

Supplementary Materials

Concentrations and probabilistic health risks of seven metals in face and eye cosmetics across seven Asian countries

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Table S1. Analytical parameters and quality control results for heavy metals in cosmetic samples

Heavy metal	R ²	LOD (mg/kg)	Recovery (% , average $\pm$ SD)		
			Low	Middle	High
Hg	0.999	0.003	96 $\pm$ 6	100 $\pm$ 3	101 $\pm$ 1
As	0.999	1.063	94 $\pm$ 6	92 $\pm$ 5	93 $\pm$ 2
Cd	0.999	0.144	92 $\pm$ 1	89 $\pm$ 0	88 $\pm$ 2
Cr	0.999	0.238	125 $\pm$ 2	110 $\pm$ 1	105 $\pm$ 2
Ni	0.999	0.152	105 $\pm$ 4	98 $\pm$ 1	96 $\pm$ 2
Pb	0.999	0.909	113 $\pm$ 4	105 $\pm$ 1	98 $\pm$ 3
Sb	0.999	1.281	88 $\pm$ 9	87 $\pm$ 3	88 $\pm$ 3

Table S2. Input parameters and probability distributions used for Monte Carlo simulation

Variables	Description	Value	Unit	Probabilistic Distribution
C	Metal concentrations in the cosmetic products	Varies by metals	mg/kg	Lognormal
AA	Applied amount ^a	Face cream: 1.54 Mascara: 0.025	g/day	Point
BW	Adult female body weight	Average: 53.43 SD: 4.11 Korea: 57.7 (SD: 9.02) ^b Philippines: 56.8 ^c Vietnam: 53.0 ^d India: 52.6 ^e Bangladesh: 49.8 ^f Indonesia: not available)	kg	Normal

a (SCSS, 2021)

b (NIER, 2019)

c (DOST-FNRI, 2022)

d (MOH Viet Nam and WHO, 2025)

e (ICMR, 2020)

f (WHO & Ministry of Health and Family Welfare, 2011)

Table S3. Reference doses (RfD_o, RfD_{ABS}), absorption fractions (ABS_{GI}, ABS) and cancer risk factors of heavy metals

Compounds	RfD _o (mg/kg/day)	ABS _{GI}	RfD _{ABS} (mg/kg/day)	ABS	CSF (mg/kg/day)
Hg	0.0003 ^a	1 ^g	0.0003	0.001 ^h	-
As	0.00006 ^b	1 ^g	0.00006	0.03 ^g	32 ⁱ
Cd	0.0005 ^c	0.025 ^g	0.0000125	0.001 ^g	6.7 ^j
Cr	1.5 ^d	0.013 ^g	0.0195	0.001 ^h	-
Ni	0.02 ^e	0.04 ^g	0.0008	0.001 ^h	0.91 ^k
Pb	-	-	0.0005 ^l	0.001 ^h	0.0085 ^k
Sb	0.0004 ^f	0.15 ^g	0.00006	0.001 ^h	-

RfD_o Oral reference dose; ABS_{GI} The fraction of contaminant absorbed in gastrointestinal tract; RfD_{ABS} Absorbed reference dose; ABS the dermal absorption fraction for a given metal; CSF Cancer risk factor

a (EPA, 1995); b (EPA, 2025); c (EPA, 1989); d (EPA, 1998); e (EPA, 1991); f (EPA, 1987); g (ATSDR, 2023); h (EPA, 1995); i (EPA, 2025); j; (Lim, 2018) k (OEHHA, 1999); l (EFSA, 2010)

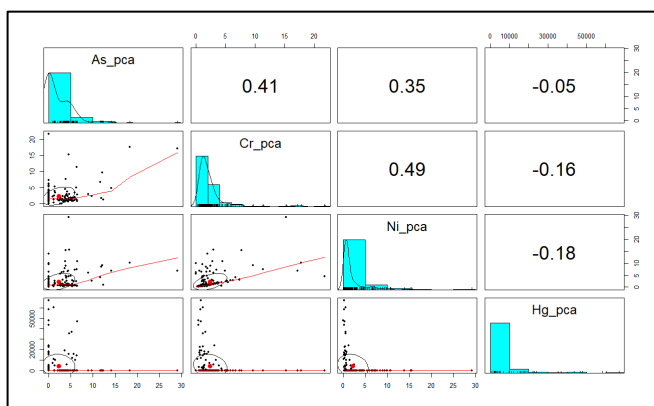


Figure S1. Pairwise correlations among Hg, As, Cr, and Ni concentrations in cosmetic products.

Table S4. PCA results for heavy metals included in the analysis (Hg, As, Cr, and Ni): eigenvalues, explained variance, and component loadings.

Heavy metals	PC1	PC2
Eigen value	1.377	0.982
Total Variance (%)	47.42	24.13
Cumulative Variance (%)	47.42	71.55
As	0.509	0.361
Cr	0.590	0.088
Ni	0.573	-0.003
Hg	-0.253	0.928

Table S5. Systemic exposure dose (SED, mg/kg/day) and hazard quotient (HQ) estimates for metals via dermal absorption from facial creams (n = 111) and mascaras (n = 55) based on Monte Carlo simulation

	Heavy metals	SED (mg/kg/day)			HQ		
		50 th	95 th	Max	50 th	95 th	Max
Face cosmetics	Hg	4.71×10^{-6}	1.90×10^{-3}	1.90×10^{-3}	0.016	6.32	6.32
(Facial cream only, n = 111)	As	2.86×10^{-6}	8.14×10^{-6}	2.17×10^{-5}	0.048	0.136	0.361
	Cd	9.90×10^{-9}	4.60×10^{-8}	1.94×10^{-7}	7.92×10^{-4}	3.68×10^{-3}	0.016
	Cr	4.62×10^{-8}	1.38×10^{-7}	3.88×10^{-7}	2.37×10^{-6}	7.09×10^{-6}	1.99×10^{-5}
	Ni	1.88×10^{-8}	1.09×10^{-7}	5.68×10^{-7}	2.35×10^{-5}	1.36×10^{-4}	7.10×10^{-4}
	Pb	4.25×10^{-8}	1.27×10^{-7}	3.54×10^{-7}	8.49×10^{-5}	2.54×10^{-4}	$7.08. \times 10^{-4}$
	Sb	6.56×10^{-8}	1.53×10^{-7}	3.40×10^{-7}	1.09×10^{-3}	2.55×10^{-3}	$5.66. \times 10^{-3}$
Eye cosmetics	Hg	7.59×10^{-12}	8.65×10^{-11}	8.49×10^{-10}	2.53×10^{-8}	2.88×10^{-7}	2.83×10^{-6}
(Mascara only, n = 55)	As	5.81×10^{-8}	1.02×10^{-7}	1.74×10^{-7}	9.69×10^{-4}	1.71×10^{-3}	2.90×10^{-3}
	Cd	1.64×10^{-10}	1.71×10^{-10}	1.79×10^{-10}	1.31×10^{-5}	1.37×10^{-5}	1.43×10^{-5}
	Cr	6.28×10^{-10}	7.55×10^{-9}	7.80×10^{-8}	3.22×10^{-8}	3.87×10^{-7}	4.00×10^{-6}
	Ni	1.02×10^{-9}	6.77×10^{-9}	3.98×10^{-8}	1.28×10^{-6}	8.46×10^{-6}	4.97×10^{-5}
	Pb	9.30×10^{-10}	1.92×10^{-9}	3.78×10^{-9}	1.86×10^{-6}	3.83×10^{-6}	7.56×10^{-6}
	Sb	5.02×10^{-9}	2.81×10^{-8}	1.42×10^{-7}	8.36×10^{-5}	4.69×10^{-4}	2.37×10^{-3}

Table S6. Selected regulatory or guidance values for metals in cosmetics (mg/kg) used for exceedance screening in this study

Heavy metals	Germany ^a	ASEAN ^b	USA ^c	Korea ^d
Hg	0.1	1	Color additive: 1	1
As	0.5	5	Color additive: 3	10
Cd	0.1	5	-	5
Ni	-	-	-	Eye: 35 Other: 10
Pb	Eye: 5 Others: 2	20	10 Color additive: 20	20
Sb	0.5	-	-	10
Cr	-	-	-	-

a BVL (2016)

b ASEAN (2019)

c FDA (2022)

d MFDS (2023)