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Health Risk Assessment of Heavy Metals (Pb, Cd, Hg) in Hydroalcoholic Gels of Abidjan, Côte d'Ivoire

Urbain Paul Gnonsoro[1] · Yolande Epouse Datte Ake Assi[2] · Naminata Soumahoro Sangare[3] · Yao Urbain Kouakou[4] · Albert Trokourey[3]

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Abstract

Despite the high consumption of hydroalcoholic gels worldwide and particularly in Côte d'Ivoire since the outbreak of the COVID-19 pandemic, very few studies have measured the heavy metal content and human exposure in this product. Thus, 30 samples from supermarkets in Abidjan, Côte d'Ivoire, were collected for the study of risk assessment of exposure to heavy metals contained in hydroalcoholic gels. This study consists of the characterization of the danger by calculating the carcinogenic and non-carcinogenic risk by skin contact. Almost all samples analysed contain trace of lead, cadmium and mercury but at concentrations below the Canadian limit in cosmetic products applied to the skin and below the US FDA limit as an impurity in colour additives used in cosmetic products. The mean values of chronic daily intake via dermal absorption (CDIdermal) for adults were found in the order of mercury > lead > cadmium. The health risk estimation indicated that the mean total hazard quotient for dermal adsorption (HIdermal) obtained is $7.10 \times 10^{-5} \pm 5.52 \times 10^{-5}$. This value was below 1, the acceptable limit, representing a non-carcinogenic risk for Abidjan residents through dermal adsorption. Moreover, the incremental lifetime cancer risk (ILCR) evaluation for lead and cadmium was insignificant, and the cancer risk can be neglected, but in case of their overusing, they can cause long-term health problems for consumers.

Keywords Hydroalcoholic gel · Heavy metals · Health risk · Dermal adsorption · Carcinogenic · Non-carcinogenic health risk

Introduction

The concentrations of metals in skin hygiene products are of significant health concern because their use represents a potential source of human exposure [1–4]. In fact, the use of skin hygiene products and so the exposure scenarios vary from one product to another. Some products are applied to the entire surface of the body (i.e. cosmetics and toiletries), while others, such as hydroalcoholic gels, lipsticks, eye mascara, cream foundations and scalp care products, are applied to restricted areas of the body, like the hands, the face, the scalp, the armpits, and so on. So, several works have been carried out around the world to study human exposure to metals in skin hygiene products [1–7]. However, few studies have been carried out in Côte d'Ivoire generally and in Abidjan particularly on human exposure to metals by skin hygiene products, although the presence of trace of metals in skin hygiene products use daily by Abidjan population is of concern. Also, metals can accumulate in the body over time, and some of them are known to cause a variety of chronic health effects including cancer; reproductive, developmental and neurological disorders; contact dermatitis; brittle hair; and hair loss [8]. However, among the daily skin hygiene products, the use of hydroalcoholic gels among Abidjan

✉ Urbain Paul Gnonsoro
urbainpaulgnonsoro@gmail.com

1 Laboratoire National d'Appui au Développement Agricole (LANADA), Laboratoire Central d'Agrochimie et d'Ecotoxicologie (LCAE), 04 BP 2365 Abidjan, Côte d'Ivoire

2 Laboratoire National d'Appui au Développement Agricole (LANADA), Laboratoire Central pour l'Hygiène Alimentaire et l'Agro-Industrie (LCHAI), 04 BP 2365 Abidjan, Côte d'Ivoire

3 Laboratoire de Constitution et Réaction de la Matière, Université Félix Houphouët Boigny, UFR SSMT, 22 BP 582 Abidjan, Côte d'Ivoire

4 UFR des Sciences et Techniques, Université de Man, BP 20 Man, Côte d'Ivoire

populations has exploded since the onset of the COVID-19 pandemic to fight more efficiently against it. Indeed, the production of hydroalcoholic gels on a large scale has been set up in order to participate in the fight against COVID-19 [9]. Unfortunately, the use of this skin hygiene product may presents some drawbacks, among which the health risk due to exposure to heavy metals potentially present in hydroalcoholic gels and the carcinogenic or non-carcinogenic effects of this compounds. Hydroalcoholic gels consist of three types of constituents: the active ingredient (alcohol or isopropanol), water and emollients (glycerin or glycerol) [10]. All these compounds make of these skin hygiene products a potential seat of metals at levels which may be harmful to the populations. Moreover, hydroalcoholic gels are quick-drying hydroalcoholic products designed specifically for hand disinfection. They are applied by friction without rinsing the hands, and they fall into the category of type 1 biocidal products, which means biocidal products intended for human hygiene. These products are the most used and the most widespread in supermarkets and in the arteries of the city of Abidjan (Côte d'Ivoire), because of its simplicity of use, its rapid drying and time saving, as it does not require water, soap or paper [11]. Thus, it is necessary to assess the health risk, in order to safeguard the health of consumers.

The health risk assessment of contaminants in humans is based on a mechanistic assumption that such chemicals may either be carcinogenic or non-carcinogenic [12]. This method has been extensively utilized by many researchers in literature for the estimation of the adverse health effects possible from exposure to contaminated water [13, 14], but few studies have focus on the health effects possible from exposure to skin hygiene products such as hydroalcoholic gels. Most of the studies on the possible health effects from exposure to contaminants have focused on ingestion and to a lesser extent on inhalation and dermal adsorption [5, 6, 15, 16]. The aim of the present research is to evaluate the levels of three heavy metals including lead (Pb), cadmium (Cd) and mercury (Hg) in the hydroalcoholic gels of Abidjan in Côte d'Ivoire and to assess the health risks linked to exposure to these heavy metals. This health risk assessment consists of the characterization of the danger by calculating the carcinogenic and non-carcinogenic risk by skin contact. So, in the case of hydroalcoholic gel, only the health effects by dermal adsorption for general adults in the community will be considered. The results of our research may provide some insight into heavy metal contamination in hydroalcoholic gels and are useful for consumers and government officials for taking protective measures to better preserve the health of consumers. Moreover, it can serve as a basis for assessing and comparing the level of contamination and the health risk of heavy metals in hydroalcoholic gels produced in Côte d'Ivoire and worldwide.

Material and Methods

Material

Thirty samples of hydroalcoholic gels produced in Côte d'Ivoire, chosen between the high-consumption brands, identified through interviews with cosmetics sellers, were collected at random in different supermarkets in the district of Abidjan (Côte d'Ivoire) between 03 and 12 March 2020. The precision balance used is manufactured by SHIMADZU model UW4200H (Philippines), while heavy metal concentrations were determined using an atomic absorption spectrophotometer to air-acetylene flame (Spectra A100 Varian spectrophotometer, Australia) equipped with a graphite furnace (GTA-110). The pH meter is manufactured by Lovibond model SensoDirect 150 (Dortmund, Germany). The reagents used included distilled water, nitric acid at 65% (Merck), hydrogen peroxide and standard solutions of lead and cadmium 1g/L (Normex).

Sample Preparation for Analysis

The density of hydroalcoholic gels was measured using a glass pycnometer as indicated by Jean Rodier et al. [17]. The pH is measured, using a pH meter with glass electrode manufactured by Lovibond model SensoDirect 150 (Dortmund, Germany), according to the method described by Jean Rodier et al. [17]. The heavy metal contents of hydroalcoholic gel samples were quantitatively determined at the Laboratoire Central pour l'Hygiène Alimentaire et l'Agro-Industrie (LCHAI), technical unit of the Laboratoire National d'Appui au Développement Agricole (LANADA) by graphite furnace atomic absorption spectroscopy (GFAAS) according to AOAC method 999.10 [18, 19]. For lead (Pb), cadmium (Cd) and mercury (Hg) analysis, an aliquot of 0.5 g of hydroalcoholic gel was digested in a microwave digester (Milestone Ethos), with 5 mL of nitric acid (65%) and 2 mL of hydrogen peroxide (30%). The mineral was then transferred into a 25-mL volumetric flask and completed to the mark with ultrapure water and kept refrigerated prior to analysis [18]. The graphite furnace atomic absorption spectroscopy (GFAAS) instrument conditions were given in Table 1.

Health Risk Assessment

Non-carcinogenic Analysis

The evaluation of the health risk of heavy metals has been realized by the risk level estimation and by the classification

Table 1 GFAAS instrument conditions

Spectrometer	SAA Varian (Spectra A110, Australia)
Gas flow	Nitrogen
Gas flow rates (Bbr)	4
Lead assay wavelength	283.3 nm
Cadmium assay wavelength	228.8 nm
Mercury assay wavelength	253.7 nm
Lead atomization temperature	2100 °C
Cadmium atomization temperature	1800 °C
Mercury dosage temperature	25 °C
Number of readings/replicate	1
Number of replicates	3

as carcinogenic or non-carcinogenic health hazards [15, 20]. So, the hazard quotients (HQ), the hazard index (HI), and the incremental lifetime cancer risk (ILCR) were used to estimate the carcinogenic and non-cancer health risk of heavy metals in hydroalcoholic gels of Abidjan caused via dermal absorption. For that, the chronic daily intake (CDI) via dermal absorption (CDIdermal), present in Equation 1, were used for adults [21, 22]:

$$\mathbf{CDIdermal} = \frac{\mathbf{Cw.HSA.Kp.ABS.ET.EF.EP.CF}}{\mathbf{BW.AT}} \quad (1)$$

All the terms given in the equation and their values are explained in Table 2.

The total potential non-carcinogenic health impacts caused by exposure to a mixture of heavy metals in hydroalcoholic gels were given by the estimation of the HI for all heavy metals through Equation 2 given by the EPA guidelines for health risk assessment [15, 25, 26]. By comparison of the HI to standard values, if HI > 1, that means that there is the possibility of non-carcinogenic impacts for consumer, while if HI < 1, the consumer is unexpected to experience evident harmful health impacts [15, 27].

$$\mathbf{HI} = \sum_{k=1}^{n} \mathbf{HQ} = \mathbf{HQ(Pb)} + \mathbf{HQ(Cd)} + \mathbf{HQ(Hg)} \quad (2)$$

In the equation above, the HQ for each heavy metal was estimated by Equation 3:

$$\mathbf{HQ} = \frac{\mathbf{CDI}}{\mathbf{RfD}}, \quad (3)$$

where CDI is the chronic daily intake (mg/kg/day) and RFD (mg/kg/day) is the reference oral dose through dermal absorption. The values of the RfD and cancer slope factor for lead, cadmium and mercury are listed in Table 3 [15, 28].

Table 2 Parameters values for CDIdermal assessment of metals [14, 23, 24]

Parameters	Unit	Dermal adsorption value
Heavy metal concentrations (Cw)	mg/kg	-
Hand skin surface area (HSA)	cm^2	420
Permeability coefficient (Kp)	cm/h	Pb, 0.0001, Cd, Hg 0.001,
Exposure time (ET)	Hour/event	0.05
Dermal exposure frequency (EF)	Day/year	350
Exposure duration (EP)	Year	30
Conversion factor (CF)	L/cm^3	0.001
Body weight (BW)	kg	70
Dermal absorption factor (ABS)	All	0.001
Average time (AT)	Days	25,550

Carcinogenic Analysis

The carcinogenic analysis is realized by the evaluation of the probable cancer risks due to exposure to heavy metal by calculation of the ILCR through Equation 4 [16]. In fact, the ILCR is the incremental probability of a person to develop any type of cancer over a lifetime as a result of 24 h per day exposure to a given daily amount of a carcinogenic element for 70 years [15, 29]. The permissible limits of ILCR for one or more heavy metals are 10^{-6} < ILCR <10^{-4} [30]:

$$\mathbf{ILCR} = \mathbf{CDI} \times \mathbf{CSF} \quad (4)$$

CSF (mg/kg/day), the cancer slope factor, is defined as the risk generated by a lifetime average amount of one of carcinogen chemical and is contaminant specific [15].

Mercury, particularly, does not have a CSF because it is not considered to create cancer.

Analytical Method Validation

The accuracy was checked throughout the recovery test. First, the pure substance of each element was prepared, and then stock solutions were prepared for Pb, Cd and

Table 3 Reference dose (RfD) and cancer slope factor (CSF) for different metals.

Element	Rdf dermal	CSF (kg/day/mg)
Pb	0.42	8.5
Cd	0.005	6.1
Hg	0.03	- *

Hg, and concentrations were determined from calibration lines established with five points for lead, cadmium and mercury [18]. The analytical procedure validation for quantitative analysis of heavy metals (Pb, Cd and Hg) in hydroalcoholic gel products was performed using selective evaluation, working and linear ranges, limit of detection (LOD), limit of quantification (LOQ), repeatability and reproducibility (precision). Analytical method validation for elemental analysis was applied in accordance with ISO and AFNOR standards [31, 32]. Values below the LOD are considered as not detected (ND). Values above the limit of detection but lower than the limit of quantification are treated as below the limit of quantification (< LOQ). Values of the limit of quantification, of the limit of detection and of the recovery obtained through this study are listed in Table 4.

Statistical Analysis

The statistical tests used for data processing, mean, minimum, maximum, standard deviation and correlation, were performed using Statistica 7.1 software (version 2006) and Microsoft Excel 2013. Comparison of means was performed, and difference was considered significant at $p < 0.05$.

Table 4 Per cent recoveries, limits of detection and limits of quantification of the elements

Heavy metals	Recovery (%)	LOD (mg/kg)	LOQ (mg/kg)
Pb	96.0	0.046	0.104
Cd	97.0	0.002	0.019
Hg	93.4	0.051	0.115

Results

Physicochemical Characteristics (pH and Density) and Heavy Metal Concentrations (Lead, Cadmium and Mercury) in Hydroalcoholic Gels

Results of the physicochemical characteristics (pH and density) of 30 hydroalcoholic gels are shown in Figure 1. pH of the hydroalcoholic gels ranged between 5.37 and 7.14 with an average of 6.44 ± 0.46. Values of density obtained were between 0.79 and 0.99 with an average of 0.91 ± 0.05 (Table 5).

Concentrations of lead, cadmium and mercury and contents in a variety of hydroalcoholic gels ($n = 30$) commonly used in Abidjan (Côte d'Ivoire) are presented in Figure 2. Results showed that the hydroalcoholic gels contain detectable levels of cadmium (between below the limit of quantification (<LOQ) and 0.024 mg/kg with a mean of 0.006 ± 0.007 mg/kg), lead (between 0.122 and 0.715 mg/kg with a mean value of 0.248 ± 0.110 mg/kg) and mercury (between <LOQ and 0.481 mg/kg with a mean value of 0.172 ± 0.134 mg/kg) (Table 6).

Table 5 pH and density of hydroalcoholic gel samples and WHO recommended guide

Parameters	Hydroalcoholic gel samples			WHO recommended formulation guide
	Mean	Minimum	Maximum	Range
pH	6.44 ± 0.46	5.37	7.14	6.0–7.0 (OMS 2010)
Density	0.91 ± 0.05	0.79	0.99	0.8–1.0 (WHO 2009)

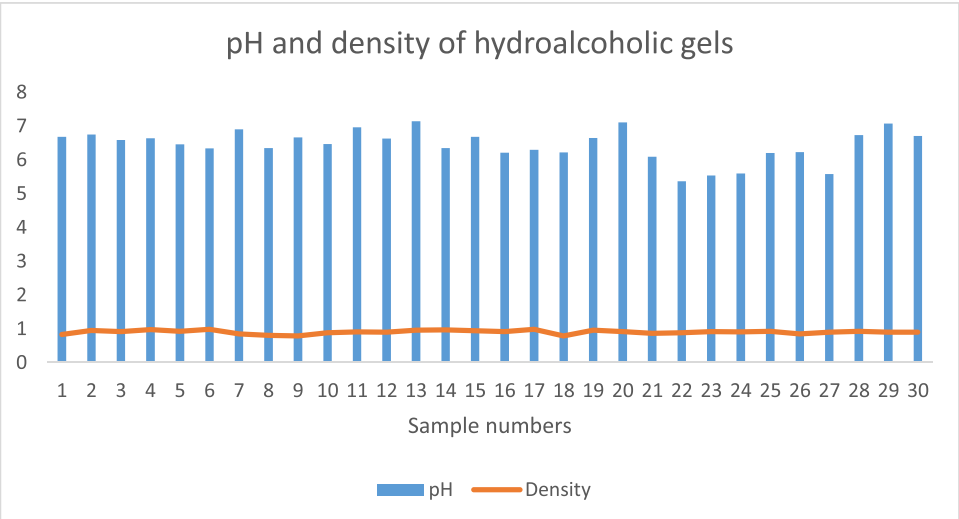

Fig. 1 pH and density of hydroalcoholic gel samples

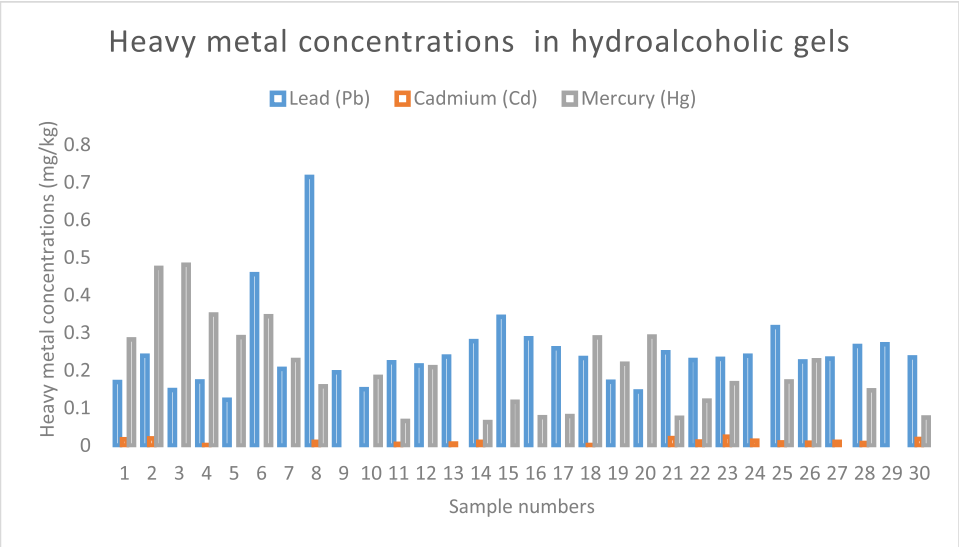

Fig. 2 Heavy metal concentrations in hydroalcoholic gels

Table 6 Heavy metal concentrations samples

Parameters	Heavy metal concentrations (mg/kg)		
	Mean	Minimum	Maximum
Lead (Pb)	0.248 ± 0.110	0.122	0.715
Cadmium (Cd)	0.006 ± 0.007	< LOD	0.024
Mercury (Hg)	0.172 ± 0.134	< LOD	0.481

Correlation Between Heavy Metal Concentrations and Physicochemical Characteristics

Results of correlations between heavy metal concentrations and physicochemical characteristics of hydroalcoholic gels are shown in Table 7. There were no correlation between physicochemical characteristics (pH and density) and heavy metal concentrations (lead, cadmium and mercury). In addition, all values of heavy metal concentrations obtained through this study showed no correlation between them.

Health Risk Assessment (Non-carcinogenic and Carcinogenic Analysis)

Values of chronic daily intake via dermal absorption routes (CDIdermal), for adults only, in hydroalcoholic gels of Abidjan in Côte d'Ivoire, are given in Table 8. Levels of HQ, as well as total HQ or HI for adults through dermal contact pathways, are also presented in Table 8, while the carcinogenic risk assessment by using of the ILCR, for adults, is given in Table 8.

Discussion

Physicochemical Characteristics (pH and Density) and Heavy Metal Concentrations (Lead, Cadmium and Mercury) in Hydroalcoholic Gels

The pH values obtained agree for some gels with the values given by the formulation guide for alcohol-based products recommended by the WHO, whose standards are between 6.0 and 7.0 [10]. Also, the density values are within the range of values set by the WHO recommended formulation guide for alcohol-based products, whose standards are between 0.8 and 1.0 [10]. Thus, the hydroalcoholic gels analysed are generally of satisfactory quality with regard to their physicochemical characteristics (pH and density) with the standards established by the WHO [33].

For the level of heavy metals in hydroalcoholic gels, results show that the hydroalcoholic gels used in Abidjan by

Table 7 Correlations between heavy metal concentrations and physicochemical characteristics

	pH	Density	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)
pH	1.00				
Density	0.10	1.00			
Lead (Pb)	− 0.13	− 0.09	1.00		
Cadmium (Cd)	− 0.42	− 0.12	0.10	1.00	
Mercury (Hg)	0.19	0.11	− 0.14	− 0.10	1.00

Table 8 Chronic daily intake (CDI), hazard quotients (HQ) and incremental lifetime cancer risk (ILCR) for heavy metals through dermal pathways

	Metals			
	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	
CDIdermal				
Range	1.50×10^{-9}–8.81×10^{-6}	0–2.95×10^{-9}	0–5.93×10^{-8}	
Mean	$3.057\times10^{-9}\pm1.35\times10^{-9}$	$1.38\times10^{-9}\pm0.79\times10^{-9}$	$2.55\times10^{-8}\pm1.48\times10^{-8}$	
HQdermal				**HI**
Range	3.58×10^{-9}–2.09×10^{-9}	0–5.91×10^{-7}	0–1.97×10^{-4}	5.72×10^{-9}–1.97×10^{-4}
Mean	$7.28\times10^{-9}\pm3.23\times10^{-9}$	$1.56\times10^{-7}\pm1.82\times10^{-7}$	$7.08\times10^{-5}\pm5.52\times10^{-5}$	$7.10\times10^{-5}\pm5.52\times10^{-5}$
ILCR				**∑ILCR**
Range	1.27×10^{-8}–4.77×10^{-8}	0–1.80×10^{-8}	-	1.27×10^{-8}–8.24×10^{-8}
Mean	$2.59\times10^{-8}\pm1.15\times10^{-8}$	$4.78\times10^{-9}\pm1.5610^{-9}$	-	$3.07\times10^{-8}\pm1.33\times10^{-8}$

consumers contain detectable levels of lead, cadmium and mercury. There is absence of legislative regulation, particularly in Côte d'Ivoire, concerning the limit of heavy metals in hydroalcoholic gels; hence, various databases were used in this study as benchmarks.

In our study, the concentration of lead is globally weaker than the value obtained in shower gel in Nigeria by Iwegbue et al. [1] (values were between < 0.09 and 23.5 mg/kg with a mean value of 7.47 ± 6.29 mg/kg) but is in the same order than the value obtained by Duck et al. [2] in Korea in shower gel (values range between ND and 1.73 mg/kg with a mean value of 0.62 ± 0.58 mg/kg). The similarity of certain components of shower gels to those of hydroalcoholic gels such as water and glycerin justified the comparison to the lead concentration in this product. Moreover, the limit for lead in cosmetic products applied to the skin set by Health Canada for Pb is 10 mg/kg [34], while those set by the US FDA for Pb as an impurity in colour additives used as ingredients in cosmetic products is 20 mg/kg [35]. In our case, Pb concentrations found in hydroalcoholic gels are below the Canadian limit for Pb in cosmetic products applied to the skin and below the US FDA limit for Pb as an impurity in colour additives used in cosmetic products.

For cadmium, the values obtained are below the maximum allowable limit of Cd in Germany set at 5.0 mg/kg [36] and also below the Canadian maximum allowable limit of Cd as an impurity in cosmetic products which is set at 3.0 mg/kg [34]. The concentration of cadmium obtained in this study is weaker than the value obtained in shower gel in Nigeria by Iwegbue et al. [1] who obtained values range between 0.06 and 1.80 mg/kg with a mean value of 0.95 ± 0.46 mg/kg, but it is higher than the value obtained by Duck et al. [2] in Korea in shower gel (values between ND and 0.01 mg/kg with a mean value of 0.002 ± 0.003 mg/kg).

Also, the mean value of mercury concentration obtained in this study is in the same order than the value obtained in shower gel in Korea by Duck et al. [2] which values range between ND and 1.93 mg/kg with a mean value of 0.16 ± 0.56 mg/kg. In front of the danger of this metal, the risks of Hg concentrations need to be considered when using hydroalcoholic gels by the Abidjan population.

Overall, low traces of lead, cadmium and mercury were found in our samples of hydroalcoholic gels. These traces of metals could come from the water used for the preparation of the gels since it is one of the essential ingredients [10]. These heavy metals have been demonstrated in the groundwater in the city of Abidjan which is used by the country's national water company for serving households with drinking water. Indeed, Ahoussi et al. [37] highlighted traces of lead (with concentration range between 0.02 and 2.80 mg/L) in groundwater in the city of Abidjan. These results are consistent with those of Ahoussi et al. [38] who also highlighted traces of lead (<0.001–0.04 mg/L) and cadmium (<0.001–0.027 mg/L) in the groundwater of Marcory, a municipality in Abidjan. Moreover, the work of Sangaré et al. [39], in the groundwater of the district of M'Badon (Cocody, Abidjan), revealed traces of lead and cadmium which were higher than the standards established by the WHO. Traces of lead in Sangaré's work ranged between ND and 0.764 mg/L, while those of cadmium ranged between 0.004 and 0.158 mg/L.

Furthermore, no significant correlation was demonstrated (p <0.005) between the levels of heavy metals obtained on the one hand and between the levels of heavy metals and the physicochemical characteristics (pH and density) of the hydroalcoholic gels analysed on the other hand.

Health Risk Assessment (Non-carcinogenic and Carcinogenic Analysis)

Non-carcinogenic Analysis

For the evaluation of the non-carcinogenic analysis, the first step is the calculation of CDI values. CDIdermal values

obtained, present in Table 8, gave mean values in mg/kg/day of $3.05 \times 10^{-9} \pm 1.35 \times 10^{-9}$, $1.38 \times 10^{-9} \pm 0.79 \times 10^{-9}$ and $2.55 \times 10^{-8} \pm 1.48 \times 10^{-8}$, respectively, for lead, cadmium and mercury. Therefore, the mean values of CDIdermal of heavy metals analysed for adults were found in the order of mercury > lead > cadmium.

The next step in evaluating human health risks posed by heavy metals in hydroalcoholic gels is the calculation of hazard quotient via dermal contact (HQdermal) which gave the results presented in Table 8. The mean values of HQdermal obtained were, respectively, $7.28 \times 10^{-9} \pm 3.23 \times 10^{-9}$, $1.56 \times 10^{-7} \pm 1.82 \times 10^{-7}$ and $7.08 \times 10^{-5} \pm 5.52 \times 10^{-5}$ for lead, cadmium and mercury. The results obtained suggest an acceptable level of non-carcinogenic harmful health risk in all hydroalcoholic gel samples analysed according to the health risk estimation of Pb and Cd [15]. Depending on the results obtained, the contribution of heavy metals analysed to the non-carcinogenic health risk was in the order of mercury > cadmium > lead.

Moreover, the estimation of the total potential non-carcinogenic health impacts caused by exposure to a mixture of heavy metals in hydroalcoholic gels was realized by the calculation of HI for all heavy metals analysed. Indeed, the HI is the summed of HQdermal for each heavy metals analysed [40]. The mean value of HIdermal obtained is $7.10 \times 10^{-5} \pm 5.52 \times 10^{-5}$ (Table 8). This value is below 1, so the persons who use hydroalcoholic gels in Abidjan are unexpected to experience evident harmful health impacts [27].

Carcinogenic risk analysis

After calculation, the values of ILCR are given in Table 8. The mean values of ILCR for lead and cadmium are, respectively, $2.59 \times 10^{-8} \pm 1.15 \times 10^{-8}$ and $4.78 \times 10^{-9} \pm 1.5610^{-9}$. For one heavy metal, an ILCR less than 1×10^{-6} is considered as insignificant, and the cancer risk can be neglected, while an ILCR above 1×10^{-4} is considered as harmful and the cancer risk is troublesome [15, 41]. In our study, the mean value of lead and cadmium is below 1×10^{-6}. So, the ILCR of lead and cadmium can be considered as insignificant, and the cancer risk can be neglected, because this value is below the value at which cancer risk is considered as troublesome. Therefore, the hydroalcoholic gel samples tested in the this study did not pose a carcinogenic risk through dermal sensitivity for lead and cadmium.

Conclusion

Evaluation of the health risks of exposure to heavy metals (lead, cadmium and mercury) in the most widely used hydroalcoholic gels in Abidjan (Côte d'Ivoire) supermarkets showed their presence in the tested products fortunately at satisfactory quality with the standards established by the WHO, the Canadian limit in cosmetic products applied to the skin and the US FDA limit as an impurity in colour additives used in cosmetic products. According to the obtained results, consumers who use hydroalcoholic gels in Abidjan are unexpected to experience evident carcinogenic and non-carcinogenic risks and dermal sensitivity. For all studied heavy metals, the ILCR do not present risk of cancer by frequent use of the hydroalcoholic gel of Abidjan through hand dermal contact, but in case of their overusing, they can cause long-term health problems for consumers. So, government officials must take protective measures to frequently control the levels of heavy metals in hydroalcoholic gels sold in arteries and supermarkets in the city of Abidjan to better preserve the health of consumers,

Abbreviations CDI: Chronic daily intake; CDIdermal: Chronic daily intake via dermal absorption; HQ: Hazard quotient; HI: Hazard index; ILCR: Incremental lifetime cancer risk; LCHAI: Laboratoire Central pour l'Hygiène Alimentaire et l'Agro-Industrie; LANADA: Laboratoire National d'Appui au Développement Agricole; AAS: Atomic absorption spectrophotometry; AOAC: Association of Official Analytical Chemist; LOD: Limit of detection; ND: Not detected; LOQ: Limit of quantification; RfD: Reference dose; CSF: Cancer slope factor; US FDA: United States Food and Drug Administration

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Author Contribution GUP and AAY defined and designed the work and the experiment. GUP collected the samples, and AAY carried out the sample preparation and analysis. GUP wrote the manuscript. AAY, SNS and KYU revised the manuscript critically. All authors read and approved the final manuscript.

Data Availability Not applicable.

Code Availability Not applicable

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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