013). However, until now no sufficient attention has been given to cosmetics as a potential source of exposure to metals. In order to underline that the health problems related to metals presence in cosmetics are still current, in this article we have presented all the contemporary cases of topical effects and poisonings caused by metals coming from cosmetics which we were able to find in scientific literature (Medline, Scopus, Elsevier, etc.) since the year 2000 up until now.

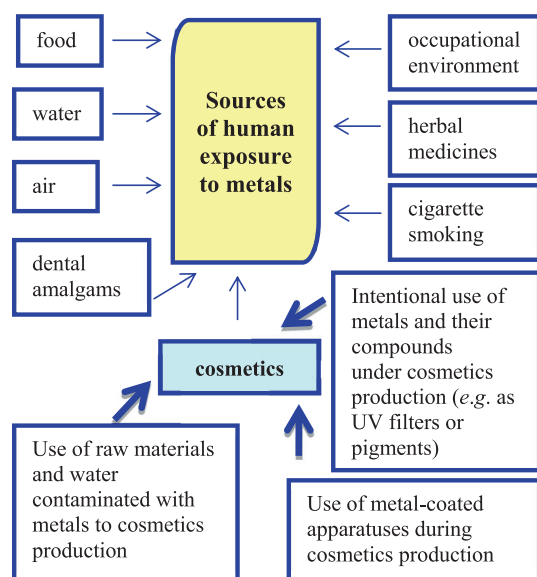


Figure 1. Cosmetics as an additional source of human exposure to metals.

Sources of Metals in Cosmetics

Data available in the literature show that toxic metals are present in various types of cosmetics at concentrations varying within relatively wide ranges from almost undetectable values to as high as 3.76 g Pb kg⁻¹ in lipsticks (Al-Saleh *et al.*, 2009) or sometimes even higher in body care products (790 g Pb kg⁻¹; CDC, 2005), 65.133 g Hg kg⁻¹ in skin-lightening creams (Chan *et al.*, 2001), 6.259 g Cd kg⁻¹ in kohl (Amry *et al.*, 2011) as well as 50.0 g Al kg⁻¹ (Al-Dayel *et al.*, 2011), 359.44 mg Ni kg⁻¹ (Omolaoye *et al.*, 2010) and 11.1 mg As kg⁻¹ in eye shadows (Atz and Pozebon, 2009). Metals present in cosmetic products may originate from various sources (Fig. 1). Using plants contaminated with metals in cosmetics production will result in the herbal products pollution (Başgel and Erdemoğlu, 2006; Jallad and Espada-Jallad, 2008; Gasser *et al.*, 2009; Sukender *et al.*, 2012). Available data show that herbs widely used in the cosmetic industry which grow in industrialized countries, are not infrequently excessively contaminated with metals (Baranowska *et al.*, 2002; Fijałek *et al.*, 2003; Başgel and Erdemoğlu, 2006; Arpadjan *et al.*, 2008; Gasser *et al.*, 2009; Tokalioğlu, 2012).

Compounds of some metals are used for purpose in the cosmetic industry, mainly as UV filters in face and body care products and pigments in coloured cosmetics. The law of the European Union (EU) allows the presence of various pigments in cosmetics in a wide range of colours: white (Al, barium sulphate, bismuth chloride oxide, calcium carbonate, calcium sulphate, magnesium carbonate, silver, 4% silver nitrate – only for colouring eyelashes and eyebrows, as well as titanium dioxide and zinc oxide – which are rather more popular as UV filters), green [chromium (III) oxide, chromium (III) hydroxide, cobalt aluminium oxide], brown (Cu, gold – Au) and iron oxides in colours such as orange, red, yellow and black (Fig. 2; OJEU, 2009). This law allows the use of 25% titanium dioxide as an UV filter and silver chloride (in the concentration of 0.004% in ready-to-use preparations) deposited on titanium dioxide as a preservative in cosmetic products (OJEU, 2009). The EU law does not allow the presence of other metals or their compounds which could be used as pigments owing to their colours, for example lead oxide (yellow or red) and lead dioxide (black; OJEU, 2009). As a result of using of metal-based pigments in colour cosmetics, metal concentrations (especially Pb, Cr, Fe) in preparations of this type are higher than in other cosmetic products (Al-Saleh *et al.*, 2009; Omolayo *et al.*, 2010; Al-Dayel *et al.*, 2011; Zakari *et al.*, 2014). Because Hg inactivates tyrosinase, being

the key melanin-forming enzyme (Hostynek, 2003), compounds of this metal are used on purpose in skin-lightening creams and thus the highest concentrations of this element are found in this type of cosmetics (Weldon *et al.*, 2000; Chan *et al.*, 2001; Soo *et al.*, 2003; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Li *et al.*, 2010; Benz *et al.*, 2011; Chakera *et al.*, 2011; CDC, 2012b; Dickenson *et al.*, 2013).

Another source of metals may also be derivatives of crude oil such as mineral oils, paraffin, silicones and aliphatic hydrocarbons used in the production of many cosmetic preparations. These ingredients by themselves are harmful to human health and in addition they may contain metals such as Cd, As, Cr and Cu (Stigter *et al.*, 2000).

Regulations on Metals Content in Cosmetics

Owing to metals harmfulness to human health, their use in cosmetic products is prohibited or restricted by regulations of many countries. However, it is important to underline that permissible concentrations of metals are individually specified by particular regulations and are different for various products and countries (MHLW, 2000; FDA, 2007, 2009, 2013, 2014; OJEU, 2009; HC-SC, 2012).

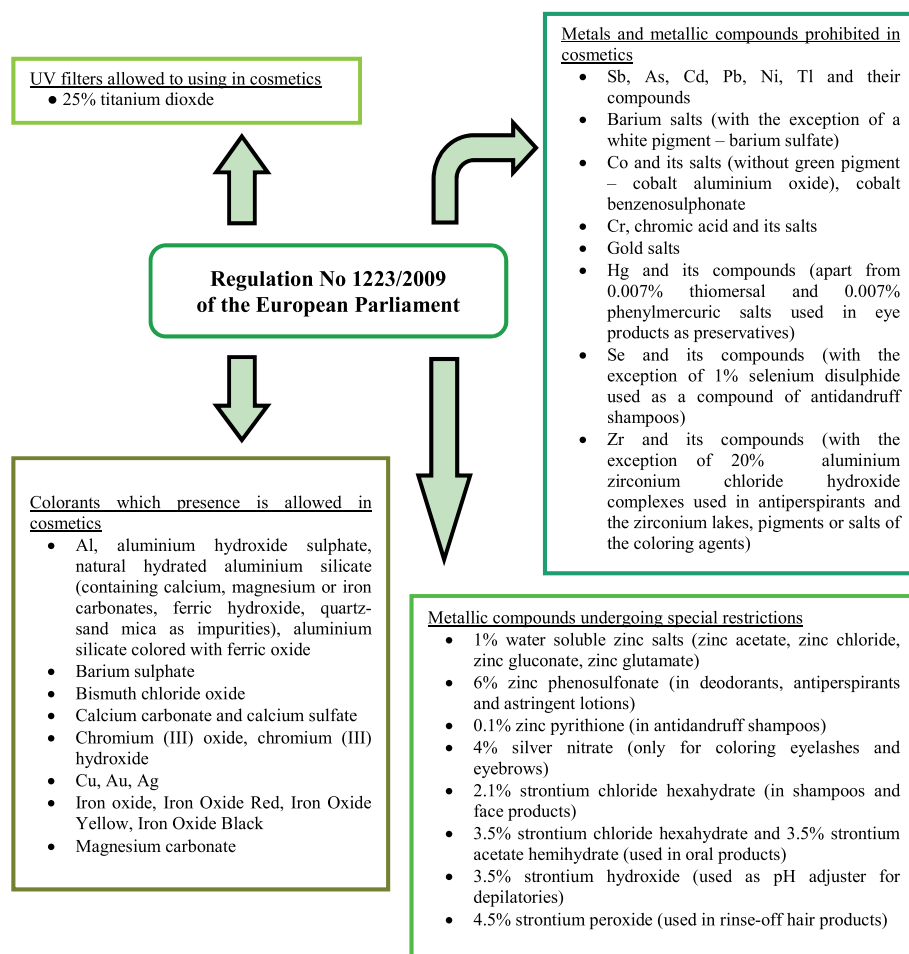


Figure 2. The Regulation No 1223/2009 of the European Parliament on metals and their compounds presence in cosmetics (OJEU, 2009). Ag, silver; Al, aluminium; As, arsenic; Au, gold; Cd, cadmium; Co, cobalt; Cr, chromium; Cu, copper; Hg, mercury; Ni, nickel; Sb, antimony; Se, selenium; Pb, lead; Tl, thallium; Zr, zirconium.

According to the Regulation No 1223/2009 of the European Parliament and the Council, the presence of cosmetic products of metals particularly dangerous for human health, such as Cd, Pb, As, Ni and Hg, is prohibited in the countries of the EU, with the exception of some Hg compounds only (Fig. 2; OJEU, 2009). Other metals such as zinc (Zn), silver (Ag), and strontium (Sr) are allowed with special restrictions (Fig. 2). According to this Regulation, aluminium zirconium chloride hydroxide complexes ($\text{Al}_x\text{Zr}(\text{OH})_y\text{Cl}_z$) and aluminium zirconium chloride hydroxide glycine complexes can be used in antiperspirants in a concentration of 20% as anhydrous aluminium zirconium chloride hydroxide and the antiperspirants containing aluminium complexes mentioned above cannot be applied to irritated or damaged skin (OJEU, 2009). In addition, Al and some of its compounds are allowed to be used as colourants in cosmetics (Fig. 2; OJEU, 2009). It is important to underline that according to the EU Regulation No 1223/2009 (article 17) small quantities of non-intended prohibited substances, including toxic metals, may be present in final cosmetic products as technically unavoidable contaminations if these preparations are safe for human health. Unfortunately, the safe levels of these technically unavoidable contaminations in cosmetics are not described.

In the USA, the Food and Drug Administration (FDA) has stated that lead acetate is safe for use in cosmetics that colour the hair and approved its use at the maximum content of 0.6% (w/v) Pb in the product (FDA, 2007, 2009). The FDA accepts the contamination of lead acetate used as a colour additive with As and Hg at levels up to 3 and 1 mg kg^{-1} , respectively (FDA, 2007). The FDA limit for Pb in colour additives is 20 mg kg^{-1} (FDA, 2014). The highest acceptable level of Hg (as unavoidable contamination) according to the FDA is 1 mg Hg kg^{-1} , but when Hg compounds are used on purpose as preservatives in cosmetics applied to the periocular area the acceptable limit is 65 mg Hg kg^{-1} (FDA, 2013). Health Canada has established the maximum acceptable limits of heavy metal concentrations in cosmetics at the following levels: Pb – 10 mg kg^{-1} , Hg – 3 mg kg^{-1} , Cd – 3 mg kg^{-1} , As – 3 mg kg^{-1} and antimony (Sb) – 5 mg kg^{-1} (HC-SC, 2012). In Japan, the use of Cd and its compounds, as well as Hg and its compounds in cosmetics, is prohibited (MHLW, 2000). Apart from the regulations in the EU, the USA and Canada, there are no precise regulations concerning limits of metals content in final cosmetic products in other countries. Although, in spite of the lack of appropriate regulations in some countries, there exist data on these elements concentrations in cosmetics produced and used in these countries.

It seems important to emphasize that the fact that the usage of a metal for the production of cosmetics is prohibited does not mean that this element cannot be present in the final product in a detectable amount. Even the most rigorous EU Regulation (OJEU, 2009) allows for the presence of trace amounts of prohibited heavy metals (as technically unavoidable contaminations). Thus, the concentrations of heavy metals in cosmetic products are more important than the mere fact of their presence. That is why it is necessary to monitor commercially available cosmetics regarding the concentrations of metals, especially the most toxic trace elements, in order to recognize whether the concentrations are within the ranges of safe values. Highly advanced analytical methods (atomic absorption spectrometry – AAS and especially inductively coupled plasma mass spectrometry – ICP-MS) used nowadays in metal analysis allow the detection of even trace amounts (part per million – ppm and part per billion – ppb) of metals (Atz and Pozebon, 2009; Al-Qutob *et al.*, 2013). The important issue raised by many

authors who determined metals in cosmetics and whose data were used for the preparation of this review article, is the lack of certified cosmetic materials (Ciaralli *et al.*, 1996; Al-Saleh *et al.*, 2009; Atz and Pozebon, 2009; Omolayo *et al.*, 2010). That is why reference materials other than cosmetic products are used by some investigators to check the reliability of metal measurements in cosmetics (Sainio *et al.*, 2000; Al-Dayel *et al.*, 2011).

Metals in Colour Cosmetics

The use of colour cosmetics by women is a very popular daily custom all over the world (Mudholkar, 2012). These cosmetics are often left on the skin for a whole day and are repeatedly used. Among the products that contain toxic metals, the most hazardous seem to be preparations which are applied to the mucous membranes, such as lipsticks and lip glosses (Gondal *et al.*, 2010; Khalid *et al.*, 2013; Soares and Nascentes, 2013). In the case of cosmetics applied to the lips there is a risk of their direct oral ingestion with food when eating or by licking lips. Eye shadows and mascaras are applied to the periocular area of the face where the skin is the thinnest, which enables easy absorption of various substances, including metals, from cosmetics into the blood (Pratchyapruit *et al.*, 2007). Some impurities and intended ingredients of eye cosmetics can cause allergic reactions of the eyelids and eyes irritation.

Metals may be absorbed from cosmetics through the conjunctiva and during lacrimation. The thin epidermis of the eyelids may be mechanically broken during eye rubbing, enabling the penetration of pigments containing metals into the blood circulation, so eye shadow should not be applied to broken skin (Sainio *et al.*, 2000; Omolayo *et al.*, 2010). In addition, slow percutaneous absorption of metals from cosmetics into the body through healthy skin is also possible (Omolayo *et al.*, 2010). Individuals sensitized to metals, especially to Ni (van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Foulds, 2006; Travassos *et al.*, 2011), should completely avoid eye shadows because sensitizing metals can occur as impurities in this sort of colour cosmetics (Table 1; van Ketel and Liem, 1981; Goh *et al.*, 1989; Sainio *et al.*, 2000; Goossens, 2004). Ni is the main metallic allergen from make-up. In dyes used in the manufacture of coloured cosmetics in Korea, metals which can cause contact allergy were detected in the following concentrations: 0 – 19.5 mg Ni kg^{-1} , 0.16 – 97.6 mg Cr kg^{-1} , 0 – 789.9 mg Fe kg^{-1} , 0 – 6.6 mg Cu kg^{-1} and 0 – 177.9 mg Co kg^{-1} (Kang *et al.*, 2006; Lee *et al.*, 2008). In Nigeria, the concentrations of metals in dyes used in the production of eye shadows were as follows: 6.11 – 55.0 mg Pb kg^{-1} , 0 – 8.89 mg Cd kg^{-1} , 80.56 – 359.44 mg Ni kg^{-1} , 0 – 150 mg Cr kg^{-1} , 1.67 – 136.67 mg Cu kg^{-1} and 15.0 – 253.33 mg Co kg^{-1} (Omolayo *et al.*, 2010).

The available literature data show that metals, such as Pb, Cd, Ni, As, Hg, Cr, Co, Cu, Fe and Al are present in many types of colour cosmetics produced and used in various parts of the world (Table 1; Supplementary Table S1). Apart from the data presented in Table 1, there is plenty of other information about the concentrations of toxic heavy metals in colour cosmetics; however, it is impossible to present all of them in one article and thus only the more recent and most important findings have been provided to emphasize that the problem of toxic metals presence in these products is still current. In addition, based on the available literature we have created ranges of metal concentrations in colour cosmetics. These concentrations

Table 1. Concentrations of heavy metals detected in colour cosmetics (mg kg⁻¹)^a

Type of product	Pb	Cd	Ni	As	Hg	Cr	Fe	Cu	Co	References
Eye shadows	0 – 202.06	0 – 55.59	0.02 – 359.44	0 – 11.1	0 – 0.74	0 – 11,900	2.2 – 300,000	0 – 99,000	0 – 258.33	(Sainio <i>et al.</i> , 2000; Kang <i>et al.</i> , 2006; Lee <i>et al.</i> , 2008; Al-Saleh <i>et al.</i> , 2009; Atz and Pozebon, 2009; Omolaoye <i>et al.</i> , 2010; Al-Dayel <i>et al.</i> , 2011; Contado and Pagnoni, 2012; Volpe <i>et al.</i> , 2012; Al-Qutob <i>et al.</i> , 2013; Mousavi <i>et al.</i> , 2013; Nourmoradi <i>et al.</i> , 2013; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014) (Nnorm <i>et al.</i> , 2005; Lee <i>et al.</i> , 2008; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014) (Lee <i>et al.</i> , 2008; Al-Dayel <i>et al.</i> , 2011; Faruruwa and Bartholomew, 2014)
Eye liners/Eye pencils	0.31 – 213.6	0.3 – 3.05	0.69 – 21.5	-	-	0.15 – 64.3	17 – 64,743.1	-	-	(Nnorm <i>et al.</i> , 2005; Lee <i>et al.</i> , 2008; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014)
Mascara	0 – 14	0 – 1.5	5.07 – 46.8	-	0 – 0.01	0.37 – 17.1	52.5 – 106,745.5	0.14 – 1.04	1.73 – 20.4	(Lee <i>et al.</i> , 2008; Al-Dayel <i>et al.</i> , 2011; Faruruwa and Bartholomew, 2014)
Colour lip cosmetics	0 – 3,760	0 – 60.2	0 – 22.8	-	0 – 0.01	0 – 93.3	0 – 6,839.7	0 – 118.6	0 – 1.77	(Nnorm <i>et al.</i> , 2005; Lee <i>et al.</i> , 2008; Al-Saleh <i>et al.</i> , 2009; Atz and Pozebon, 2009; Gondal <i>et al.</i> , 2010; Perkin Elmer, 2012; Sah, 2012; Al-Qutob <i>et al.</i> , 2013; Gunduz and Akman, 2013; Khalid <i>et al.</i> , 2013; Liu <i>et al.</i> , 2013; Nourmoradi <i>et al.</i> , 2013; Orisakwe and Otaraku, 2013; Piccini <i>et al.</i> , 2013; Soares and Nascentes, 2013; Ullah <i>et al.</i> , 2013; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014) (Nnorm <i>et al.</i> , 2005; Lee <i>et al.</i> , 2008; Hwang <i>et al.</i> , 2009; Al-Qutob <i>et al.</i> , 2013; Orisakwe and Otaraku, 2013; Ullah <i>et al.</i> , 2013; Umar and Caleb, 2013)
Foundation creams, make-up bases, powders	0 – 61.86	0.18 – 29.05	0.72 – 214.54	-	-	0.26 – 15.75	0 – 1067	0 – 9.69	0 – 13.02	(Nnorm <i>et al.</i> , 2005; Lee <i>et al.</i> , 2008; Hwang <i>et al.</i> , 2009; Al-Qutob <i>et al.</i> , 2013; Orisakwe and Otaraku, 2013; Ullah <i>et al.</i> , 2013; Umar and Caleb, 2013)
Blushers	0.2 – 31.7	0.1 – 0.3	4.1 – 13.1	-	-	2.77 – 15.09	15,103.7 – 53,084.1	-	-	(Faruruwa and Bartholomew, 2014)
Nail polish	0.2 – 6.03	0.01 – 1.68	1.89	-	0 – 0.19	0 – 10.9	0 – 17,900	-	0 – 0.58	(Favaro <i>et al.</i> , 2005; Perkin Elmer, 2012; Umar and Caleb, 2013)

^aDetailed data on the concentrations of heavy metals detected in colour cosmetics produced in various countries are presented as the Supplementary Tables S1–S4. Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

range from 0 (undetectable values) up to 300.0 g Fe kg⁻¹, 99.0 g Cu kg⁻¹, 11.9 g Cr kg⁻¹, 3.76 g Pb kg⁻¹, 359.44 mg Ni kg⁻¹, 258.33 mg Co kg⁻¹, 60.2 mg Cd kg⁻¹, 0.74 mg Hg kg⁻¹ and 50.0 g Al kg⁻¹ (Tables 1 and 2; Supplementary Tables S1–S4). Brandão *et al.* (2012) have noted the following concentrations of Pb in cosmetics commonly used in South Africa: 7.4 ± 1.3 mg kg⁻¹ in concealer, 29 ± 9.2 mg kg⁻¹ in lip liner, 17.3 ± 2.9 mg kg⁻¹ in oil absorbent powder, 15.8 ± 0.2 mg kg⁻¹ in mascara, 4.7 – 11.7 mg kg⁻¹ in lip glosses, 0 – 73.1 mg kg⁻¹ in lipsticks and 7.8 – 32.9 mg kg⁻¹ in foundations. Adepoju-Bello *et al.* (2012) have found the following toxic metals while evaluating 50 various cosmetics from Nigeria, including lipsticks, lip glosses and skin-whitening creams: As (0.006 – 0.31 mg kg⁻¹), Cd (0.023 – 0.203 mg kg⁻¹), Pb (0.017 – 0.9 mg kg⁻¹), Hg (0.09 – 0.207 mg kg⁻¹) and Ni (0.032 – 0.105 mg kg⁻¹). However, they have not provided any data on concentrations of these metals in particular categories of these products. Among cosmetics such as face cleansers, lip polishes, nail paints, powders, styling gels and aloe facial scrubs from Nigeria Pb (0 – 0.17 mg kg⁻¹), Cd (0.01 – 0.09 mg kg⁻¹), Ni (0 – 0.08 mg kg⁻¹), Cr (0.01 – 0.47 mg kg⁻¹), Fe (0.52 – 6.65 mg kg⁻¹) and Cu (0.04 – 1.03 mg kg⁻¹) were detected (Odukudu *et al.*, 2014).

The highest concentration of Pb was found in shimmering and brown colours, whereas the lowest concentration was found in red colours of lipsticks from Saudi Arabia (Al-Saleh *et al.*, 2009). Among the lipsticks from Pakistan, the highest concentrations of heavy metals were found in dark brown and shocking pink colours (Khalid *et al.*, 2013). On the Brazilian market, the highest concentrations of Pb were found in red lipsticks (Soares and Nascentes, 2013). Lip glosses produced in the EU contained less Pb than lipsticks present on the European market, and this can be explained by a lower content of pigments in lip glosses (Piccini *et al.*, 2013). The Pb concentration in most of the lip colour products currently

present in Europe was in most cases below 1 mg kg⁻¹, and the maximum concentration of this metal observed in lipsticks and lip glosses reached 3.75 mg kg⁻¹ and 2.12 mg kg⁻¹, respectively (Piccini *et al.*, 2013). In 2007, the FDA detected Pb in lipsticks ranging from 0.09 to 3.06 mg kg⁻¹ (FDA, 2014) and in 2010 Frontier Global Sciences under contract with the US FDA detected Pb in this kind of products in more than twice higher concentrations (0 – 7.19 mg kg⁻¹; FDA, 2014).

Recently, a growing popularity of toy make-up has been observed and toy cosmetics is widely available. However, these products can be potentially dangerous for children, including especially atopic children. The children's skin is particularly thin, so it is very susceptible to external harmful factors (Brandão and Gontijo, 2012). Toy cosmetics are sold in kits such as eye shadows and lipsticks. Each product in the kit is a cosmetic product and should be compliant to the cosmetic directive. These products are often used on children's faces and usually stay on as long as real cosmetics. Ni, Cr and Co were detected in these products and these metals were present in the highest concentrations in toy eye shadows (Table 3; Corazza *et al.*, 2009; Contado and Pagnoni, 2012).

To sum up, metals were detected in different concentrations in various types of colour cosmetics (Tables 1–3). Pb was detected in the highest concentrations in lipsticks, reaching up to 3.76 g kg⁻¹ in a lipstick from Saudi Arabia (Table 1; Al-Saleh *et al.*, 2009), whereas Ni, Cr, Fe, Cu, Co and Al were detected in high concentrations in eye shadows (Tables 1 and 2). In the eye shadows from Nigeria, Ni was found in a concentration as high as 359.44 mg kg⁻¹ (Omolaoye *et al.*, 2010). Ni and Cr were also present in high concentrations in toy make-up products (Corazza *et al.*, 2009; Contado and Pagnoni, 2012). Based on the available literature data, the concentrations of metals in colour cosmetics can be set in the following order: Fe > Cu > Al > Cr > Pb > Ni > Co > Cd > As > Hg. As can be seen from the presented data (Tables 1–3; Supplementary

Table 2. Concentrations of aluminium (Al) detected in various types of cosmetics (mg kg⁻¹)

Type of product	Origin	Concentration of Al	References
Eye shadows	Saudi Arabia	20,000 – 50,000	(Al-Dayel <i>et al.</i> , 2011)
	Palestine	62.17	(Al-Qutob <i>et al.</i> , 2013)
Mascara	Saudi Arabia	117 – 20,000	(Al-Dayel <i>et al.</i> , 2011)
Lipsticks	Palestine	10.98 – 694.5	(Al-Qutob <i>et al.</i> , 2013)
	USA	14.2 – 27,032	(Liu <i>et al.</i> , 2013)
Lip glosses	USA	0.415 – 10,536	(Liu <i>et al.</i> , 2013)
Foundation creams, compact powders	Palestine	33.26 – 18,661.5	(Al-Qutob <i>et al.</i> , 2013)
Creams (anti-freckles, moisturizing)	Palestine	15.31 – 62.17	(Al-Qutob <i>et al.</i> , 2013)
Cosmetic emulsions	Africa	0 – 0.861	(Oyedeji <i>et al.</i> , 2011)
	Europe	0 – 0.958	(Oyedeji <i>et al.</i> , 2011)
	USA	0 – 1.002	(Oyedeji <i>et al.</i> , 2011)
Commercial muds	Dead Sea	4,500 – 7,900	(Abdel-Fattah and Pingitore, 2009)
Cosmetics with muds from Dead Sea			
Body lotions		0 – 6	(Abdel-Fattah and Pingitore, 2009)
Hand creams		5 – 102	(Abdel-Fattah and Pingitore, 2009)
Facial masks		5,400 – 8,500	(Abdel-Fattah and Pingitore, 2009)
Soaps		170 – 650	(Abdel-Fattah and Pingitore, 2009)
Shaving soap		98	(Abdel-Fattah and Pingitore, 2009)
Shampoo		6	(Abdel-Fattah and Pingitore, 2009)
Moisturizer		2	(Abdel-Fattah and Pingitore, 2009)
Henna	Palestine	142.1	(Al-Qutob <i>et al.</i> , 2013)
Kohl	Palestine	56.75 – 1,009.3	(Al-Qutob <i>et al.</i> , 2013)

Table 3. Concentrations of metals detected in toy make up (mg kg^{-1})

Type of product	Ni	Cr	Co	References
Eye shadows	1.4 – 320	1.61 – 3,620	0.47 – 12.5	(Corazza <i>et al.</i> , 2009; Contado and Pagnoni, 2012)
Lipsticks	0 – 2.35	1.1 – 5.05	-	(Corazza <i>et al.</i> , 2009)
Lip gloss	-	0 – 5.48	-	(Corazza <i>et al.</i> , 2009)
Lip balm	-	0.6	-	(Corazza <i>et al.</i> , 2009)
Lip pencil	1.41	1.69	0.48	(Corazza <i>et al.</i> , 2009)

Ni, nickel; Cr, chromium; Co, cobalt.

Tables S1–S4), metals, whose usage is prohibited or restricted by the EU law (OJEU, 2009) or other regulations (FDA, 2009, 2014; HC-SC, 2012), were detected in excessive concentrations in commercially available colour cosmetics. Detailed data on the concentrations of heavy metals detected in colour cosmetics produced in various countries are presented as the Supplementary Material (Supplementary Tables S1–S4).

Metals in Face and Body Care Products

Heavy metals and Al have also been detected in various kinds of face and body care products (Tables 2 and 4; Supplementary Tables S5 and S6). While most of the heavy metals are probably present in these cosmetics by accident, it is possible that Hg is sometimes used intentionally because of its ability to lighten the skin. The heavy metal detected in the highest concentrations in these products, especially in skin-lightening preparations, was definitely Hg (Table 4; Weldon *et al.*, 2000; Soo *et al.*, 2003; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Li *et al.*, 2010; Benz *et al.*, 2011; Chakera *et al.*, 2011; CDC, 2012b; Dickenson *et al.*, 2013). Many face creams used for freckle removal and skin whitening, for acne and the prevention and elimination of wrinkles contain Hg (Table 4; Supplementary Table S5). Abdulla *et al.* (2013) have revealed that in the United Arab Emirates heavy metals were present in all types of cosmetics, including face and body care products (face masks, powders, soaps, perfumes, foam baths, creams for shaving, deodorants, Table 4 sunbathing products, make-up products, face creams, hair bleaches, shampoos, lacquers and brilliantine) at the mean concentrations of $0.1027 \pm 0.5 \text{ mg Cd kg}^{-1}$, $1.211 \pm 5.475 \text{ mg Cr kg}^{-1}$, $1.2764 \pm 7.9481 \text{ mg Pb kg}^{-1}$ and $0.107 \pm 0.3273 \text{ mg As kg}^{-1}$.

In addition, Al may be present in antiperspirants owing to the intentional use of its compounds for blocking the sweat ducts. This action of Al compounds consists of the formation of a physical plug composed of a combination of metal-proteoglycan precipitate and damaged cells at the top of the duct resulting in the prevention from the escape of sweat onto the body surface (Laden and Felger, 1988). Mesurolle *et al.* (2014) have found that 43 antiperspirants commercially available on the Canadian market contained aluminium-based complexes in concentrations ranging from 16% to 25%. Similarly, Guillard *et al.* (2004) have noted that aluminium chlorohydrate content in an antiperspirant cream reached 20%. Sappino *et al.* (2012) have determined the following concentrations of aluminium chlorohydrate in three antiperspirants investigated by them: 417.31, 483.81 and 653.48 mM. Unfortunately, all the authors (Guillard *et al.*, 2004; Sappino *et al.*, 2012; Mesurolle *et al.*, 2014) did not mention about the cosmetic brands of these products.

Based on the available literature data, the order of metals concentration in the face and body care products is as follows: $\text{Pb (0 – 790 g kg}^{-1}) > \text{Hg (0 – 65.133 g kg}^{-1}) > \text{Fe (0 – 2.469 g kg}^{-1})$

$> \text{Al (0 – 62.17 mg kg}^{-1}) > \text{Ni (0 – 29.39 mg kg}^{-1}) > \text{Cd (0 – 28.73 mg kg}^{-1}) > \text{Cu (0 – 18.95 mg kg}^{-1}) > \text{Cr (0 – 6.29 mg kg}^{-1})$. Detailed data on the concentrations of metals detected in the face and body care products produced in various countries are presented in Table 2 and as the Supplementary Material (Supplementary Tables S5 and S6).

Metals in Hair Cosmetics

Numerous metals have been detected in various types of hair cosmetics, including conditioners, pomades, dyes and shampoos (Tables 2 and 5; Supplementary Tables S7A and S7B; Li *et al.*, 2010). Detailed data on the concentrations of heavy metals detected in hair cosmetics produced in various countries are presented in the Supplementary Material (Supplementary Tables S7A and S7B). The presence of Pb and its compounds in hair cosmetics, including hair dyes, is prohibited in Europe (OJEU, 2009), but FDA accepts lead acetate in cosmetics that colour the hair up to a maximum content of 0.6% (w/v) Pb in the final product (FDA, 2009). Lead acetate in hair dyes is accepted by the FDA owing to its black colour and the ability of changing the colour of hair into black. Apart from lead acetate other heavy metal compounds are present in hair cosmetics only by accident.

During hair colouring the disulphide bonds of keratin are oxidized, forming binding sites for metal ions (Smart *et al.*, 2009). It is important to underline that hair bind metals more easily when their structure is damaged. Higher concentrations of Cd, Ni, Sb, Fe, Cu and manganese (Mn) have been reported in dyed hair in comparison with non-dyed hair (Smart *et al.*, 2009; Wei *et al.*, 2008).

According to the available literature data the order of the concentrations of metals in hair cosmetics is as follows: $\text{Fe (0 – 421 mg kg}^{-1}) > \text{Ni (0 – 72 mg kg}^{-1}) > \text{Co (0 – 25.35 mg kg}^{-1}) > \text{Pb (0 – 17.7 mg kg}^{-1}) > \text{Cu (0 – 12.8 mg kg}^{-1}) > \text{Cr (0 – 11 mg kg}^{-1}) > \text{Cd (0 – 6.95 mg kg}^{-1})$. Pb and Ni were detected in high concentrations mainly in hair pomades, whereas Cd was in hair creams (Table 5; Supplementary Tables S7A and S7B). Apart from the above-mentioned metals, As and Al were also present in the shampoo with muds from the Dead Sea from Jordan in concentrations of 0.2 and 6.0 mg kg^{-1} , respectively (Abdel-Fattah and Pingitore, 2009).

Metals in Traditional Cosmetics and Cosmetics Containing Herbs and Minerals Considered as Natural Products

Herbal cosmetics have been known and used worldwide since ancient times; however, in the last years, there has been a renewed interest in these products. This resulted from the growing belief that herbal products are safe whereas chemical-based ones may be harmful (Sukender *et al.*, 2012). Herbal cosmetics are valuable products consisting of plants and their bioactive extracts, which

Table 4. Concentrations of heavy metals detected in face and body care products (mg kg⁻¹)^a

Type of product	Pb	Cd	Ni	Hg	Cr	Fe	Cu	Co	References
Creams (e.g. skin-whitening, skin-lightening, anti-freckles, anti-wrinkles, for acne, medicated)	0 – 41,600	0 – 5.05	0.01 – 18.45	0 – 65,133	0 – 4.3	0.53 – 2,469	0 – 18.95	0.22 – 0.25	(Chan <i>et al.</i> , 2001; Sin and Tsang, 2003; Ayenimo <i>et al.</i> , 2010a, 2010b; Chauhan <i>et al.</i> , 2010; McKelvey <i>et al.</i> , 2011; Onwordi <i>et al.</i> , 2011; Perkin Elmer, 2012; Adawe and Oberg, 2013; Al-Qutob <i>et al.</i> , 2013; Cristuado <i>et al.</i> , 2013; Ullah <i>et al.</i> , 2013; Umar and Caleb, 2013) (McKelvey <i>et al.</i> , 2011)
Germicidal creams, soaps and balms	-	-	-	204 – 4,770	-	-	-	-	
Body creams/lotions/milks	0 – 9.2	0 – 16.67	0 – 6.56	-	0.02 – 0.4	-	0 – 0.05	-	(Bocca <i>et al.</i> , 2007; Cristuado <i>et al.</i> , 2013; Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)
Shaving creams	0.66 – 0.72	0.01 – 0.02	-	-	-	-	-	-	(Chauhan <i>et al.</i> , 2010)
Eye cleansers, cleansing oil	8.06 – 213.6	0.3 – 3.88	-	-	0.28	-	-	-	(Nnorm <i>et al.</i> , 2006; Hwang <i>et al.</i> , 2009)
Emulsions	0 – 0.39	-	-	-	0 – 0.5	0.05 – 1.83	-	-	(Oyedeeji <i>et al.</i> , 2011)
Foam bath products, bathing soaps	3.82 – 4.63	0.03 – 0.04	0.03 – 0.29	-	0.02 – 0.2	-	-	-	(Ciaralli <i>et al.</i> , 1996; Chauhan <i>et al.</i> , 2010)
Soaps (e.g. toilet, medicated, skin-lightening)	0 – 5.8	0 – 12.85	0 – 5.76	0 – 7.4	0.01 – 0.72	0.45 – 1.58	-	0.1 – 0.87	(Harada <i>et al.</i> , 2001; Ayenimo <i>et al.</i> , 2010a, 2010b; Cristuado <i>et al.</i> , 2013; Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)
Toothpastes, mouth-cleansing powder	0 – 8.89	0 – 28.73	0.01 – 29.39	0.01 – 1.11	0.01 – 6.29	0.51 – 0.7	0.1 – 0.31	-	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Hand and cuticle cream	0.39	6.83	1.38	-	0.25	-	-	-	(Umar and Caleb, 2013)

^aDetailed data on the concentrations of heavy metals detected in face and body care products produced in various countries are presented as the Supplementary Tables S5–S6. Pb, lead; Cd, cadmium; Ni, nickel; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

Table 5. Concentrations of heavy metals detected in hair products (mg kg⁻¹)^a

Type of product	Pb	Cd	Ni	Cr	Fe	Cu	Co	References
Hair relaxers	0 – 0.45	0.31 – 2.52	0.02 – 0.83	0.06 – 0.6	0.76 – 1.03	0.57 – 0.67	-	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Hair creams	0 – 0.49	0.28 – 6.95	0.01 – 2.03	0.01 – 0.49	0.51 – 2.15	0.52 – 0.81	-	(Ayenimo <i>et al.</i> , 2010a, 2010b; Umar and Caleb, 2013)
Shampoos	0.96 – 3.32	0.03 – 4.17	0.06 – 3.11	0.34 – 1.5	27.97 – 154.2	0.07 – 2.39	0.18 – 0.37	(Abdel-Fattah and Pingitore, 2009; Chauhan <i>et al.</i> , 2010; Ullah <i>et al.</i> , 2013; Umar and Caleb, 2013)
Hair conditioner	0.18	3.6	1.84	-	-	-	-	(Umar and Caleb, 2013)
Hair pomades	1.3 – 17.7	4.2 – 6.8	1.3 – 72	-	81.6 – 421	0.7 – 12.8	10.67 – 25.35	(Amartey <i>et al.</i> , 2011)
Hair dyes	-	-	-	5 – 11	-	-	-	(Gondal <i>et al.</i> , 2013; Gondal <i>et al.</i> , 2014)

^aDetailed data on the concentrations of heavy metals detected in hair products produced in various countries are presented as the Supplementary Tables S7A and S7B. Pb, lead; Cd, cadmium; Ni, nickel; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

enrich the skin with nutrients (Sukender *et al.*, 2012). However, not every product containing herbs and minerals is a natural product. These items often contain only trace quantities of plant extracts and high quantities of synthetic ingredients, preservatives and toxic metals. Concentrations of metals in herbal cosmetics depend on the content of these unintended impurities in herbs. Herbal materials that are used in cosmetics production should come from certificated ecological cultures or controlled wild crops. However, according to the EU Regulation No 1223/2009, small quantities of non-intended prohibited metals can be present in final cosmetic products as technically unavoidable contaminations (OJEU, 2009). According to the WHO, the maximum allowed amounts of Pb and Cd in dried plant materials used in cosmetology are 10 and 0.3 mg kg⁻¹, respectively (WHO, 2007). The Cosmetic Ingredient Review Expert Panel established by FDA in the USA advised the cosmetic industry that the contamination of any plant-derived ingredient should be limited to not more than 3 mg kg⁻¹ for As, 5 mg kg⁻¹ for Pb and 20 mg kg⁻¹ for other heavy metals (Cosmetic Ingredient Review Expert Panel, 2007). The same Committee allows for the presence of toxic metals in cottonseed oil used for the production of colour cosmetics and face and body care products in the following concentrations: As ≤ 3 mg kg⁻¹, Pb ≤ 0.1 mg kg⁻¹ and Hg ≤ 1 mg kg⁻¹ [Final Report on the Safety Assessment of Hydrogenated Cottonseed Oil, Cottonseed (*Gossypium*) Oil, Cottonseed Acid, Cottonseed Glyceride, and Hydrogenated Cottonseed Glyceride, 2001].

Apart from pesticides and fertilizers, toxic metals are the main contaminants of herbal and mineral raw materials, but in the available literature there are no data concerning chemical contamination of the herbs used for cosmetic reasons. However, there are a lot of data on pollution of herbs by heavy metals in general, including the plants used in medicine (Table 6). Numerous data show that even plants growing under controlled conditions in unpolluted areas contain some amounts of toxic heavy metals, including particularly Pb and Cd (Table 6; Harcz *et al.*, 2007). Thus, toxic metals are always present in commercially available herbs and herbal products including cosmetics. Depending on the place of origin, the concentrations of metals in herbal plants vary in a wide range of values from very low, sometimes almost undetectable, to excessively high values. The available data show that excessive concentrations of Cd (up to 0.63 mg kg⁻¹) and Pb (up to 4,249.6 mg kg⁻¹), in comparison with the limits set up by WHO (0.3 mg Cd kg⁻¹ and 10 mg Pb kg⁻¹), were detected in raw plant materials originating from various countries, including Germany, Turkey, Poland and Bulgaria (Başgel and Erdemoğlu, 2006; Gasser *et al.*, 2009; Tokalioğlu, 2012). We found data indicating that the concentrations of heavy metals in the nettle (*Urtica dioica*), chamomile (*Chamomilla recutita*) and horsetail (*Equisetum arvense*) belonging to the group of plants most often used in herbal cosmetics are sometimes too high (Table 6). Unlike heavy metals, there is a lack of data on Al content in herbs, but the presence of this metal in herbal plants, and therefore in herbal cosmetics, is very possible due to the growing problem of the increasing Al concentration in plants. This is connected with the fact that sparingly soluble, poorly absorbed minerals containing Al present in large amounts in the Earth crust become better soluble owing to soil acidification (caused by acid rains) and for this reason Al is easier absorbed from soil by plants (Minocha and Minocha, 2005). Thus, more interest Table 6 should be focused on the herbs used in cosmetology and herbal cosmetics contamination with Al.

Table 6. Concentrations of heavy metals in raw plant material from Europe which can be used for pharmaceutical and cosmetic reasons (mg kg⁻¹)

	Pb	Cd	Ni	As	Hg	References
Poland						
Nettle	1.1 – 7.23	0.06 – 0.27	1.49	0.09 – 0.24		(Baranowska <i>et al.</i> , 2002; Fijałek <i>et al.</i> , 2003)
Chamomile	8.08	0.3	1.17	-	-	(Baranowska <i>et al.</i> , 2002)
Turkey						
Nettle	1.59 – 4.8	0.06	3.6 – 13.1	-	-	(Başgel and Erdemoğlu, 2006; Tokalioğlu, 2012)
Chamomile	0.06 – 0.72	0.44	1.8 – 3.68	-	-	(Başgel and Erdemoğlu, 2006; Tokalioğlu, 2012)
Horsetail	-	-	4.73	-	-	(Tokalioğlu, 2012)
Germany						
Nettle	0 – 4,249.6	0 – 0.2	-	-	0 – 0.17	(Gasser <i>et al.</i> , 2009)
Horsetail	0 – 21.45	0 – 0.63	-	-	0 – 0.1	(Gasser <i>et al.</i> , 2009)
Bulgaria						
Chamomile	0.29 – 1.62	0.18 – 0.26	-	0.08 – 0.12	-	(Arpadjan <i>et al.</i> , 2008)
	Cr	Fe	Cu	Co		
Poland						
Nettle	-	56.2 – 266	7.26 – 13	-		(Fijałek <i>et al.</i> , 2003)
Turkey						
Nettle	1.2 – 8.71	810 – 3,456	5.6 – 15.2	0.48 – 2.35		(Başgel and Erdemoğlu, 2006; Tokalioğlu, 2012)
Chamomile	1.22 – 3.48	502.7 – 716	8.34 – 13.9	0.32 – 0.44		(Başgel and Erdemoğlu, 2006; Tokalioğlu, 2012)
Horsetail	1.02	804	8.59	0.43		(Tokalioğlu, 2012)

Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

Heavy metals, such as Cd, Pb, Ni, As, Hg, Cr, Fe, Cu and Co were also detected in numerous other raw materials which can be used for the production of cosmetics considered as natural products, for example in honey (Table 7; Roman, 2003; Borawska *et al.*, 2012), argan oil (Mohammed *et al.*, 2013), and olive oil (Brkljača *et al.*, 2013) as well as in citrus essential oils (lemon, mandarin, bergamot, and sweet orange oils; Table 8) often used as natural ingredients of cosmetics and as aromatizing agents. Another raw materials containing metals and used in the production of cosmetics are Dead Sea muds used as an ingredient in body lotions, hand creams, facial masks, soaps and shampoos as well as in healing muds from

other seas (e.g. Adriatic Sea), cosmetic clays (Tateo *et al.*, 2009; Otto and Haydel, 2013) and talcum used especially in powders (Tables 2 and 9; Supplementary Tables S8A, S8B and S9). These raw materials contain toxic metals in concentrations corresponding to their concentrations in the Earth's upper crust. Toxic metals bound with the surface of natural clays can be exchanged with ions present in the skin and can be absorbed through the skin (Tateo *et al.*, 2009; Otto and Haydel, 2013). In cosmetic clays from Nigeria such as calabash stone (a mixture of aluminium silicate hydroxide, seashells, clay mud, sand, wood ash and salt) and black antimony, metals such as Pb, Cr, and Cd were detected (Table 9; Supplementary

Table 7. Concentrations of heavy metals detected in honey (which is one of often ingredients of natural cosmetics; mg kg⁻¹)

Origin	Pb	Cd	Ni	As	Hg	References
Croatia	0.01 – 0.84	0 – 0.2	-	0 – 0.1	0 – 0.31	(Bilandžić <i>et al.</i> , 2001)
Greece	-	0.08 – 0.22	-	-	-	(Ioannidou <i>et al.</i> , 2005)
Italy	0.1 – 1.53	0.01 – 0.27	-	-	-	(Sanna <i>et al.</i> , 2000)
Spain	0 – 0.12	0 – 0.002	-	-	-	(Muñoz and Palmero, 2006)
Turkey	0 – 0.06	-	0 – 0.13	-	-	(Silici <i>et al.</i> , 2008)
	Cr	Fe	Cu	Co		
Croatia	-	-	0.04 – 41.27	-		(Bilandžić <i>et al.</i> , 2001)
Greece	-	-	0 – 0.48	0.01 – 0.09		(Ioannidou <i>et al.</i> , 2005)
Italy	-	-	0.19 – 2.98	-		(Sanna <i>et al.</i> , 2000)
Turkey	0 – 0.01	1.12 – 12.9	0.01 – 0.04	0 – 0.03		(Silici <i>et al.</i> , 2008)

Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

Table 8. Mean concentrations of cadmium (Cd), lead (Pb) and copper (Cu) determined in methanol extracts of citrus essential oils (mg kg⁻¹) according to Pera *et al.* (2003)

Citrus essential oil kind	Cd	Pb	Cu
Lemon	0.002	0.10	0.02
Mandarin	0.002	0.17	0.27
Sweet orange	0.008	0.08	0.07
Bergamot	0.02	0.08	0.36

Tables S8A and S9). The mean concentrations of Pb and Cr in cal-abash stone reached 5.13 ± 9.08 and 7.69 ± 4.41 mg kg⁻¹ respectively, whereas the Cd concentration was below the limit of detection. The concentrations of these metals in black antimony were 171.14 ± 5.85 mg Pb kg⁻¹, 5.75 ± 3.33 mg Cr kg⁻¹ and 0.53 ± 4.19 mg Cd kg⁻¹ (Popoola *et al.*, 2013). Another natural raw material used for cosmetics production, especially shimmering lipsticks, which may contain heavy metals (mainly Pb), is Mica (Al-Saleh *et al.*, 2009) being a group of natural silicate minerals (Al-Saleh *et al.*, 2009; Volpe *et al.*, 2012; Piccini *et al.*, 2013).

Heavy metals were detected in excessive concentrations in herbal cosmetic formulations of preparations sold on the Indian market and in herbal (including antiseptic) soaps from Nigeria (Tables 9; Obi *et al.*, 2006). It was found that alkalis used for the production of cheap soaps in Nigeria contain 0.02 mg Pb kg⁻¹, 0.003 mg Cd kg⁻¹, 0.05–0.06 mg Ni kg⁻¹, 0.02–0.04 mg Cr kg⁻¹, 1.67–2.45 mg Cu kg⁻¹ and 99.18–241.63 mg Fe kg⁻¹ (Oluremi Olabanji *et al.*, 2012).

Henna is another traditional product that has been used over the centuries for medical and cosmetic purposes in many parts of the world. Henna dye is obtained from the dried leaves of the *Lawsonia inermis* or *Cassia obovata*, which are powdered and mixed with oil and water (Kang and Lee, 2006; Jallad and Espada-Jallad, 2008). It is applied to the hair for the purpose of hair dying and giving it a healthy and beautiful look (Jallad and Espada-Jallad, 2008). This product is a substitute for chemical hair dyes (Kang and Lee, 2006). Henna is also applied as temporary paint-on-tattoos on hands and feet as an alternative to permanent tattoos (Kang and Lee, 2006; Jallad and Espada-Jallad, 2008). Henna preparations are fortified with mineral products and various herbs in order to give it a stronger colour and to shorten the time of application (Kang and Lee, 2006; Jallad and Espada-Jallad, 2008). These mineral products and herbs are rich in Pb (Jallad and Espada-Jallad, 2008). The highest concentrations of this metal are reaching values as high as 65.98 mg kg⁻¹ were found in henna from the United Arab Emirates (Table 9; Jallad and Espada-Jallad, 2008). Ni and Co present in henna mixtures provoke sensitization, which plays a role in the occurrence of allergic contact dermatitis (Kang and Lee, 2006), whereas Pb is absorbed through the skin (Jallad and Espada-Jallad, 2008). A prolonged period of henna tattoos remaining on the skin facilitates this action. Apart from heavy metals (Table 9), Al has also been detected in henna (Table 2).

The problem of natural cosmetics contamination with toxic metals also refers to kohl (surma) being one of the traditional products used in Asia and Africa as eyeliner to darken the eyelids and as mascara for the eyelashes (Tables 2 and 9; Hardy *et al.*, 2006; Amry

et al., 2011). Kohl is an ointment prepared by burning vegetable fat and adding charcoal to the residue or a powder made from lead sulphide and ingredients added such as carbon, herbs, plant juices and vegetable ashes (Jallad and Espada-Jallad, 2008; Amry *et al.*, 2011). Medicinally, kohl is used to stop bleeding and after circumcision for hygienic purposes (Al Mahroos and Faap, 1993; Al-Ashban *et al.*, 2004). Mothers apply kohl to their children to protect them from the 'evil eye' (Hardy *et al.*, 2004; Hardy *et al.*, 2006). Sometimes manufacturers of kohl give false information on the labels about many benefits connected with their product, e.g. that it is helpful in the treatment of all kinds of eye trouble (e.g. sore eyes, tears, reddishness, eye dirt and burning eyes); however, none of the ingredients present in samples of kohl have these properties (Hardy *et al.*, 2006). The mean concentrations of toxic metals in Nigerian local kohl were the following: 277,300 mg Pb kg⁻¹, 2,256 mg Ni kg⁻¹, 810 mg As kg⁻¹, whereas in kohl imported to Nigeria they reached 180,900 mg Pb kg⁻¹, 1,140 mg Ni kg⁻¹ (1970–2690 mg Ni kg⁻¹), 1630 mg As kg⁻¹ and 7460 mg Cr kg⁻¹ (3450–9270 mg Cr kg⁻¹; Zakari *et al.*, 2014). The mean Pb concentration in the imported kohl samples available on the Nigerian market reached $178,366 \pm 947$ mg kg⁻¹ and one-third out of the 15 evaluated samples contained this metal in the concentration far beyond the recommended limit (20 mg kg⁻¹), while they were labelled as containing Pb below this limit. It is important to underline that Pb concentrations declared by the producers on kohl labels were not in conformity with the actual content of this metal (Zakari *et al.*, 2014). The Pb concentration in kohl from Saudi Arabia was 141.2 ± 2.8 mg kg⁻¹ (Haider *et al.*, 2012) and in that from Bangladesh it ranged from 89.8 ± 3.5 mg kg⁻¹ to 146.1 ± 4.8 mg kg⁻¹ (Haider *et al.*, 2012).

Metal Nanoparticles in Cosmetic Products

In recent years, a growing popularity of nanocosmetics has been observed. These products contain one or more nanoscale ingredients. The nanoscale version of ingredients provides better UV protection, deeper skin penetration, higher stability of active ingredients and long-lasting effects as well as increases the colour and quality of finished products (Raj *et al.*, 2012). In addition, some nanoparticles (calcium carbonate or calcium phosphate) are capable of preventing allergenic metal ions penetration into the skin (by capturing them by means of cation exchange and remaining on the surface of the skin, allowing them to be removed simply by washing with water; Vemula *et al.*, 2011).

Many different types of nanomaterials, including nanometals, are used in cosmetics. The usage of nanometals in cosmetics has many advantages. Nanoparticles of Ag and Au have antibacterial properties and thus they are useful in face and body care products, e.g. toothpastes or soaps (Raj *et al.*, 2012; Ramakritinan *et al.*, 2013). Cu species-coated silica nanoparticles are used in some deodorants because this element placement on nanoparticles increases the surface of Cu having antibacterial properties and neutralizing odours (Singh *et al.*, 2010). Nanoparticles of aluminium oxide are used in mineral foundations and concealers owing to their properties of diffusing light and disguising wrinkles (FOE-Australia, 2014). Titanium dioxide and zinc oxide in the size range of 20 nm are used in sunscreen products as efficient UV filters (Raj *et al.*, 2012). Popov *et al.* (2005) have suggested that titanium dioxide nanoparticles are more effective during the exposure to UVB (310 nm) than to UVA (400 nm) because, as they have revealed, in the case of exposure to UVB, nanoparticles of titanium dioxide with diameters 56–62 nm effectively decreased the transmission of UVB through

Table 9. Concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products (mg kg⁻¹)^a

Type of product	Pb	Cd	Ni	As	Hg	Cr	Fe	Cu	Co	References
Muds	2.5 – 4.5	0.14 – 2.6	13 – 15	1.3 – 1.7	-	23 – 30	-	4 – 63	2.3 – 4.5	(Vreca and Dolenc, 2005; Abdel-Fattah and Pingitore, 2009)
Cosmetics with muds from Dead Sea	0.01 – 6.2	0 – 1.7	0.01 – 17	0.03 – 1.8	-	0.81 – 24	-	0 – 10	0 – 4	(Abdel-Fattah and Pingitore, 2009)
Cosmetic clays	3.74 – 171.14	0.1 – 0.56	-	-	-	0.39 – 7.69	-	-	-	(Popoola <i>et al.</i> , 2013)
Talcum	0.24 – 20	0.01 – 2.1	-	-	-	0.2 – 30	-	-	0.7	(Chauhan <i>et al.</i> , 2010; Nnorm, 2011; Gondal <i>et al.</i> , 2012)
Henna	2 – 65.98	-	2.5 – 83	-	-	-	-	7.75	2.96 – 3.54	(Tosti <i>et al.</i> , 1991; Kang and Lee, 2006; Jallad and Espada-Jallad, 2008)
Kohl	3.2 – 1,219.4	0.94	1.01	-	-	0.08 – 9	1,272	302.2	0.72	(Malakootian <i>et al.</i> , 2010; Gondal <i>et al.</i> , 2013; Ullah <i>et al.</i> , 2013)
Black soap	1.42	5.69	5.84	-	-	0.9	-	-	-	(Umar and Caleb, 2013)
Various herbal cosmetics (soaps, toothpastes, creams)	0 – 54.9	0.62 – 21.42	1.04 – 24.03	0.69 – 3.68	0 – 2.18	0.15 – 2.16	-	-	-	(Nnorm <i>et al.</i> , 2006; Sukender <i>et al.</i> , 2012; Umar and Caleb, 2013)

^aDetailed data on the concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products produced in various countries are presented as the Supplementary Tables S8A, S8B and S9.

Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

the skin up to 1%, whereas in the case of exposure to UVA, higher diameters of titanium dioxide nanoparticles were necessary to decrease the transmission of UVA from 50% to 25%. Zinc oxide nanoparticles are effective UV filters in a broader spectrum of radiation, including UVA (Mitchnick *et al.*, 1999). Zinc oxide and titanium dioxide from sunscreens were only present in the uppermost layer of the *stratum corneum* after 2 h of application so they are considered to be relatively safe (Filipe *et al.*, 2009). However, Monteiro-Riviere *et al.* (2011) have revealed that damage to the skin caused by UVB slightly increased the penetration of titanium dioxide and zinc oxide nanoparticles through the skin. Ag and zinc oxide nanoparticles are ingredients of chemically modified clays because of their microbicidal activity against bacteria, fungi and viruses present on the skin (Otto and Haydel, 2013). Moreover, it has been revealed that 70-nm nanoparticles of calcium carbonate and calcium phosphate present in a glycerine emollient used on the skin surface can reduce the skin's exposure to Ni ions (Vemula *et al.*, 2011).

Although using metal nanoparticles in cosmetology has many advantages, there may be risk factors for human health. Because of their very small size, nanoparticles can penetrate the skin (particularly if the skin is damaged) and easily gain access to the blood stream and they can be transported to various organs (Raj *et al.*, 2012). People may inhale nanoparticles when they use nanomaterial products such as spray versions of sunscreens containing nanoparticles of titanium dioxide (Raj *et al.*, 2012). Topically applied nanoparticles of copper (II) oxide have been reported to induce inflammatory cytokine secretion and necrosis in human skin organ culture (Cohen *et al.*, 2013). In contrast to nanoparticles of copper (II) oxide, nanoparticles of Al probably have no cytotoxic activity. Monteiro-Riviere *et al.* (2010) have reported that exposure to nanoparticles of Al (50 and 80 nm) in the concentrations of 0.0004–4.0 mg mL⁻¹ for 24 h did not cause cytotoxicity in cultured human neonatal epidermal keratinocytes.

Results of experimental studies conducted in various animal models (Balasubramanyam *et al.*, 2009; Prabhakar *et al.*, 2012; Ze *et al.*, 2014) confirm toxicity of metal nanoparticles used in cosmetology and medicine. Prabhakar *et al.* (2012) have reported that acute oral treatment with aluminium oxide (Al₂O₃) nanoparticles (30 and 40 nm) in a single dose of 500, 1000 and 2000 mg kg⁻¹ induced oxidative stress in the liver, kidneys and brain of rats. The administration of Al₂O₃ nanoparticles, in a dose-dependent manner, decreased the concentration of reduced glutathione and the activities of superoxide dismutase and glutathione reductase, while increased activities of catalase and glutathione S-transferase, and malondialdehyde concentration (a biomarker of lipid peroxidation). The changes were different in various organs and depended not only on the dose, but also on the size of the nanoparticles. The Al₂O₃ nanoparticles-induced oxidative stress in the liver contributed to the development of histopathological changes in this organ such as dilated central vein and expanded portal tract (hepatic artery, hepatic portal vein and bile duct). Balasubramanyam *et al.* (2009) have revealed that exposure to aluminium oxide nanoparticles (30–40 nm, in the concentrations of 500–2000 mg kg⁻¹ body weight) caused genetic damages in the bone marrow of rats. Inhalation of titanium dioxide nanoparticles (in the concentrations of 2.5–10 mg kg⁻¹ body weight) during 90 days caused accumulation of these nanoparticles in the brain of mice, oxidative stress in the cells of the brain, overproliferation of all glial cells, tissue necrosis, hippocampal cell apoptosis and alterations in the expression of 249 known function genes (Ze *et al.*, 2014).

It is important to emphasize that the current knowledge about the danger connected with the use of nanometals in cosmetics is insufficient. This is related to methodological problems with nanometals determination on the one hand and the fact they have not been used long enough for evaluation of the long-term effects of exposure to them, on the other hand. Further investigations should provide more information on whether nanoparticles of metals are really safe for human health and give more advantages than hazards.

Absorption of Metals Through the Skin

Metals present in cosmetics may be accumulated in the skin or absorbed by this route (Fig. 3). Elements such as Ni, Co and Cr are accumulated in the *stratum corneum* and may cause allergic contact dermatitis (Larese *et al.*, 2007; Filon *et al.*, 2009), whereas Hg, Pb, Cd and Al pass through the skin layers to blood vessels and are transported into various organs where they are accumulated and exert toxic effects (Stauber *et al.*, 1994; Lansdown and Sampson, 1996; Palmer *et al.*, 2000; Sun *et al.*, 2002; CDC, 2012b; Lin *et al.*, 2012). Increased Pb, Cd, Hg and Al concentrations in the blood, urine or internal organs noted in individuals in whom the use of cosmetic products was the only source of excessive exposure to these metals confirm their absorption through the skin (Warley *et al.*, 1968; Shaltout *et al.*, 1981; Al Mahroos and Faap, 1993; Weldon *et al.*, 2000; Chan *et al.*, 2001; Soo *et al.*, 2003; Guillard *et al.*, 2004; CDC, 2005, 2012a, 2012b, 2013a; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Al Naama *et al.*, 2010; Li *et al.*, 2010; Amry *et al.*, 2011; Benz *et al.*, 2011; Chakera *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013). Although absorption of these metals by the skin is less effective than by the gastrointestinal tract or inhalation, some amounts of them may enter the body by this way as a result of the use of cosmetics.

Hg enters the skin mainly through appendages such as hair follicles and sweat ducts (Guy *et al.*, 1999; Palmer *et al.*, 2000). Part of

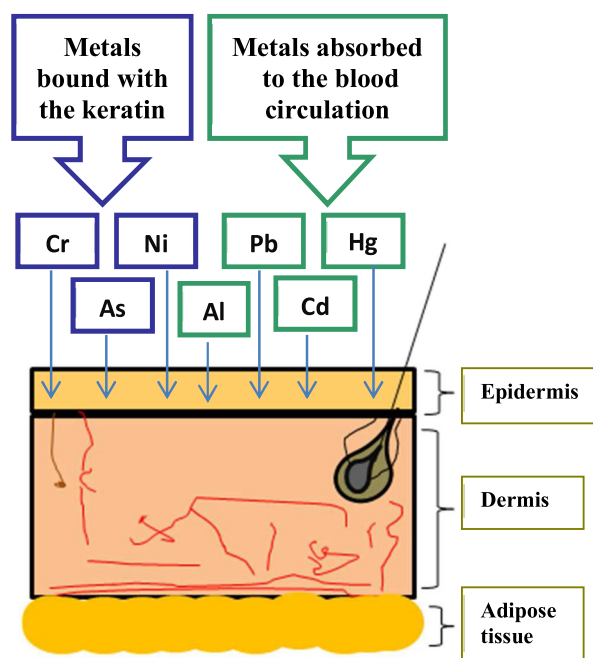


Figure 3. Schematic representation of metals accumulation in the skin and their absorption by the skin. Al, aluminium; As, arsenic; Cd, cadmium; Cr, chromium; Hg, mercury; Ni, nickel; Pb, lead.

the amount of this element is reduced in the skin to the metallic form and is accumulated in dermal tissues, which is seen as characteristic discolouration of the skin (Hg localized in the skin inactivates tyrosinase, which is the key melanine-forming enzyme; Chan *et al.*, 2001; Hostynek, 2003). It has been revealed, using an *in vitro* human skin model, that Hg is easily absorbed from popular skin-lightening creams (Palmer *et al.*, 2000). Application (without rubbing) of 90 mg of skin-lightening cream (a typical amount of the cosmetic required to cover the exposed surface of the skin) containing $290 \mu\text{g Hg l}^{-1}$ resulted in the concentration of $12 \pm 1 \mu\text{g Hg l}^{-1}$ in the receptor compartment (representing systemic absorption) after 3 h, whereas between the 18th and 24th hour the concentration increased up to $33 \pm 9 \mu\text{g l}^{-1}$ (Palmer *et al.*, 2000).

Similarly to Hg, Pb is rapidly absorbed via skin appendages (Stauber *et al.*, 1994). It has been detected (using ^{204}Pb isotope) that within 24 h almost 30% of the amount of lead nitrate applied to the skin (4.4 mg) was absorbed (Stauber *et al.*, 1994). Sun *et al.* (2002) have revealed Pb absorption by the skin from various compounds of this metal (lead sulphate, lead oxide, lead powder and lead stearate) applied to the dorsal side of the hand and the back of Pb-battery workers based on an increased Pb concentration in their blood.

Cd is absorbed well through the skin and is accumulated in the liver and kidneys (Lansdown and Sampson, 1996). Moreover, Cd^{2+} ions bind tightly to epidermal keratin (Guy *et al.*, 1999). Lansdown and Sampson (1996) have noted that after 10-day application of 1% solution of cadmium chloride to the rat's skin, the blood concentration of this heavy metal reached $11.65 \mu\text{g l}^{-1}$, whereas its concentration in the liver and kidneys was 0.526 and 0.216 mg kg^{-1} , respectively, providing clear evidence of this heavy metal absorption via the skin. An average Cd concentration in the skin of these animals reached 6 mg kg^{-1} , confirming its accumulation in the skin (Lansdown and Sampson, 1996).

It has been revealed that a single application to the human skin of aluminium chlorohydrate, used as the active ingredient in many antiperspirants, is not a significant contributor to the body burden of Al (Flarend *et al.*, 2001). Flarend *et al.* (2001) have noted that only $4.5 \mu\text{g}$ of Al (0.04%) in a woman and $2.6 \mu\text{g}$ (0.02%) in a man were absorbed during 6 days after a single application to the skin under an occlusive bandage of 12.4 and 13.3 mg, respectively. Some amounts ($1.9 \mu\text{g}$ in the woman and $1.1 \mu\text{g}$ in the man) of the metal applied to the skin were eliminated in the urine during the 6-day period.

In the available literature, there are no *in vivo* data indicating that Ni, Cr or Co can permeate through the skin into internal organs. These metals form deposits at deeper layers of the *stratum corneum* causing allergic contact dermatitis (van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Saxena *et al.*, 2001; Kang and Lee, 2006; Filon *et al.*, 2009; Travassos *et al.*, 2011). Ni binds mainly to carboxyl groups of keratin in epidermal and dermal tissue and penetrates the *stratum corneum* via diffusion through intercellular lipids (Guy *et al.*, 1999). Cr (III) ions are unable to penetrate biological membranes and are linked with epithelial and dermal tissues, forming stable complexes (Guy *et al.*, 1999). Cr (VI) compounds such as chromate (CrO_4^{2-}) and dichromate ($\text{Cr}_2\text{O}_7^{2-}$) are rapidly taken up by cells through the anion transport system (Guy *et al.*, 1999). Cr (VI) applied to the skin is reduced to Cr (III) ions during passage through the skin (Guy *et al.*, 1999). It has been revealed that metal absorption through the skin is closely related to the capacity of sweat to oxidize metals (Larese *et al.*, 2007). Larese *et al.* (2007), using the Franz diffusion cells with human skin, demonstrated that metal powders of Ni and Co can be

oxidized when suspended in synthetic sweat into Ni^{2+} and Co^{2+} ions that can permeate the skin, whereas Cr powder is not oxidized and thus cannot permeate the skin. The impact of sweat on Ni and Co penetration by the skin and these elements retention in the *stratum corneum* were confirmed by Sartorelli *et al.* (2012). They have noted that *in vitro* percutaneous absorption of ^{63}Ni (from nickel chloride) and ^{57}Co (from cobalt chloride) through the human skin during 24 h from application in water and artificial sweat reached $0.23 \pm 0.34\%$ and $1.04 \pm 0.64\%$, respectively, and $0.76 \pm 1.21\%$ and $3.30 \pm 2.65\%$ respectively. The amounts of ^{63}Ni and ^{57}Co present in the *stratum corneum* reached $50.33 \pm 19.91\%$ and $27.62 \pm 14.96\%$, respectively, in the case of application of these elements in water and $36.16 \pm 9.30\%$ and $41.30 \pm 18.83\%$, respectively, when they were applied in artificial sweat (Sartorelli *et al.*, 2012).

The percutaneous metal absorption is determined by many exo- and endogenous factors. The first group involves the dose, vehicle, polarity, solubility, pH, frequency of application and the duration of remaining on the skin as well as the temperature of the skin (Palmer *et al.*, 2000; Lin *et al.*, 2012; Sartorelli *et al.*, 2012; Otto and Haydel, 2013). The main endogenous factors involve anatomical differences in skin properties, age (incomplete barrier function in infants and neonates, diminishing lipid surface and blood supply, and transepidermal water loss in the elderly), skin health, and oxidation or reduction of metals in the skin (Hostynek, 2003). A very important factor influencing the efficiency of metal absorption via the skin is the place of cosmetic application. It is worth underlining that the skin of the eyelids is the thinnest skin in the body (Pratchyapruit *et al.*, 2007), which enables easy absorption of chemical substances, including metals, from eye make-up products. Moreover, dabbing a cosmetic in the skin facilitates metal absorption (Lin *et al.*, 2012). It is obvious that absorption of xenobiotics via damaged skin is higher than through the intact skin (Lachenmeier, 2008; Pinneau *et al.*, 2012). This also refers to metals (Filon *et al.*, 2009). Filon *et al.* (2009) in *in vitro* permeation experiments, performed using Franz diffusion cells with intact and damaged human skin, noted that Co and Ni powders (dispersed in synthetic sweat at $\text{pH} = 4.5$ and applied to the outer surface of the skin for 24-h) permeate through the skin more easily than Cr powder. Moreover, they have revealed that Co and Ni permeation through the abraded skin barrier (3.6% and 1.27% of the applied dose, respectively) was significantly higher compared with the intact skin (0.02% and 0.03% of the applied dose, respectively). In the case of Cr, no significant difference in permeation through intact and damaged skin (0.03% and 0.01% of the applied dose, respectively) was noted. Lower skin penetration by Cr powder than by Co and Ni powders may be explained with stronger binding of Cr by the skin proteins (Filon *et al.*, 2009).

Unfavourable Health Effects of Heavy Metals Presence in Cosmetics

In the available literature, some cases of topical and systemic effects, related to the use of cosmetics containing heavy metals, including serious clinical cases, have been reported (Warley *et al.*, 1968; Waldron, 1979; Shaltout *et al.*, 1981; van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Chan *et al.*, 2001; Saxena *et al.*, 2001; Soo *et al.*, 2003; CDC, 2005, 2012a, 2012b; Foulds, 2006; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Li *et al.*, 2010; Amry *et al.*, 2011; Benz *et al.*, 2011; Chakera *et al.*, 2011; Travassos *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013). Topical effects such as various allergic reactions were caused mainly by

Ni and Fe present particularly in colour cosmetics (van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Saxena *et al.*, 2001; Foulds, 2006; Travassos *et al.*, 2011), whereas especially unfavourable effects, including internal organs damage, were reported as a result of Hg or Pb presence (Warley *et al.*, 1968; Shaltout *et al.*, 1981; Al Mahroos and Faap, 1993; Weldon *et al.*, 2000; Chan *et al.*, 2001; Soo *et al.*, 2003; CDC, 2005, 2012a, 2012b, 2013a; Tang *et al.*, 2006, 2013; Held and Bayerl, 2008; Özkaya *et al.*, 2009; Al Naama *et al.*, 2010; Li *et al.*, 2010; Benz *et al.*, 2011; Chakera *et al.*, 2011; Lin *et al.*, 2012; Dickenson *et al.*, 2013). In most cases, we did not find any information that the products responsible for the harmful effects had labels indicating the presence of metals as ingredients. Only Özkaya *et al.* (2009) mentioned that one cream had the abbreviation 'precip blanc' on the label, which should suggest that this product contains Hg. None of the authors describing cases of poisoning and other unfavourable health effects caused by metals from cosmetics provided information whether health authorities had removed these products from the market and we cannot be sure if these products are still available or not.

A few cases of allergic contact dermatitis caused by Ni from eye make-up products have been described (van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992). In one case, a woman suffered from oedema and eczema of her eyelids after using for a few days the eye shadows containing 15.9 mg Ni kg⁻¹ and 4.5 mg Co kg⁻¹. Her problems disappeared after she had stopped using this product. She had the same kind of skin problems in the past because of using an eye shadow of another brand (Goh *et al.*, 1989). Another woman was suffering from eyelid eczema for 13 months because of using an eye pencil containing 1.4 mg Ni kg⁻¹ and 6.19 mg Cr kg⁻¹. Her health problem disappeared after corticosteroids treatment, but the eczema returned when she started to use this product again (Zemba *et al.*, 1992). van Ketel and Liem (1981) mentioned two women with eyelid dermatitis, one of whom also had hand dermatitis. They considered Ni as a cause of these problems. The eye shadows used by these women contained 76 and 87 mg Ni kg⁻¹, whereas the mascara used by one of them contained 102 mg Ni kg⁻¹. Allergic contact dermatitis, itching, erythema, moderate infiltration and scaling of both eyelids (symptoms lasting 4 months) were also noticed in a woman from Belgium who used an eye pencil containing Ni in the concentration of 0.028 mg kg⁻¹. These symptoms disappeared after stopping the use of this cosmetic, but they returned after she started to use this eye pencil again (Travassos *et al.*, 2011). Five cases of facial eczema connected with using foundations containing iron oxide pigments with trace amounts of Ni have been reported (Foulds, 2006). Ni was also found in iron oxide brown pigments (1.9–250 mg kg⁻¹) used for the production of eye cosmetics (van Ketel and Liem, 1981). In addition, an incident of a 44-year-old woman with persistent eyelid allergic contact dermatitis (lasting for 10 months) caused by 5% black iron oxide from a mascara has been noticed. Simultaneously the patch tests showed that she was also susceptible to lanolin present in this cosmetic (Saxena *et al.*, 2001). However, her condition improved after she stopped using the mascara. Another allergen often present in coloured cosmetics is Cr (Zemba *et al.*, 1992; Sainio *et al.*, 2000; Kang *et al.*, 2006; Atz and Pozebon, 2009; Al-Dayel *et al.*, 2011). Chromium hydroxide green [Cr₂O(OH)₄] and chromium oxide green (Cr₂O₃) are added intentionally to eye shadows as colouring agents (Kang *et al.*, 2006), which is approved by EU regulations (OJEU, 2009). The threshold for allergic reactivity to Cr (VI) is 5 mg l⁻¹ (Kang *et al.*, 2006). It should be emphasized that metals causing allergic reactions may be present in

the same product (especially in coloured cosmetics, for example Ni and Cr in eye pencils; Table 1; Zemba *et al.*, 1992). Kang and Lee (2006) noticed a case of allergic contact dermatitis after the use of henna because of Ni, Co and *p*-phenylenediamine were present in this product. In most of the above-described cases of allergy caused by the use of cosmetics containing metals (especially Ni), the allergy to metals was confirmed by patch tests (van Ketel and Liem, 1981; Goh *et al.*, 1989; Zemba *et al.*, 1992; Saxena *et al.*, 2001; Foulds, 2006; Kang and Lee, 2006; Travassos *et al.*, 2011). People who know that they are allergic to metals should completely avoid cosmetics containing metals such as Ni, Cr, Co or Fe. Thus, manufacturers should provide on packagings the information about the presence and levels of these metals in the final products.

Cd and Cu present in cosmetics are other metals responsible for unintended effects to the human body. A case of change of the hair colour into green after the use of henna containing Cu was observed (Tosti *et al.*, 1991). Severe eye keratitis after using kohl, which contained high amounts of Cd (6259 mg kg⁻¹) and trace concentrations of Hg and thallium (Tl), has been reported in a 21-year-old woman (Amry *et al.*, 2011).

Although Hg is widely known as a dangerous heavy metal (Karagas *et al.*, 2012; Sommar *et al.*, 2013) and some cases of poisonings owing to the use of skin creams containing this element have been reported in the past (Karagas *et al.*, 2012; Sommar *et al.*, 2013), Hg-containing skin-lightening creams are still commonly used in many developing countries. Some women, especially from Africa, Asia or Mexico, often use such creams (Weldon *et al.*, 2000; Soo *et al.*, 2003; Tang *et al.*, 2006, 2013; Chakera *et al.*, 2011; CDC, 2012b). Using skin-lightening creams containing 1762–30 000 mg Hg kg⁻¹ resulted in an elevated concentration of Hg in hair (22.5 mg kg⁻¹ vs. < 11.6 mg kg⁻¹ in the family members non-using these cosmetics; Chan *et al.*, 2001), blood (26–233 nmol l⁻¹ vs. its normal concentration < 30–50 nmol l⁻¹ according to various authors; Chan *et al.*, 2001; Soo *et al.*, 2003; Chakera *et al.*, 2011; Tang *et al.*, 2013) and urine (316–2521 nmol per day vs. normal concentration < 10–50 nmol per 24 h according to various authors; Chan *et al.*, 2001; Soo *et al.*, 2003; Tang *et al.*, 2013). Using skin-lightening creams resulted in low back pain (Chan *et al.*, 2001), sleep disorders, as well as in kidney damage manifested by the oedema of this organ, stiffness of the glomerular peripheral capillary loops, slight thickening of the glomerular basement membrane, mild proliferation of mesangial cells and matrix (Soo *et al.*, 2003; Li *et al.*, 2010), ankle swelling, frothy urine (Soo *et al.*, 2003), proteinuria (Soo *et al.*, 2003; Tang *et al.*, 2006, 2013; Li *et al.*, 2010), as well as peripheral and periorbital oedema (Chakera *et al.*, 2011). In addition, systemic allergic dermatitis, erythema and itchy papulo-vesicular lesions 5–6 h after the application of the skin-lightening cream containing Hg have been observed (Özkaya *et al.*, 2009). Nephropathy was also reported in a woman exposed to Hg for 36 months from a hair dye who had the urinary concentration of this metal at the level of 27 µg l⁻¹ (Li *et al.*, 2010). Weldon *et al.* (2000) detected an elevated concentration of Hg in the urine (mean 146.7 µg l⁻¹; range 0 – 1,170 µg l⁻¹; whereas the safe concentration is up to 20 µg l⁻¹; CDC, 1990) among 330 lightening-cream users from Texas (USA).

It is very important to underline that there exists strong and well-confirmed evidence that using Hg-containing cosmetics may be a source of exposure to this metal of the family members non-using these products. The exposure may occur by the dermal route and through the gastrointestinal tract as well as by inhalation of Hg vapours (Held and Bayerl, 2008; CDC, 2012b). In the USA, a study was performed to establish a Hg concentration in the urine

of 22 members of 5 households where skin-lightening creams coming from Mexico were used (CDC, 2012b). Hg was detected in excessive amounts ($\geq 5 \mu\text{g g}^{-1}$ creatinine) in the urine of 15 people; however, only 10 of the 22 people declared the use of skin-lightening creams. Among the 15 people (9 users and 6 non-users of these creams), the Hg concentration in the urine ranged from 26–317 $\mu\text{g g}^{-1}$ of creatinine for users and from 20 to 276 $\mu\text{g g}^{-1}$ of creatinine for non-users. Only in one user of these creams, the Hg concentration in the urine was below 5 $\mu\text{g g}^{-1}$ creatinine. High concentrations of Hg in the urine were also observed in young children from families described above (up to 276 $\mu\text{g g}^{-1}$ creatinine; CDC, 2012b). The non-specific symptoms of chronic Hg poisoning (numbness, tingling, dizziness, forgetfulness, headaches, and depression) were observed in six users of these products. The results suggest that the 6 family members who had an increased Hg concentration in the urine also were exposed to this metal from the bleaching creams. The concentration of Hg vapours in spot household locations (for example near items frequently touched by cream users or furniture where creams were stored) reached 17–50 $\mu\text{g per m}^3$ (CDC, 2012b). Cases of Hg poisonings from skin-bleaching creams containing this element were also affirmed in two families who originated from the Kosovo–Albanian region (Held and Bayerl, 2008). Elevated Hg concentrations in the urine were detected in a school survey in one of the sons of each family and it was the reason for screening all members of these families. The highest concentrations of Hg were found in females who had used creams containing this element. One of them suffered from chronic headaches and another lost weight and had high blood pressure. One of the male members of these families who did not use these creams suffered from concentration impairment and gastrointestinal disorders. Because the women kept their creams in the fridges, the family members might be exposed to this metal present in their diet (Held and Bayerl, 2008).

Particularly dangerous poisonings caused by Hg from cosmetics were noted in children and pregnant women (Benz *et al.*, 2011; Dickenson *et al.*, 2013). In a 4-year-old Iraqi girl, symptoms indicating chronic intoxication with Hg such as clonic seizures, loss of appetite, and weight loss, weakness, dysthymia, impulsiveness, itching rash in the palms, tachycardia, and hypertension, and hyperintense lesions in the brain were observed after 3-month use of this metal-containing skin-whitening cream. The concentrations of Hg in her blood and urine reached 32.5 and 41.1 $\mu\text{g l}^{-1}$, respectively (Benz *et al.*, 2011), whereas the safe level of Hg in urine has been considered to be $< 20 \mu\text{g per l}^{-1}$ (CDC, 1990) and the highest acceptable concentration of this element in the blood is 6 $\mu\text{g l}^{-1}$ (Kuno *et al.*, 2013). Using two different face creams, containing 21 and 30 g Hg kg^{-1} , purchased from a pharmacy in Mexico by a woman who was in the third trimester of pregnancy resulted in a blood Hg concentration of 15.16 $\mu\text{g l}^{-1}$ (Dickenson *et al.*, 2013). The concentration of this element detected in her bathroom near the jars of these face creams reached above 11 $\mu\text{g per m}^3$ (Dickenson *et al.*, 2013), while its acceptable residential indoor air concentration is $\leq 0.5 \mu\text{g per m}^3$ (CDC, 1990).

According to Centers for Disease Control and Prevention (CDC), the acceptable Pb level in the blood of children is below 5 $\mu\text{g 100 ml}^{-1}$, whereas in adults from the general population (not working in factory or other places where high concentrations of Pb are present) the level is below 10 $\mu\text{g Pb 100 ml}^{-1}$ (CDC, 2013b, 2013c). Elevated Pb concentrations in the blood were reported in children and adults as a result of using cosmetic products containing this heavy metal (Warley *et al.*, 1968; Shaltout *et al.*, 1981; Al Mahroos and Faap, 1993; CDC, 2005, 2012a, 2013a; Al Naama

et al., 2010; Lin *et al.*, 2012; Goswami, 2013). The blood Pb concentrations in 222 children from China having applied Pb powder for a skin care purpose (as a folk remedy) ranged from 0.19 to 69.0 $\mu\text{g 100 ml}^{-1}$. The mean blood concentration of this heavy metal in the entire group reached 18.1 $\mu\text{g 100 ml}^{-1}$, whereas in regular users, irregular users and non-users of this powder the concentration was 32 $\mu\text{g 100 ml}^{-1}$, 12 $\mu\text{g 100 ml}^{-1}$ and 6 $\mu\text{g 100 ml}^{-1}$, respectively (Lin *et al.*, 2012). The final formulations (prepared by mixing lead monoxide – reddish powder with talcum powder) used for infants' eczema and other skin problems in these children contained from 42 g Pb kg^{-1} to 623 g Pb kg^{-1} (Lin *et al.*, 2012).

The blood Pb concentrations in two twin children from the Hispanic community in the USA who used a yellow powder called 'litargirio' containing 790 g Pb kg^{-1} as an antiperspirant reached 14 $\mu\text{g 100 ml}^{-1}$ and then increased (from June 2001 to May 2003) up to 42 $\mu\text{g 100 ml}^{-1}$ for one of them and 15 $\mu\text{g 100 ml}^{-1}$ in the other and then increased up to 26 $\mu\text{g 100 ml}^{-1}$ (CDC, 2005). The Pb concentration in the blood of their female cousins aged 1 and 5 years was 32 $\mu\text{g 100 ml}^{-1}$ (from June 2002 to January 2003) and then increased up to 44 $\mu\text{g 100 ml}^{-1}$, and 24 $\mu\text{g 100 ml}^{-1}$ and then increased up to 29 $\mu\text{g 100 ml}^{-1}$, respectively (CDC, 2005). The younger sister had not used litargirio, but she shared a bedroom with her sister (who used it regularly) and probably she ingested residues of this product present on various surfaces through hand-to-mouth activity. The concentration of Pb in the blood of this girl decreased after her sister stopped using this product (CDC, 2005).

In the available literature, we can find many cases of poisonings caused by Pb from kohl (surma), which might be absorbed through the conjunctiva, lacrimation, eye rubbing and finger sucking by children (Warley *et al.*, 1968; Shaltout *et al.*, 1981; Al Mahroos and Faap, 1993; Al Naama *et al.*, 2010; CDC, 2012a, 2013a; Goswami, 2013). Many years ago, Warley *et al.* (1968) reported a case of Pb poisoning from kohl in a 3-year-old Indian boy (resident in England) admitted to hospital with Pb encephalopathy. This child had convulsions, Pb lines in the long bones and intestinal opacities, suggesting ingestion of this heavy metal. The Pb concentration in his blood was very high and reached 178 $\mu\text{g 100 ml}^{-1}$. The blood concentrations of this metal in his mother and a 5-year-old sibling were 65 $\mu\text{g 100 ml}^{-1}$ and 72 $\mu\text{g 100 ml}^{-1}$, respectively. The only source of the three subjects' exposure to Pb was surma used by the mother for cosmetic reasons and in children for 'health' (Warley *et al.*, 1968). Pb from kohl has also been considered as the cause of encephalopathy noted in Kuwait (Shaltout *et al.*, 1981) and Bahrain children (Al Mahroos and Faap, 1993).

Too high concentrations of Pb in the blood of children of two families originating from Afghanistan and Nigeria were noticed in USA as the result of using kohl or 'tiro' (a Nigerian cosmetic very similar to kohl used in Asia) to promote eye health or to protect the children from 'the evil eye' (CDC, 2012a, 2013a). Fortunately, despite too high concentrations of Pb in the blood (reaching up to 33.5 $\mu\text{g 100 ml}^{-1}$), they had no signs of Pb toxicity, because the chelation therapy was performed very quickly (CDC, 2012a, 2013a). The content of Pb in the kohl used by the family originating from Afghanistan reached 54% (CDC, 2013a), whereas this metal content in the tiro used by the Nigerian family was 82.6% (CDC, 2012a). The mean blood Pb concentration among 69 children in India whose parents applied kohl on their bodies (e.g. to stop bleeding after a circumcision) was $29.6 \pm 10.2 \mu\text{g 100 ml}^{-1}$ (Goswami, 2013). On the labels of the surma packages it was not mentioned that this product contained Pb; however, this metal was present in all collected samples in the concentrations ranging from 0.64 to 32.13 mg kg^{-1} (Goswami, 2013). Al Naama *et al.* (2010)

have reported higher Pb concentrations in the blood of women from Iraq using kohl ($13.91 \pm 4.42 \mu\text{g } 100 \text{ mL}^{-1}$) in comparison with their counterparts not using this product ($9.88 \pm 2.68 \mu\text{g } 100 \text{ mL}^{-1}$).

Many years ago a case of poisoning with Pb in a child from a hair cosmetic used to darken hair was described. The concentration of Pb in the blood of the 4-year-old girl was $1,360 \mu\text{g L}^{-1}$. The Environmental Health Department discovered that the only source of Pb in her home was the product that her mother used to darken her hair. The girl was in the habit of putting her fingers into cosmetic and licking them, and she suffered from Pb encephalopathy, headaches, nausea and pale-grey colour of the skin (Waldron, 1979).

The above-mentioned, well-documented reports on the unfavourable effects related to metals presence in commercially available cosmetics provide strong evidence that heavy metals present in these products may be dangerous.

Danger for Health Created by Al Presence in Cosmetics

As was mentioned previously, Al compounds may be present in various types of cosmetic products, including antiperspirants, colour cosmetics, creams and cosmetic emulsions, as well as in traditional products and cosmetics containing minerals from the Dead Sea (Table 2). The use of these cosmetics is one of the sources of exposure to Al, which is absorbed through the skin, and accumulated in the organism as the result of repeated use of these products. Al is a metal characterized by high toxicity and under prolonged exposure it accumulates in the bone tissue leading to osteomalacia (Guillard *et al.*, 2004) and in the brain contributing to the development of Alzheimer's disease and other neurodegenerative disorders (Exley and Vickers, 2014).

Some literature data shows that Al presence in cosmetic products may create a danger for human health (Guillard *et al.*, 2004; Sappino *et al.*, 2012). Guillard *et al.* (2004) have provided clear evidence of an unfavourable action of Al present in antiperspirants on the health of these products users. They have reported a case of 43-year-old woman suffering from hyperaluminemia, bone pain, and extreme fatigue after using everyday for 4 years an antiperspirant cream containing aluminium chlorohydrate. The woman applied to each underarm about 1 g of the antiperspirant cream containing 20% of aluminium chlorohydrate (the authors did not provide data about a brand of this product), what constituted a daily dose of 0.108 g of Al(III), which over a 4-year period amounted to 157.3 g. The use of this antiperspirant was the only source of this woman's exposure to Al. This element was detected in her plasma and urine in concentrations of $3.88 \pm 0.07 \mu\text{mol L}^{-1}$ (the normal concentration is $< 0.37 \mu\text{mol L}^{-1}$) and $1.71 \mu\text{mol per } 24 \text{ h}$ (the normal concentration is $< 1.1 \mu\text{mol per } 24 \text{ h}$), respectively. When the woman has stopped using the antiperspirant, the Al concentrations in the urine and plasma decreased and reached the reference levels (3 and 8 months later, respectively), and then the bone pain and fatigue completely disappeared (Guillard *et al.*, 2004). This case clearly indicates that Al present in antiperspirants may be harmful for human health and that cessation of use of this cosmetic allows recovery.

It is supposed that the presence of Al in antiperspirants can contribute to the development of breast cancer, especially of the upper outer quadrant of the breast being a part of the body where antiperspirants are applied (Darbre, 2003; Darbre, 2006; Mannello *et al.*, 2009, 2011; Sappino *et al.*, 2012; Darbre *et al.*, 2013). Al-based complexes (used in antiperspirants as active ingredients) produce

radiopaque particles in an ultrasound gel pad, simulating breast tissue. These particles were seen on a mammography, mimicking microcalcifications whose shape depends on the mode of application (solid, gel and roll-on) of the antiperspirants (Mesurrolle *et al.*, 2014). The presence of radiopaque particles originating from antiperspirants in an ultrasound gel pad, simulating breast tissue, clearly shows that Al is accumulated in the breast tissue. Moreover, some data indicate that Al is accumulated in high concentrations in nipple aspirate fluid present in the breast ducts of the people suffering from the breast cancer (Mannello *et al.*, 2011) and in the human breast cyst fluid of the people suffering from gross cystic breast disease (Mannello *et al.*, 2009). However, it is unclear whether this metal found in the breast of the human who suffered from breast cancer originated from antiperspirants.

The results of experiments conducted in recent years (Sappino *et al.*, 2012; Darbre *et al.*, 2013) confirmed the possibility of Al participation in the development of cancer. Sappino *et al.* (2012) revealed that aluminium chloride in concentrations of 10–300 μM (approximately 100 000-fold lower than those found in antiperspirants) acts as an activated oncogene in proliferating primary human mammary epithelial cells because it induces genomic instability, DNA synthesis, senescence in proliferating primary human mammary epithelial cells and DNA double-strand breaks, as well as it displays strong upregulation of the p53/p21^{Waf1} pathway (a key mediator of growth arrest and senescence) and it promotes anchorage-independent growth in human mammary epithelial cells. Mutagenic action was observed only in the cell line present in the human breast while it was not observed neither in bacteria nor in human keratinocytes, and it is strong evidence that Al has cancerogenic activity in human breasts (Sappino *et al.*, 2012). Darbre *et al.* (2013) have noticed that Al can increase migratory and invasive properties of the human breast cancer cell line.

Conclusions

The numerous data presented in this review paper provide evidence that heavy metals and the presence of Al and their too high concentrations have been detected in cosmetics produced in various countries, including countries with established strict law limitations on metals in cosmetics. The fact that nowadays people may buy cosmetic products via the Internet or bring them from the countries without any specific regulations concerning the maximum levels of metals in cosmetics creates the risk of the use of contaminated cosmetic products even in countries with strict regulations on metals content in these products. Reported in the literature are cases of allergic reactions and systemic actions caused by heavy metals present in cosmetics together with the available data on metal concentrations in cosmetics nowadays produced show that the risk of the unfavourable health effects due to metals presence in the used cosmetics is still real. Thus, appropriate actions, including especially the setting of limits of occurrence when they are lacking until now as well as regular control of raw materials, conditions of cosmetics production and the final products are necessary. This is particularly important because cosmetic products are used every day all over the world not only by women and men but also by children and older people in who metal absorption via the skin is facilitated and who are more susceptible to their toxic action. That is why cosmetics should be considered as a possible source of exposure to toxic metals and in the case of poisonings with metals when the history of the case do not provide evidence of exposure to metals from occupational and environmental

conditions, cosmetics should be considered as possible causative factors. It is necessary to make efforts to reduce dangerous metal concentrations in cosmetics with the aim to enhance the safety of these commonly used products.

Conflict of interest

The authors declare that there are no conflicts of interest.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web-site:

Table S1. Concentrations of heavy metals detected in colour eye cosmetics produced in various countries (mg kg⁻¹)

Table S2. Concentrations of heavy metals detected in colour eye cosmetics produced in various countries (mg kg⁻¹)

Table S3. Concentrations of heavy metals detected in colour lip cosmetics (lipsticks and lip glosses) produced in various countries (mg kg⁻¹)

Table S4. Concentrations of metals detected in foundation creams, make-up bases, powders, nail polish and blushers produced in various countries (mg kg^{-1})

Table S5. Concentrations of heavy metals detected in face and body care products (mg kg^{-1})

Table S6 Concentrations of heavy metals detected in face and body care products (mg kg^{-1})

Table S7A. Concentrations of heavy metals detected in hair cosmetics (mg kg^{-1})

Table S7B. Concentrations of heavy metals detected in hair cosmetics (mg kg^{-1})

Table S8A. Concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products (mg kg^{-1})

Table S8B. Concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products (mg kg^{-1})

Table S9 Concentrations of heavy metals detected in raw material, natural cosmetics and cosmetics considered as natural products (mg kg^{-1})

Supplementary Material

Metals in cosmetics – implications for human health

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Short title
Metals in cosmetics

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Abbreviations

As, arsenic; Cd, cadmium; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Hg, mercury; Ni, nickel; Pb, lead.

Table S1. Concentrations of heavy metals detected in colour eye cosmetics produced in various countries (mg kg⁻¹)

Origin	Pb	Cd	Ni	As	Hg	References
Eye shadows						
England	8.16 – 16.81	0.9 – 3.1	-	-	-	(Mousavi <i>et al.</i> , 2013)
Finland	0.5 – 16.8	-	0.5 – 49.7	0 – 2.3	-	(Sainio <i>et al.</i> , 2000)
Italy	-	0.02 – 0.07	0.03 – 344	-	-	(Contado and Pagnoni, 2012; Volpe <i>et al.</i> , 2012)
USA	3.7 – 3.8	0 – 1.5	0.02 – 12.9	-	-	(Volpe <i>et al.</i> , 2012; Faruruwa and Bartholomew, 2014)
Brazil	0 – 13	0 – 0.4	7.21 – 106	0 – 11.1	0 – 0.74	(Atz and Pozebon, 2009)
China	5.2 – 202.06	0 – 10.95	0.03 – 22.7	-	-	(Contado and Pagnoni, 2012; Volpe <i>et al.</i> , 2012; Mousavi <i>et al.</i> , 2013)
Iran	0.6 – 42.79	0.62 – 55.59	-	-	-	(Mousavi <i>et al.</i> , 2013; Nouromoradi <i>et al.</i> , 2013)
Korea	8.65 – 20.79	1.28 – 1.96	-	-	-	(Kang <i>et al.</i> , 2006; Lee <i>et al.</i> , 2008; Mousavi <i>et al.</i> , 2013)
Nigeria	0 – 55	0 – 15.38	2.9 – 359.44	-	-	(Omolaoye <i>et al.</i> , 2010; Umar and Caleb, 2013)
Palestine	-	-	18.45	-	-	(Al-Qutob <i>et al.</i> , 2013)
Saudi Arabia	0.42 – 58.7	0.01 – 0.27	3.26 – 112	-	0 – 0.01	(Al-Saleh <i>et al.</i> , 2009; Al-Dayel <i>et al.</i> , 2011)
Turkey	0.52 – 4.65	8.0 – 26.33	-	-	-	(Mousavi <i>et al.</i> , 2013)
Eye liners/ Eye pencils						
Nigeria	0.31 – 213.6	0.3 – 3.05	0.69 – 21.5	-	-	(Nnorm <i>et al.</i> , 2005; Umar and Caleb, 2013)
Mascara						
USA	4.7 – 14	0.6 – 1.5	6.4 – 21.5	-	-	(Faruruwa and Bartholomew, 2014)
Saudi Arabia	0.15 – 2.18	0 – 0.04	5.07 – 46.8	-	0 – 0.01	(Al-Dayel <i>et al.</i> , 2011)
Taiwan	0 – 5	1.25 – 1.5	35.5 – 37.5	-	-	(Faruruwa and Bartholomew, 2014)

Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic; Hg, mercury.

Table S2. Concentrations of heavy metals detected in colour eye cosmetics produced in various countries (mg kg⁻¹)

Origin	Cr	Fe	Cu	Co	References
Eye shadows					
Finland	0.3 – 5,470	-	-	0.5 – 41.2	(Sainio <i>et al.</i> , 2000)
Italy	0.04 – 149.5	-	-	0 – 17.3	(Contado and Pagnoni, 2012; Volpe <i>et al.</i> , 2012)
USA	0.01 – 2.86	2,509 – 2,912.8	-	0 – 0.004	(Volpe <i>et al.</i> , 2012; Faruruwa and Bartholomew, 2014)
Brazil	3.29 – 11,900	-	0.34 – 99,000	1.13 – 16.8	(Atz and Pozebon, 2009)
China	0.02 – 37	48,692.2 – 48,727.4	-	0 – 4.9	(Contado and Pagnoni, 2012; Volpe <i>et al.</i> , 2012; Faruruwa and Bartholomew, 2014)
Korea	0 – 1.28	2.2 – 66.9	0 – 2.5	-	(Kang <i>et al.</i> , 2006; Lee <i>et al.</i> , 2008)
Nigeria	0 – 150	-	1.67 – 465	122.78 – 258.33	(Omolaoye <i>et al.</i> , 2010; Umar and Caleb, 2013)
Palestine	-	-	18.95	-	(Al-Qutob <i>et al.</i> , 2013)
Saudi Arabia	5.89 – 7,000	7,860 – 300,000	14.3 – 37.3	1.28 – 31.3	(Al-Dayel <i>et al.</i> , 2011)
Eye liners/Eye pencils					
Korea	-	115.7 – 683.1	-	-	(Lee <i>et al.</i> , 2008)
Nigeria	0.15 – 64.3	17 – 64,743.1	-	-	(Nnorm <i>et al.</i> , 2005; Umar and Caleb, 2013; Faruruwa and Bartholomew, 2014)
Mascara					
USA	2.01 – 7.04	3,482.5 – 4,468.8	-	-	(Faruruwa and Bartholomew, 2014)
Korea	-	52.5 – 224.1	-	-	(Lee <i>et al.</i> , 2003)
Saudi Arabia	0.37 – 17.1	30,000 – 100,000	0.14 – 1.04	1.73 – 20.4	(Al-Dayel <i>et al.</i> , 2011)
Taiwan	9.31 – 14.59	93,094.38 – 106,745.5			(Faruruwa and Bartholomew, 2014)
Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.					

Table S3. Concentrations of heavy metals detected in colour lip cosmetics (lipsticks and lip glosses) produced in various countries (mg kg⁻¹)

Origin	Pb	Cd	Ni	Hg	References
European Union	0.04 – 3.75	-	-	-	(Piccini <i>et al.</i> , 2013)
USA	0 – 4.8	0 – 3.48	0 – 9.73	0 – 0.01	(Perkin Elmer, 2012; Liu <i>et al.</i> , 2013; Faruruwa and Bartholomew, 2014)
Brazil	0 – 2.67	0 – 0.86	0.54 – 4.43	-	(Atz and Pozebon, 2009; Soares and Nascentes, 2013)
China	2.07 – 4.54	0.2	0.7	-	(Soares and Nascentes, 2013; Ullah <i>et al.</i> , 2013)
Iran	0.08 – 5.2	4.08 – 60.2	-	-	(Nourmoradi <i>et al.</i> , 2013)
Japan	11.2	0.21	0.79	-	(Ullah <i>et al.</i> , 2013)
Nepal	30 – 145	-	-	-	(Sah, 2012)
Nigeria	0.27 – 252.4	0.5 – 7.98	0.55 – 22.8	-	(Nnorm <i>et al.</i> , 2005; Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)
Pakistan	0.27 – 11.3	0.2 – 0.5	0.6 – 5.98	-	(Khalid <i>et al.</i> , 2013; Ullah <i>et al.</i> , 2013)
Palestine	0 – 15.92	0 – 0.14	0 – 4.94	-	(Al-Qutob <i>et al.</i> , 2013)
Saudi Arabia	0.27 – 3,760	4.9 – 10.4	-	-	(Al-Saleh <i>et al.</i> , 2009; Gondal <i>et al.</i> , 2010)
Taiwan	3.4 – 3.64	-	2.8 – 3.6	-	(Soares and Nascentes, 2013; Faruruwa and Bartholomew, 2014)
Turkey	0 – 0.005	-	-	-	(Gunduz and Akman, 2013)
	Cr	Fe	Cu	Co	
USA	0 – 93.3	6,063.3 – 6,839.7	0 – 7.38	0 – 1.3	(Perkin Elmer, 2012; Liu <i>et al.</i> , 2013; Faruruwa and Bartholomew, 2014)
Brazil	0.35 – 5.43	-	0 – 0.89	0 – 1.77	(Atz and Pozebon, 2009)
China	-	2.58	1.93	0.52	(Ullah <i>et al.</i> , 2013)
Japan	-	540	0.03	0.3	(Ullah <i>et al.</i> , 2013)
Korea	-	0 – 2.9	0 – 2.6	-	(Lee <i>et al.</i> , 2008)
Nigeria	0.4 – 58.8	92.2 – 632	-	-	(Nnorm <i>et al.</i> , 2005; Umar and Caleb, 2013)
Pakistan	0.22 – 5.43	1,164	6.04	0.87	(Khalid <i>et al.</i> , 2013; Ullah <i>et al.</i> , 2013)
Palestine	0 – 81.6	-	0 – 118.6	-	(Al-Qutob <i>et al.</i> , 2013)
Saudi Arabia	10.2 – 40.8	-	-	-	(Gondal <i>et al.</i> , 2010)
Taiwan	6.04 – 9.81	2,123.8 – 2,190.9			(Faruruwa and Bartholomew, 2014)
Pb, lead; Cd, cadmium; Ni, nickel; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.					

Table S4. Concentrations of metals detected in foundation creams, make-up bases, powders, nail polish and blushers produced in various countries (mg kg⁻¹)

Origin	Pb	Cd	Ni	Hg	References
Foundation creams, make-up bases, powders					
India	2.33 – 3.11	0.26 – 0.36	0.72 – 1.18	-	(Ullah <i>et al.</i> , 2013)
Nigeria	1.3 – 61.86	0.18 – 29.05	2.5 – 19.7	-	(Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)
Pakistan	3.97	0.32	1.42	-	(Ullah <i>et al.</i> , 2013)
Palestine	0 – 9.38	-	3.23 – 214.54	-	(Al-Qutob <i>et al.</i> , 2013)
Blushers					
USA	12 – 31.7	0.1	4.1 – 7.3	-	(Faruruwa and Bartholomew, 2014)
Nigeria	0.2 – 5.1	0.1 – 0.3	6.3 – 13.1	-	(Faruruwa and Bartholomew, 2014)
Nail polish					
USA	0.2 – 6.03	0.01 – 0.36	-	0 – 0.19	(Perkin Elmer, 2012)
Nigeria	1.24	1.68	1.89	-	(Umar and Caleb, 2013)
	Cr	Fe	Cu	Co	
Foundation creams, make-up bases, powders					
India	-	625 – 1,067	1.09 – 1.51	0.66 – 1.02	(Ullah <i>et al.</i> , 2013)
Korea	1.52 – 2.02	0 – 8.4	0 – 0.5	-	(Lee <i>et al.</i> , 2008; Hwang <i>et al.</i> , 2009)
Nigeria	1.28 – 1.47	-	-	-	(Nnorm <i>et al.</i> , 2005)
Pakistan	0.26	779.8	1.36	1.22	(Ullah <i>et al.</i> , 2013)
Palestine	4.45 – 15.75	-	0.89 – 9.69	0 – 13.02	(Al-Qutob <i>et al.</i> , 2013)
Blushers					
USA	14.59 – 15.09	15,103.7 – 23,430.4	-	-	(Faruruwa and Bartholomew, 2014)
Nigeria	2.77 – 9.81	15,263.5 – 53,084.1	-	-	(Faruruwa and Bartholomew, 2014)
Nail polish					
USA	0.8 – 10.9	-	-	-	(Perkin Elmer, 2012)
Brazil	0 – 5.07	0 – 17,900	-	0 – 0.58	(Favaro <i>et al.</i> , 2003)
Nigeria	0.26	-	-	-	(Umar and Caleb, 2013)

Pb, lead; Cd, cadmium; Ni, nickel; Hg, mercury; Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

Table S5. Concentrations of heavy metals detected in face and body care products (mg kg⁻¹)

Origin	Pb	Cd	Ni	Hg	References
Creams (skin-whitening, anti-freckles, anti-wrinkles, for acne)					
Hong Kong	-	-	-	0 – 65,133	(Chan <i>et al.</i> , 2001; Sin and Tsang, 2003)
Skin-lightening creams/moisturizing creams/face creams					
Italy	0.2	-	0.02 – 0.41	0.04	(Cristuado <i>et al.</i> , 2013)
USA	3.37 – 41,600	-	-	-	(McKelvey <i>et al.</i> , 2011; Perkin Elmer, 2012; Adawe and Oberg, 2013)
India	0.03 – 1.84	0.02 – 0.04	0.27	-	(Chauhan <i>et al.</i> , 2010; Ullah <i>et al.</i> , 2013)
Nigeria	0 – 0.93	0 – 5.05	1.06 – 8.43	-	(Ayenimo <i>et al.</i> , 2010b; Onwordi <i>et al.</i> , 2011)
Pakistan	1.74	0.06	0.31	-	(Ullah <i>et al.</i> , 2013)
Palestine	-	-	2.89 – 18.45	-	(Al-Qutob <i>et al.</i> , 2013)
The United Arab Emirates	3.71	0.04	0.26	-	(Ullah <i>et al.</i> , 2013)
Germicidal creams, soaps and balms					
USA	-	-	-	204 – 4,770	(McKelvey <i>et al.</i> , 2011)
Medicated creams/Non-medicated creams/Non-skin-lightening creams					
Nigeria	0 – 0.13	0.02 – 0.36	0.01 – 1.01	-	(Ayenimo <i>et al.</i> , 2010a, 2010b)
Body creams/lotions/milks					
Italy	0 – 0.01	0 – 0.02	0.02 – 0.15	-	(Bocca <i>et al.</i> , 2007; Cristuado <i>et al.</i> , 2013)
Nigeria	0.21 – 9.2	0.2 – 16.67	0 – 6.56	-	(Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)
Shaving creams					
India	0.66 – 0.72	0.01 – 0.02	-	-	(Chauhan <i>et al.</i> , 2010)
Emulsions (creams, lotions, petroleum jellies, gels)					
Europe	0 – 0.24	-	-	-	(Oyediji <i>et al.</i> , 2011)
USA	0 – 0.28	-	-	-	(Oyediji <i>et al.</i> , 2011)
Africa	0 – 0.39	-	-	-	(Oyediji <i>et al.</i> , 2011)
Asia	0.25	-	-	-	(Oyediji <i>et al.</i> , 2011)
Eye cleansers					
Nigeria	8.06 – 213.6	0.3 – 3.88	-	-	(Nnorm <i>et al.</i> , 2006)
Foam bath products					
Italy	-	-	0.03 – 0.29	-	(Ciaralli <i>et al.</i> , 1996)
Toothpastes					
Nigeria	0 – 0.48	0 – 0.44	0.01 – 2.47	0.01 – 1.11	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Mouth-cleansing powder					
Nigeria	8.89	28.73	29.39	-	(Umar and Caleb, 2013)
Hand and cuticle cream					
Nigeria	0.39	6.83	1.38	-	(Umar and Caleb, 2013)
Bathing soaps					
India	3.82 – 4.63	0.03 – 0.04	-	-	(Chauhan <i>et al.</i> , 2010)
Soaps (toilet soaps, medicated, non-medicated, skin-lightening, non-skin-lightening soaps)					
Europe	0.05	-	0.03	2.1 – 7.4	(Harada <i>et al.</i> , 2001; Cristuado <i>et al.</i> , 2013)
Kenya	-	-	-	0 – 0.002	(Harada <i>et al.</i> , 2001)
Nigeria	0 – 5.8	0 – 12.85	0 – 5.76	-	(Ayenimo <i>et al.</i> , 2010a, 2010b; Orisakwe and Otaraku, 2013; Umar and Caleb, 2013)

Pb, lead; Cd, cadmium; Ni, nickel; Hg, mercury.

Table S6. Concentrations of heavy metals detected in face and body care products (mg kg⁻¹)

Origin	Cr	Fe	Cu	Co	References
Skin-lightening creams/Moisturizing creams/Face creams					
Italy	0.14 – 0.72	-	-	-	(Cristuado <i>et al.</i> , 2013)
USA	0.01 – 0.08	-	-	-	(Perkin Elmer, 2012)
India	-	1,846	2.06	0.25	(Ullah <i>et al.</i> , 2013)
Nigeria	0.23 – 0.3	0.53 – 1.18	2.27 – 17.85	-	(Ayenimo <i>et al.</i> , 2010b; Onwordi <i>et al.</i> , 2011; Cristuado <i>et al.</i> , 2013; Umar and Caleb, 2013)
Pakistan	-	2,469	65.34	0.22	(Ullah <i>et al.</i> , 2013)
Palestine	0 – 4.3	-	0.84 – 18.95	-	(Al-Qutob <i>et al.</i> , 2013)
The United Arab Emirates	-	2,250	2.9	0.23	(Ullah <i>et al.</i> , 2013)
Body creams/ lotions					
Italy	0.02 – 0.3	-	0 – 0.05	-	(Bocca <i>et al.</i> , 2007)
Nigeria	0.15 – 0.4	-	-	-	(Umar and Caleb, 2013)
Medicated creams/Non-medicated creams/Non-skin-lightening creams					
Nigeria	0.03 – 0.47	0.19 – 0.86	0.57 – 6.85	-	(Ayenimo <i>et al.</i> , 2010a, 2010b)
Emulsions (creams, lotions, petroleum jellies, gels)					
Europe	0 – 0.1	0.06 – 1.09	-	-	(Oyededeji <i>et al.</i> , 2011)
USA	0 – 0.07	0.05 – 1.83	-	-	(Oyededeji <i>et al.</i> , 2011)
Africa	0 – 0.5	0.33 – 1.58	-	-	(Oyededeji <i>et al.</i> , 2011)
Asia	0.05	0.61	-	-	(Oyededeji <i>et al.</i> , 2011)
Cleansing oil					
Korea	0.28	-	-	-	(Hwang <i>et al.</i> , 2009)
Foam bath products					
Italy	0.02 – 0.2	-	-	-	(Ciaralli <i>et al.</i> , 1996)
Soaps/ Toilet soaps					
Italy	0.04 – 0.1	-	-	-	(Cristuado <i>et al.</i> , 2013)
Nigeria	0.72	-	-	-	(Umar and Caleb, 2013)
Medicated soaps/ Non-medicated soaps					
Nigeria	0.01 – 0.39	-	-	0.1 – 0.87	(Ayenimo <i>et al.</i> , 2010a)
Skin-lightening soaps/ Non-skin-lightening soaps					
Nigeria	-	0.45 – 1.58	-	-	(Ayenimo <i>et al.</i> , 2010b)
Toothpastes					
Nigeria	0.01 – 0.3	0.51 – 0.7	0.1 – 0.31	-	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Mouth-cleansing powder					
Nigeria	6.29	-	-	-	(Umar and Caleb, 2013)
Hand and cuticle cream					
Nigeria	0.25	-	-	-	(Umar and Caleb, 2013)

Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.

Table S7A. Concentrations of heavy metals detected in hair cosmetics (mg kg⁻¹)

Origin	Pb	Cd	Ni	References
Hair relaxer				
Nigeria	0 – 0.45	0.31 – 2.52	0.02 – 0.83	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Hair creams				
Nigeria	0 – 0.49	0.28 – 6.95	0.01 – 2.03	(Ayenimo <i>et al.</i> , 2010a, 2010b; Umar and Caleb, 2013)
Shampoos				
India	0.96	0.03	-	(Chauhan <i>et al.</i> , 2010)
Nigeria	1.3	4.17	3.11	(Umar and Caleb, 2013)
Pakistan	2.3	0.2	0.39	(Ullah <i>et al.</i> , 2013)
Saudi Arabia	3.32	0.06	0.09	(Ullah <i>et al.</i> , 2013)
The United Arab Emirates	1.78	0.12	0.36	(Ullah <i>et al.</i> , 2013)
Shampoo with muds from Dead Sea				
Jordan	-	-	0.06	(Abdel-Fattah and Pingitore, 2009)
Hair conditioner				
Nigeria	0.18	3.6	1.84	(Umar and Caleb, 2013)
Hair pomades				
Ghana	1.3 – 17.7	4.2 – 6.8	1.3 – 72	(Amartey <i>et al.</i> , 2011)
Pb, lead; Cd, cadmium; Ni, nickel.				

Table S7B. Concentrations of heavy metals detected in hair cosmetics (mg kg⁻¹)

Origin	Cr	Fe	Cu	Co	References
Hair relaxer Nigeria	0.06 – 0.6	0.76 – 1.03	0.57 – 0.67	-	(Umar and Caleb, 2013; Odukudu <i>et al.</i> , 2014)
Hair creams Nigeria	0.01 – 0.49	0.51 – 2.15	0.52 – 0.81	-	(Ayenimo <i>et al.</i> , 2010a, 2010b; Umar and Caleb, 2013)
Shampoos Nigeria	0.34	-	-	-	(Umar and Caleb, 2013)
Pakistan	-	154.2	2.39	0.37	(Ullah <i>et al.</i> , 2013)
Saudi Arabia	-	27.97	0.07	0.18	(Ullah <i>et al.</i> , 2013)
The United Arab Emirates	-	34.66	0.9	0.37	(Ullah <i>et al.</i> , 2013)
Shampoos with muds from Dead Sea Jordan	1.5	-	0.6	-	(Abdel-Fattah and Pingitore, 2009)
Hair conditioner Nigeria	0.3	-	-	-	(Umar and Caleb, 2013)
Hair pomades Ghana	-	81.6 – 421	0.7 – 12.8	10.67 – 25.35	(Amartey <i>et al.</i> , 2011)
Hair dyes Saudi Arabia	5 – 11	-	-	-	(Gondal <i>et al.</i> , 2013; Gondal <i>et al.</i> , 2014)
Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.					

Table S8A. Concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products (mg kg⁻¹)

Origin	Pb	Cd	Ni	As	References
Commercial muds					
Dead Sea	2.5 – 4.5	0.14 – 2.6	13 – 15	1.3 – 1.7	(Abdel-Fattah and Pingitore, 2009)
Cosmetics with muds from Dead Sea (body lotions, hand creams, facial masks, soaps, shaving soap, moisturizer)	0.01 – 6.2	0 – 1.7	0.01 – 17	0.03 – 1.8	(Abdel-Fattah and Pingitore, 2009)
Cosmetic clays					
Nigeria	3.74 – 171.14	0.1 – 0.56	-	-	(Popoola <i>et al.</i> , 2013)
Henna					
Egypt	2.29	-	-	-	(Jallad and Espada-Jallad, 2008)
India	2 – 8	-	83	-	(Tosti <i>et al.</i> , 1991; Jallad and Espada-Jallad, 2008)
Korea	-	-	2.5 – 3.96	-	(Kang and Lee, 2006)
Pakistan	6.53	-	-	-	(Jallad and Espada-Jallad, 2008)
Sudan	3.98	-	-	-	(Jallad and Espada-Jallad, 2008)
The United Arab Emirates	2.32 – 65.98	-	-	-	(Jallad and Espada-Jallad, 2008)
Talcum					
India	0.24 – 0.38	0.01	-	-	(Chauhan <i>et al.</i> , 2010)
Nigeria	5	2.1	-	-	(Nnorm, 2011)
Saudi Arabia	15 - 20	-	-	-	(Gondal <i>et al.</i> , 2012)
Pb, lead; Cd, cadmium; Ni, nickel; As, arsenic.					

Table S8B. Concentrations of heavy metals detected in raw materials, natural cosmetics and cosmetics considered as natural products (mg kg⁻¹)

[illegible]

Table S9. Concentrations of heavy metals detected in raw material, natural cosmetics and cosmetics considered as natural products (mg kg⁻¹)

Origin	Cr	Fe	Cu	Co	References
Commercial muds					
Dead Sea	23 – 30	-	4 – 6.4	2.3 – 4.5	(Abdel-Fattah and Pingitore, 2009)
Cosmetic with muds from Dead Sea (body lotions, hand creams, facial masks, soaps, shaving soaps, moisturizers)	0.81 – 24	-	0 – 10	0 – 4.0	(Abdel-Fattah and Pingitore, 2009)
Healing muds					
Adriatic	-	-	12 – 63	-	(Vreca and Dolenec, 2005)
Cosmetic clays					
Nigeria	0.39 – 7.69	-	-	-	(Popoola <i>et al.</i> , 2013)
Henna					
India	-	-	7.75	-	(Tosti <i>et al.</i> , 1991)
Korea	-	-	-	2.96 – 3.54	(Kang and Lee, 2006)
Kohl					
Pakistan	0.08	1,272	302.2	0.72	(Ullah <i>et al.</i> , 2013)
Saudi Arabia	4 – 9	-	-	-	(Gondal <i>et al.</i> , 2013)
Black soap					
Nigeria	0.9	-	-	-	(Umar and Caleb, 2013)
Herbal toothpastes					
Nigeria	1.92 – 2.16	-	-	-	(Umar and Caleb, 2013)
Herbal soaps					
Nigeria	0.15 – 0.3	-	-	-	(Umar and Caleb, 2013)
Talcum					
Nigeria	0.2	-	-	0.7	(Nnorm, 2011)
Saudi Arabia	20 – 30	-	-	-	(Gondal <i>et al.</i> , 2012)
Cr, chromium; Fe, iron; Cu, copper; Co, cobalt.					