Home textile as a potential pathway for dermal exposure to trace elements. Assessment of health risks

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The concentrations of a number of trace elements (Ag, Al, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Sc, Se, Sm, Sn, Sr, Ti, Tl, V, and Zn) were analyzed in samples of home textiles (i.e., towels, bedclothes and pyjamas). Dermal absorption of these elements, associated to the daily use of those clothes, was also estimated. Textile samples were characterized according to colour, fibber material, origin of manufacture, eco label, and content of organic cotton. Arsenic, Be, Cd, Sc, Se, Sm, and Tl levels were below their respective detection limits, while Hg, Mo, and V could be only detected in a few samples. The highest mean levels corresponded to Mg (142 mg/kg), Cu (32.8 mg/kg), Sb (26.9 mg/kg), Al (14.7 mg/kg), Fe (12.9 mg/kg), and Ti (10.9 mg/kg). In agreement with previous findings in casual wear, home textiles made of polyester, either exclusively or partially, showed significant higher levels of Sb than those made of cotton, while Ti levels were also significantly higher in synthetic fibber items. The levels of Cr and Cu were especially relevant in colour clothes. The dermal absorption of trace elements during sleeping and that resulting of towels use were also estimated, being the health risks subsequently assessed. The maximum hazard quotient (HQ) for all elements was well below 0.01, indicating a safe situation. The only exception was Sb, whose HQs due to bedclothes/pyjamas and the use of towels use were 0.4 and >1, respectively. When compared with other daily activities, towels use, by effect of the towel-to-hand-to-mouth action, was the most relevant action leading to a dermal exposure for most trace elements. In general terms, cancer risks did not exceed threshold levels, excepting Cr(VI), whose risk was above 10^{-5}.

Keywords: home textile; trace elements; bedclothes; pyjamas; towels; health risk assessment

Introduction

Textiles may contain a wide range of chemicals, being most of them intentionally added for the improvement of its functionalities. Traces of organic compounds such as formaldehyde, phthalates, nonylphenols, perfluorinated compounds, organotin, or polybrominated substances, have been detected in clothes (Brigden, Hetherington, Wang, Santillo, & Johnston, 2013; Darbra et al., 2012; Herzke, Olsson, & Posner, 2012; Supreeyasunthorn, Boontanon, & Boontanon, 2016; Swedish Chemicals Agency, 2013). In addition, trace elements (mainly metals) may be also embedded during textile manufacturing to add new properties (i.e., Ag, Ti, Sn, Zn), being also present in raw fibbers (i.e., Sb or Mg), or in dyes and pigments (i.e., Cr, Cu, Co) (Chakraborty, 2011; Panda, 2013; Patra & Gouda, 2013; Rezić & Steffan, 2008; Stefaniak et al., 2014; Thiele, 2004). These elements may be released from the fabric due to sweat leachate or physical stress, ultimately entering in contact with skin (Leme et al., 2014; Matoso & Cadore, 2012; Rovira et al. 2016; Windler et al., 2012). Textiles may be also a notable source of particles, to which chemicals are attached, especially in indoor environments (Swedish Chemicals Agency, 2013).

In recent years, a number of investigations have been focused on analysing the content of trace elements in a variety of clothes (Matoso & Cadore, 2012; Rezić, 2009; Rezić & Steffan, 2007; Rovira et al. 2015, 2016). Moreover, the migration of these elements into artificial sweat has been also a recurrent topic of study (Nakashima, Miyano, & Takatuka, 2008; Rovira et al., 2016; Stefaniak et al., 2014; von Goetz, Lorenz, Windler, Nowack, & Heuberger, 2013). The chemical pollution of textile production, its ecological risks, as well as the potential health risks for the workers, have been also investigated (Checkoway et al., 2011; Ning et al., 2014, 2015; Reul et al., 2016). Nevertheless, information regarding human health risks, potentially associated to the use of home textiles, is much more limited. With respect to this, most of the attention has been given to occupational exposure to heavy metals for the use of laundered shop towels (Beyer, Greenberg, & Beck, 2014; Beyer, Seeley, & Beck, 2003; Connor & Magee, 2014).

Some home textiles, such as bedclothes or pyjamas, are in contact with skin for long periods, as they are worn while people are sleeping. In contrast, other home textiles, such as towels, have a shorter skin-contact. However, this contact occurs in a more aggressive way, due to the scrub to dry the wet skin, further leading a potential release of chemicals contained in the textile material. Exposure to trace elements has been associated to harmful effects on skin, such as irritations and dermatitis (Lisi et al., 2014; Ryberg et al., 2006; Schaumlöffel, 2012), skin micro flora reduction (Walter, McQueen, & Keelan, 2014), as well as other adverse health effects (Bianco et al., 2015; Bocca et al. 2014).

In this study, we determined the levels of 28 trace elements (Ag, Al, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Sc, Se, Sm, Sn, Sr, Ti, Tl, V, and Zn) in 78 samples of home textile (towels, bedclothes, and pyjamas). Data were used to estimate the contribution of this apparel to human exposure to trace elements and to evaluate human health risks. The main goal of the study was to establish the potential presence of trace elements in commercially available home textiles, as well as to assess the adverse health effects of a continued exposure during their use. To the best of our knowledge, there is not currently any available scientific information on this potentially important topic.

Materials and methods

Textile sampling

Textile items (n=78) were purchased in stores and supermarkets from two cities (Reus and Tarragona) in Catalonia (NE of Spain), and from "online" stores. There were 3 categories of samples: bedclothes (n=31), towels (n=25) and pyjamas (n=22). They included coloured (n=60) and white (n=18) items, being made of different materials (mainly cotton, either organic or not, and polyester). Eco-labelling information was also considered, being 16 of the samples identified as eco-labelled. Basic information, such as material, colour, and production place, was obtained from the labels. Furthermore, the textile density obtained by cutting and weighing a dry area of each item, was calculated in the laboratory. Full information of the samples here analysed is given in Table 1.

Microwave digestion and elemental analysis

The analytical procedure of trace element determination was recently described (Rovira et al., 2015, 2016). Briefly, textile samples were dried and approximately 0.3 g of each sample were digested with 8 mL of HNO_3 (65% Suprapur, E. Merck, Darmstadt, Germany) and 2 mL of H_2O_2 in a Milestone Start D Microwave Digestion System following a 3-step temperature ramp: 5 min at 105ºC, 15 min at 180ºC, and 20 min at 200ºC. After cooling, the extracts were filtered and made up to 25 mL with ultrapure water.

The content of aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), samarium (Sm), scandium (Sc), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), tin (Sn), titanium (Ti), vanadium (V), and zinc (Zn), was determined by inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer Elan 6000). Blank and control samples, as well as reference materials (SRM 1570a - Trace Elements in Spinach Leaves, National Institute of Standards and Technology, U.S.), were analysed to check the accuracy of the instrumental methods. Recovery percentages of standard materials ranged between 67% for Zn, and 126% for As. Detection limits were the following: 0.02 mg/kg for Ag, Bi, Cd, Pb, and Tl; 0.04 mg/kg for Be, Co, Cu, Mn, Mo, Sm, Sn, and Sr; 0.08 mg/kg for As, Ba, Hg, Ni, Sb, Sc, and Zn; 0.21 mg/kg for Cr, Ti, and V; 0.42 mg/kg for B and Se, and 0.83 mg/kg for Al, Fe, and Mg.

Exposure assessment and health risk characterization

Human exposure to trace elements during sleeping was evaluated under different scenarios, based on the way of sleeping (naked or wearing pyjamas) and the season (summer or winter). In winter, the entire body skin surface, excepting the head, was considered to be in contact with bedclothes for naked sleepers. In turn, for people with sleepwear, bedclothes were only in contact with feet and hands, being the rest of body surface, excepting the head, covered by long-sleeves/pants of the pyjamas. In summer, we assumed that sheets were not used. Therefore, people sleeping snaked were exposed to one-half of the body surface, excepting the head, while only the trunk and one-half of legs and arms surface of people with pyjamas were covered by clothes. Dermal exposure was estimated by applying equation 1, which is based on the European Chemical Agency (ECHA) guidance on information requirements and chemical safety assessment (European Chemicals Agency, 2012). Descriptions and values of the different parameters of equation 1 are shown in Table 2.

$$Exp_{dermal\ bedclothes/pyjamas} = \frac{F_{cloth} \times d_{cloth} \times A_{skin} \times F_{skin} \times F_{mig} \times F_{contact} \times F_{pen} \times T_{contact} \times N_b}{BW} \quad \text{(equation 1)}$$

With respect to the dermal exposure to metals through towels use, 2 scenarios were considered: a) dermal contact with migrated metals during whole body towelling after a bath or shower (equation 2), and b) oral ingestion of towel-to-hand-to-mouth and towel-to-mouth contact after hand and face wash (equations 3 and 4, respectively). The equations were obtained from previous publications (Beyer, Greenberg, & Beck, 2014b; Beyer et al., 2003; Connor & Magee, 2014), being specific descriptions and values of the parameters summarized in Table 2.

$$Exp_{dermal\ toweling} = \frac{F_{cloth} \times d_{cloth} \times A_{body\ towel} \times F_{mig} \times F_{contact} \times F_{pen} \times T_{contact\ towel} \times N_{Tb}}{BW} \quad \text{(equation 2)}$$

$$Exp_{oral\ towel\text{-}to\text{-}hand\text{-}to\text{-}mouth} = \frac{F_{cloth} \times d_{cloth} \times A_{hand\ towel} \times F_{mig} \times F_{contact} \times F_{h\text{-}to\text{-}m} \times N_{Th}}{BW} \quad \text{(equation 3)}$$

$$Exp_{oral\ towel\text{-}to\text{-}mouth} = \frac{F_{cloth} \times d_{cloth} \times A_{lips} \times F_{mig} \times F_{contact} \times F_{lips\text{-}to\text{-}mouth} \times N_{Th}}{BW} \quad \text{(equation 4)}$$

Non-carcinogenic risks were assessed by calculating the hazard quotient (HQ). It is defined as the quotient between the predicted exposure and the respective reference dose (RfD). HQ values below one (<1) indicate a safe exposure to chemicals. On the other hand, cancer risks were evaluated by multiplying the predicted exposure by the respective slope factor (SF). The dermal RfD was calculated multiplying the respective oral RfD by the gastrointestinal (GI) absorption factor, whereas dermal SFs were calculated dividing the respective oral SF by the GI absorption factor.

Values for RfDs and SFs were obtained from the Risk Assessment Information System (RAIS, 2016), with the only exception of oral RfD for Pb, which was obtained from Seiler & Sigel (1988). GI absorption factors were obtained from U.S. EPA Preliminary Remediation Goals (United States Environmental Protection Agency, 2015).

Statistics

For data analysis, the levels of those elements with a value under the limit of detection (LOD) were assumed to be one-half of that value (ND = ½ LOD). Data analysis was carried out with the statistical software package XLSTAT (Version 2015.2.02.18681). The level of significance was set at a probability lower than 0.05 ($p<0.05$). To evaluate significant differences between groups, the Levene test was applied to verify the equality of variances. Subsequently, ANOVA or Kruskal-Wallis/Mann-Whitney tests were applied depending on whether the data followed a normal distribution or not, respectively.

Results and discussion

Concentration of trace elements in home textile apparel

The levels of 28 trace elements in 78 samples of household textile (bedclothes, pyjamas, and towels) are summarized in Table 3. Arsenic, Be, Cd, Sc, Se, Sm, and Tl showed concentrations below their respective LODs in all samples, while Hg, Mo, and V were detected in only a few (~2-4 items). The highest mean levels corresponded to Mg (142 mg/kg), Cu (32.8 mg/kg), Sb (26.9 mg/kg), Al (14.7 mg/kg), Fe (12.9 mg/kg), and Ti (10.9 mg/kg). When assessing individually the samples, the highest concentrations corresponded to Cu in sample #16 (black, 100% cotton) and Mn in sample #25 (brown, 50% lyocell - 50% cotton), with concentrations of 1065 and 889 mg/kg, respectively.

According to the fabric material, samples were classified into 3 categories: 100% cotton, cotton + synthetic, and synthetic. Significant higher concentrations of Co, Sb and Ti were found in synthetic items, when compared with samples 100% made of cotton ($p<0.05$). Moreover, Sb and Ti were also found to be significantly higher in samples made of cotton and synthetic materials, than those in 100% cotton items. In polyester apparel, Sb levels were within 0.20 and 202 mg/kg (mean: 88.4 mg/kg), while in cotton samples, Sb concentrations ranged between <0.08 and 0.40 mg/kg (mean: 0.05 mg/kg). Antimony is not only used as catalyst in polyester fabric (Henckens, Driessen, & Worrell, 2016), but it is also commonly applied in the textile industry in combination with decabromodiphenyl ether (Deca-BDE), a brominated flame retardant (Derden & Huybrechts, 2013). Titanium showed significant higher levels ($p<0.05$) in synthetic and synthetic + cotton items (23.6 and 25.1 mg/kg, respectively) than in 100% cotton items (2.69 mg/kg). Titanium is used as a delustering agent and pigment in synthetic fibbers in the textile industry (Vann et al., 2009). In addition, Ti compounds also provide solar protection from UV for synthetic fabrics, while TiO_2 nanoparticles can also provide antimicrobial and antistatic properties as well as wrinkle resistance (Pakdel, Daoud, & Wang, 2014; Windler et al., 2012). In contrast, and because Mg is naturally present in cotton, the levels of this element were significantly higher ($p<0.05$) in those items made of cotton. Mean Mg concentrations in 100% cotton and cotton + synthetic fabrics were 138 and 218 mg/kg, respectively, while the mean level in synthetic clothes was 13.0 mg/kg. Finally, some statistically significant differences were also noted for B and Sr ($p<0.05$) when comparing items made of a mixture of cotton + synthetic and synthetic samples.

In recent studies, we also found increased concentrations of Cr and Cu in coloured clothes (Rovira et al., 2015, 2016). By contrast, in the current investigation Sn was the only element whose concentrations were significantly higher ($p<0.05$) in coloured items of home textile than in white apparel (0.09 vs. 0.04 mg/kg). However, in spite of the difference was not statistically significant ($p>0.05$), higher concentrations of Cr and Cu were observed in coloured items than in white samples (8.58 vs. 0.13 mg/kg for Cr, and

42.1 vs. 3.54 mg/kg for Cu). High levels of Cr were found in sample #17 (black, 100% cotton) and #75 (black, polyester/polyamide), with levels of up to 374 and 129 mg/kg, respectively. Since Cr is used as metal complex dye in black polyamide clothes (Chakraborty, 2011), the presence of this metal in synthetic material was expected. On the other hand, Cu was undetected in most of the white items (<0.04 mg/kg), while coloured (pink, green, blue, black or brown) samples made of cotton showed higher levels of Cu. Copper compounds are used as green, blue and red-brown dyes and pigments in the textile industry (Panda, 2013; Wöhrle et al. 2012).

The concentrations of trace elements in home textile were also considered according to label indications. Samples labelled as Oeko-Tex Standard showed significant higher levels of Ni (0.28 vs. 0.16 mg/kg) and significant lower concentrations of Mg (57.7 vs. 161 mg/kg). Oeko-Tex standard 100 establishes that the content of Cd and Pb in digested textile samples should not exceed 40 and 90 mg/kg, respectively (Brunn Poulsen, 2004). In addition, the EU ecolabel establishes a maximum content of Sb in polyester fibbers of 260 mg/kg (European Commission, 2009). None of the samples exceeded these thresholds. Samples made of organic cotton showed significant higher concentrations of Co (0.33 vs. 0.21 mg/kg) and Ni (0.35 vs. 0.12 mg/kg), and significant lower levels of Sr (2.03 vs. 6.74 mg/kg) than those of non-organic cotton items. Finally, a slight increase of Sn was found in home textile made inside the EU with respect to that manufactured outside (0.11 vs 0.04 mg/kg).

Exposure and health risk assessment

Based on the concentrations of the trace elements found in the analysed samples of bedclothes, pyjamas and towels, the daily exposure to these elements through dermal absorption was evaluated under 2 scenarios: sleeping and towels use (Tables 4 and 5, respectively). Exposure to those elements while sleeping was higher in winter due to the increased skin surface in contact with textiles during that season. Sleeping naked would be associated to a lower exposure to all the trace elements, excepting Cr and Cu, two metals with relatively higher concentrations in bedclothes. When comparing different activities related with the use of towels, the highest exposure to trace elements was associated to hand-to-mouth oral exposure after hand washing, being followed by towelling exposure and mouth contact with towels. Among the analyzed elements, the highest value of dermal absorption in both scenarios, sleeping and use of towels, corresponded to Cu.

Non-carcinogenic risks derived from the dermal contact with bedclothes, pyjamas and towels, were assessed by calculating the hazardous quotient (HQ). Maximum HQ levels were well under 0.01, two orders of magnitude below the threshold (HQ=1), which indicates a safe situation. An exception was Sb, whose maximum HQ was between 0.2 and 0.4, due to the use of bedclothes and pyjamas, respectively. The increased of the HQ for Sb would be linked to the presence of this element in items #22 (blue, 50% cotton + 50% polyester, 191 mg/kg) and #51 (black-dotted white, 95% polyester + 5% elastane, 202 mg/kg). In addition, Sb presented a mean HQ of 0.14 (max: 0.93), 0.08 (max: 0.55), and 0.001 (max: 0.01) for towelling, hand-to-mouth after towelling, and mouth contact with towels, respectively. Maximum HQ values for Sb due towels use would correspond to the amount of this element in sample #75 (Sb: 112 mg/kg), a black polyester/polyamide towel.

Since slope factors (SFs) for dermal absorption have been only established for As, Cr(VI) and Pb, cancer risks were only calculated for these 3 elements. Carcinogenic risks derived from the dermal contact through bedclothes, pyjamas and towels, are depicted in Figure 1. For calculations purposes, we assumed that one-sixth part of total Cr was as hexavalent chromium. Moreover, since As was not detected in any sample, its concentration was considered to be one-half of the LOD. Carcinogenic risks of dermal absorption of As and Pb were much lower than the threshold, set al 10^{-6}, meaning an acceptable risk level. In contrast, the mean cancer risk of Cr(VI) was around 10^{-6}, but maximum Cr(VI) risk levels fell within 10^{-5} and 10^{-4}. However, it must be highlighted that a speciation study was not conducted, being cancer risk calculations performed under a conservative scenario, which may easily lead to an overestimation of the risk.

Contribution of home textile vs. other apparel

Recently, we measured the concentrations of the same elements here analysed in various skin-contact clothes (T-shirts, blouses, socks, baby pyjamas, and bodysuits) purchased from the Catalan market (Rovira et al., 2015, 2016). While our previous investigations were focused on the role of casual clothes and underwear, which are worn during the daytime, the current study included different target clothes, such as bedclothes/pyjamas and towels. In order to integrate all data, the dermal contact to trace elements was estimated for 3 different daily activities: sleeping, personal care (undressed), and dressed with casual clothes. According to recent data on the Catalan population (Institut d’Estadística de Catalunya, 2016), the daily exposure duration of each of these 3 activities was assumed to be 8:39, 0:43 and 14:38 (hours:minutes), respectively. It must be remarked that all the textile items, both home and clothes, presented concentrations of As below the respective LODs. In terms of exposure, oral intake of trace elements in the towel-to-hand-to-mouth was the most relevant exposure pathway for most elements (Figure 2). In turn, the dermal exposure of Cd, Co, Cr, Mo, Sc, Se, Sm, Tl, and Zn, was dominated by wearing daytime clothing (Figure 2). Cadmium, Mo, Sc, Se, Sm, and Tl were not detected in towels, while Co, Cr and Zn showed relatively high concentrations in casual clothes.

Regarding non-carcinogenic risks, the HQ of all the elements, excepting Sb, was below the safety limit (HQ<0.05). As previously reported (Rovira et al., 2015, 2016), Sb was again identified as a priority chemical, in terms of risk assessment. When integrating a number of daily activities, the mean HQ of Sb exposure was 0.46. Moreover, the maximum HQ exceeded the safety value, suggesting a potential risk of this element for people (i.e., athletes) usually wearing polyester clothes and pyjamas, and using bedclothes and towels that include this element. Again, when summing the different exposure pathways, the cancer risk due to Cr(VI) exposure slightly exceeded the acceptable threshold ($5.0 \cdot 10^{-6}$). The current findings on home textile, together with those from our previous studies (Rovira et al., 2015, 2016), suggest that an excessive use of clothes, towels and/or bedclothes, made exclusively of polyester or dark coloured polyamide should be avoided to reduce the potential exposure to Sb and Cr though dermal contact with those items.

Conclusions

To the best of our knowledge, this is the first time that health risks of dermal contact to a number of trace elements, which are potentially contained in home apparel (bedclothes, pyjamas and towels), are evaluated. Moreover, data were compared with risk values derived from exposure of wearing casual clothes during the daytime. In accordance with the results of our recent studies on other clothing (Rovira et al., 2015, 2016), polyester items contained high levels of Sb, while Ti concentrations were also increased in synthetic fibber samples. On the other hand, textile colour was a key issue because of the high levels of Cr, especially in polyamide black clothes, as well as those of Cu, in coloured (blue, green, red, and brown) clothes made of cotton.

The results of the health risk assessment indicate that the high presence of Sb in some home textiles, such as polyester fibbers, might lead to a potential systemic risk, especially after a possible misuse of polyester items. In addition, because of the relatively high concentrations of Cr in black polyamide textiles, an excess of wearing and using textiles of these characteristics might mean non-assumable cancer risks for the adult population. Further studies should pay special attention to elucidate Cr(VI) as a species of concern, in terms of dermal exposure through clothing.

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Table 1: Characteristics of the analysed home textile items.

Sample	Type	Material	Colour	Oeko-Tex Standard 100	Made in	Density (mg/cm^2)
1	Bedclothes	100% Ct org	White and black		NA	10
2	Bedclothes	100% Ct	White		Pakistan	12
3	Bedclothes	100% Ct	White		Portugal	10
4	Bedclothes	100% Ct	White		NA	12
5	Bedclothes	100% Ct org	White	YES	India	11
6	Bedclothes	100% Ct	Pink		Portugal	10
7	Bedclothes	100% Ct org	Ochre	YES	India	12
8	Bedclothes	100% Ct	Orange		NA	11
9	Bedclothes	100% Ct	Green		China	12
10	Bedclothes	100% Ct	Green		Portugal	11
11	Bedclothes	100% Ct org	Brown		Bangladesh	20
12	Bedclothes	100% Ct org	Brown		India	20
13	Bedclothes	100% Ct org	Brown	YES	India	12
14	Bedclothes	100% Ct	Blue		NA	12
15	Bedclothes	100% Ct org	Blue	YES	India	12
16	Bedclothes	100% Ct	Black		Turkey	12
17	Bedclothes	100% Ct	Black		NA	11
18	Bedclothes	50% Ct; 50% PE	White	YES	Turkey	13
19	Bedclothes	50% Ct; 50% PE	White		Pakistan	10
20	Bedclothes	50% Ct; 50% PE	Pink (Fuchsia)		Pakistan	10
21	Bedclothes	50% Ct; 50% PE	Green		Pakistan	11
22	Bedclothes	50% Ct; 50% PE	Blue (turquoise)		Pakistan	10
23	Bedclothes	50% Ct; 50% PE	Blue	YES	Pakistan	12
24	Bedclothes	50% Ct; 50% Ly	White		Turkey	23
25	Bedclothes	50% Ct; 50% Ly	Brown		Turkey	14
26	Bedclothes	52% PE; 48% Ct	white		Pakistan	24
27	Bedclothes	52% PE; 48% Ct	White		Pakistan	9
28	Bedclothes	52% PE; 48% Ct	Vanilla		Pakistan	10
29	Bedclothes	52% PE; 48% Ct	Pink		Pakistan	11
30	Bedclothes	52% PE; 48% Ct	Green		Pakistan	11
31	Bedclothes	52% PE; 48% Ct	Blue		Pakistan	9
32	Pyjamas	100% Ct	Yellow		Bangladesh	20
33	Pyjamas	100% Ct	White striped pink		China	10
34	Pyjamas	100% Ct	White	YES	Bangladesh	15
35	Pyjamas	100% Ct	White		Bangladesh	19
36	Pyjamas	100% Ct org	White		Bangladesh	15
37	Pyjamas	100% Ct	Pink		India	18
38	Pyjamas	100% Ct	Grey striped white		India	19
39	Pyjamas	100% Ct	Multicolour		Morocco	15
40	Pyjamas	100% Ct	Black		Bangladesh	18
41	Pyjamas	100% Ct org	Black		Bangladesh	20
42	Pyjamas	100% Ct	Black		Bangladesh	18
43	Pyjamas	100% PE	Red		Indonesia	9
44	Pyjamas	100% PE	Pink pointed black		Indonesia	8
45	Pyjamas	100% PE	Black		Indonesia	9
46	Pyjamas	100% PE	Black pointed white		China	16
47	Pyjamas	60% Ct; 40% PE	Blue		Bangladesh	15
48	Pyjamas	93% Ct; 7% Vs	Grey		Bangladesh	14
49	Pyjamas	95% Ct; 5% E	White		China	16
50	Pyjamas	95% Ct; 5% E	Pink		China	17
51	Pyjamas	95% PE; 5% E	White pointed black	YES	Bangladesh	10
52	Pyjamas	95% PE; 5% E	Black	YES	Bangladesh	8
53	Pyjamas	96% Ct org 4% E	Pink		Bangladesh	20
54	Towel	100% Ct	Yellow		Bangladesh	36
55	Towel	100% Ct	White	YES	Turkey	38
56	Towel	100% Ct	White		Bangladesh	36

57	Towel	100% Ct	White		Pakistan	10
58	Towel	100% Ct	White		Portugal	50
59	Towel	100% Ct	White		NA	47
60	Towel	100% Ct org	White	YES	Portugal	51
61	Towel	100% Ct	Red		India	46
62	Towel	100% Ct org	Pink (Burgundy)	YES	Portugal	52
63	Towel	100% Ct	Pink		NA	41
64	Towel	100% Ct	Gris		Portugal	65
65	Towel	100% Ct	Green		NA	43
66	Towel	100% Ct org	Green	YES	Portugal	81
67	Towel	100% Ct	Brown		Pakistan	33
68	Towel	100% Ct	Brown		Portugal	42
69	Towel	100% Ct org	Brown	YES	Portugal	52
70	Towel	100% Ct	Blue		Bangladesh	36
71	Towel	100% Ct	Blue		Portugal	44
72	Towel	100% Ct	Black	YES	Turkey	38
73	Towel	100% Ct org	Black	YES	Portugal	49
74	Towel	80% PE; 20% PA	Blue		NA	16
75	Towel	80% PE; 20% PA	Black		NA	17
76	Towel	88% PE; 12% PA	Purple		China	20
77	Towel	88% PE; 12% PA	Blue		China	22
78	Towel	88% PE; 12% PA	Black		Morocco	21

Ct: Cotton; Ct org: Organic cotton; PE: Polyester; E: Elastane; PA: Polyamide; Vs: Viscose; Lyocell.
NA: Information not available.

Table 2. Human exposure and risk assessment parameters.

Variable	Description	Value	Reference
d_{cloth}	Cloth surface density	Table 1 (mg/cm^2)	Present study
F_{cloth}	Weight fraction of metal in cloth	Table 3	Present study
F_{mig}	Fraction of substance migrating to skin	Element specific 0.005	Rovira et al., 2016 Bundesinstitut für Risikobewertung, 2012
F_{pen}	Fraction of penetration inside the body	0.01 (0.03 for As)	United States Environmental Protection Agency, 2015
$F_{contact}$	Fraction of contact area for skin Bedclothes or/and pyjamas	1	Bundesinstitut für Risikobewertung, 2012
$F_{h\text{-}to\text{-}m}$	Fraction transference from hand to mouth	13%	Beyer et al., 2003
$F_{lips\text{-}to\text{-}m}$	Fraction transference from lips to mouth	50%	Beyer et al., 2003
$T_{contact}$	Contact duration between skin-textile Bedclothes or/and pyjamas Towel	0.36 d (8:39) 1 d	Institut d'Estadística de Catalunya, 2016 Assumed
BW	Body weight of an adult male	70 kg	Bundesinstitut für Risikobewertung, 2012
A_{skin}	Skin area of an adult male	20600 cm^2	United States Environmental Protection Agency, 2011
F_{skin}	Legs Feet Trunk Arms hands	31.2 % 7.0 % 35.9 % 14.1 % 5.2 %	United States Environmental Protection Agency, 2011
A_{lips}	Lips area surface	5.2 cm^2	Beyer et al., 2003
$A_{body\ towel}$	Area body towel	15200 cm^2	Assumed
$A_{hand\ towel}$	Area hand towel	1500 cm^2	Assumed
N	Mean number of events per day N_b: Bedclothes/pyjamas N_{Tb}: Body Towel N_{Th}: Hand towel	1 1/d 1 3	Assumed

Table 3. Concentrations (mg/kg) of a number of trace elements in 78 household textile items.

	% detected	Mean	St. Dev.	Median	Min	Max
Ag	13	0.02	0.02	<0.02	<0.02	0.13
Al	97	14.7	14.89	10.9	<0.83	108
As	0	<0.08				
B	35	0.64	0.84	<0.42	<0.42	3.93
Ba	97	0.96	1.14	0.66	<0.08	7.20
Be	0	<0.04				
Bi	9	0.01	0.01	<0.02	<0.02	0.08
Cd	0	<0.02				
Co	23	0.05	0.14	<0.04	<0.04	1.20
Cr	41	6.55	44.3	<0.21	<0.21	374
Cu	50	32.8	136	0.11	<0.04	1065
Fe	99	12.9	7.96	10.1	<0.83	40.7
Hg	3	0.04	0.01	<0.08	<0.08	0.13
Mg	97	142	168	83.5	<0.83	889
Mn	99	0.91	1.03	0.57	<0.04	7.68
Mo	5	0.02	0.02	<0.04	<0.04	0.16
Ni	58	0.19	0.24	0.10	<0.08	1.20
Pb	78	0.13	0.16	0.07	<0.02	0.90
Sb	37	26.9	48.3	<0.08	<0.08	202
Sc	0	<0.08				
Se	0	<0.42				
Sm	0	<0.04				
Sn	28	0.05	0.07	<0.04	<0.04	0.35
Sr	99	5.37	7.37	2.06	<0.04	33.8
Ti	86	10.9	19.7	1.58	<0.21	124
Tl	0	<0.02				
V	1	0.11	0.05	<0.21	<0.21	0.57
Zn	46	1.57	3.12	<0.08	<0.08	16.4

Table 4. Exposure levels to trace elements (in mg/kg/day) contained in bedclothes and pyjamas.

Scenario	Sleeping naked				Sleeping with pyjamas			
Period	Winter		Summer		Winter		Summer	
	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
Ag	3.9E-08	1.5E-07	2.0E-08	7.7E-08	4.9E-08	2.6E-07	3.8E-08	2.7E-07
Al	7.2E-05	2.2E-04	3.6E-05	1.1E-04	9.8E-05	7.7E-04	5.3E-05	1.5E-04
As	NC		NC		NC		NC	
B	1.2E-05	6.3E-05	6.2E-06	3.2E-05	3.8E-06	1.1E-05	8.4E-06	4.3E-05
Ba	7.6E-06	7.7E-05	3.8E-06	3.9E-05	6.0E-06	3.1E-05	5.6E-06	5.3E-05
Be	1.3E-09	2.5E-09	6.4E-10	1.2E-09	1.5E-09	2.2E-09	1.0E-09	2.3E-09
Bi	6.4E-10	1.2E-09	3.2E-10	6.2E-10	9.4E-10	2.8E-09	6.0E-10	2.8E-09
Cd	NC		NC		NC		NC	
Co	3.0E-09	8.3E-09	1.5E-09	4.2E-09	2.9E-09	1.4E-08	2.2E-09	5.7E-09
Cr	2.8E-07	8.5E-06	1.4E-07	4.2E-06	4.1E-08	1.1E-06	1.9E-07	5.8E-06
Cu	2.7E-04	4.1E-03	1.3E-04	2.0E-03	3.5E-05	5.4E-04	1.8E-04	2.8E-03
Fe	3.7E-05	1.3E-04	1.8E-05	6.4E-05	3.3E-05	7.5E-05	2.7E-05	8.8E-05
Hg	2.7E-09	7.3E-09	1.4E-09	3.7E-09	3.0E-09	4.6E-09	2.1E-09	5.0E-09
Mg	1.4E-05	6.9E-05	7.2E-06	3.4E-05	9.8E-06	5.5E-05	9.4E-06	4.7E-05
Mn	1.2E-05	1.2E-04	5.9E-06	6.0E-05	7.2E-06	3.7E-05	8.2E-06	8.3E-05
Mo	1.7E-09	8.6E-09	8.3E-10	4.3E-09	1.5E-09	2.9E-09	1.3E-09	5.9E-09
Ni	1.6E-07	1.2E-06	8.1E-08	5.8E-07	1.6E-07	5.8E-07	1.2E-07	8.0E-07
Pb	3.8E-07	1.8E-06	1.9E-07	9.2E-07	3.2E-07	1.3E-06	2.5E-07	1.3E-06
Sb	4.0E-06	2.6E-05	2.0E-06	1.3E-05	5.2E-06	2.7E-05	2.8E-06	1.8E-05
Sc	NC		NC		NC		NC	
Se	NC		NC		NC		NC	
Sm	NC		NC		NC		NC	
Sn	3.3E-09	1.5E-08	1.7E-09	7.6E-09	3.0E-09	2.5E-08	2.3E-09	8.8E-09
Sr	6.2E-05	2.1E-04	3.1E-05	1.0E-04	2.9E-05	1.1E-04	4.0E-05	1.4E-04
Ti	1.1E-05	1.1E-04	5.3E-06	5.6E-05	9.4E-06	7.1E-05	7.3E-06	7.7E-05
Tl	NC		NC		NC		NC	
V	7.2E-09	3.0E-08	3.6E-09	1.5E-08	7.7E-09	1.3E-08	5.5E-09	2.0E-08
Zn	1.6E-05	1.8E-04	7.9E-06	8.8E-05	8.9E-06	8.9E-05	1.0E-05	1.2E-04

Max.: Maximum exposure.
NC: Not calculated because the element was below the detection limit in all the samples.

Table 5. Exposure levels to trace elements (in mg/kg/day) contained in towels.

Scenario	Towelling		Hand to mouth		Mouth contact	
	Mean	**Max.**	**Mean**	**Max.**	**Mean**	**Max.**
Ag	2.9E-07	2.2E-06	1.1E-06	8.8E-06	1.5E-08	1.1E-07
Al	4.7E-04	1.7E-03	1.9E-03	6.8E-03	2.4E-05	8.7E-05
As	NC		NC		NC	
B	2.1E-05	5.6E-05	8.3E-05	2.2E-04	1.1E-06	2.8E-06
Ba	3.7E-05	2.4E-04	1.5E-04	9.5E-04	1.9E-06	1.2E-05
Be	NC		NC		NC	
Bi	8.3E-09	4.8E-08	3.3E-08	1.9E-07	4.2E-10	2.4E-09
Cd	NC		NC		NC	
Co	1.8E-08	2.2E-07	7.2E-08	8.9E-07	9.2E-10	1.1E-08
Cr	4.5E-07	1.0E-05	1.8E-06	4.1E-05	2.3E-08	5.3E-07
Cu	5.4E-04	7.0E-03	2.1E-03	2.8E-02	2.8E-05	3.6E-04
Fe	2.0E-04	5.8E-04	8.0E-04	2.3E-03	1.0E-05	2.9E-05
Hg	1.9E-08	3.7E-08	7.4E-08	1.5E-07	9.5E-10	1.9E-09
Mg	2.8E-05	1.2E-04	1.1E-04	4.9E-04	1.4E-06	6.3E-06
Mn	3.8E-05	1.6E-04	1.5E-04	6.5E-04	1.9E-06	8.4E-06
Mo	NC		NC		NC	
Ni	1.3E-06	8.6E-06	5.1E-06	3.4E-05	6.5E-08	4.4E-07
Pb	1.0E-06	4.0E-06	4.2E-06	1.6E-05	5.3E-08	2.1E-07
Sb	8.5E-06	5.6E-05	3.4E-05	2.2E-04	4.3E-07	2.8E-06
Sc	NC		NC		NC	
Se	NC		NC		NC	
Sm	NC		NC		NC	
Sn	2.6E-08	1.6E-07	1.0E-07	6.4E-07	1.3E-09	8.2E-09
Sr	1.2E-04	5.9E-04	4.9E-04	2.3E-03	6.3E-06	3.0E-05
Ti	3.8E-05	3.5E-04	1.5E-04	1.4E-03	1.9E-06	1.8E-05
Tl	NC		NC		NC	
V	NC		NC		NC	
Zn	5.0E-05	3.6E-04	2.0E-04	1.4E-03	2.6E-06	1.9E-05

Max.: Maximum exposure
NC: Not calculated because the element was below the detection limit in all the samples.

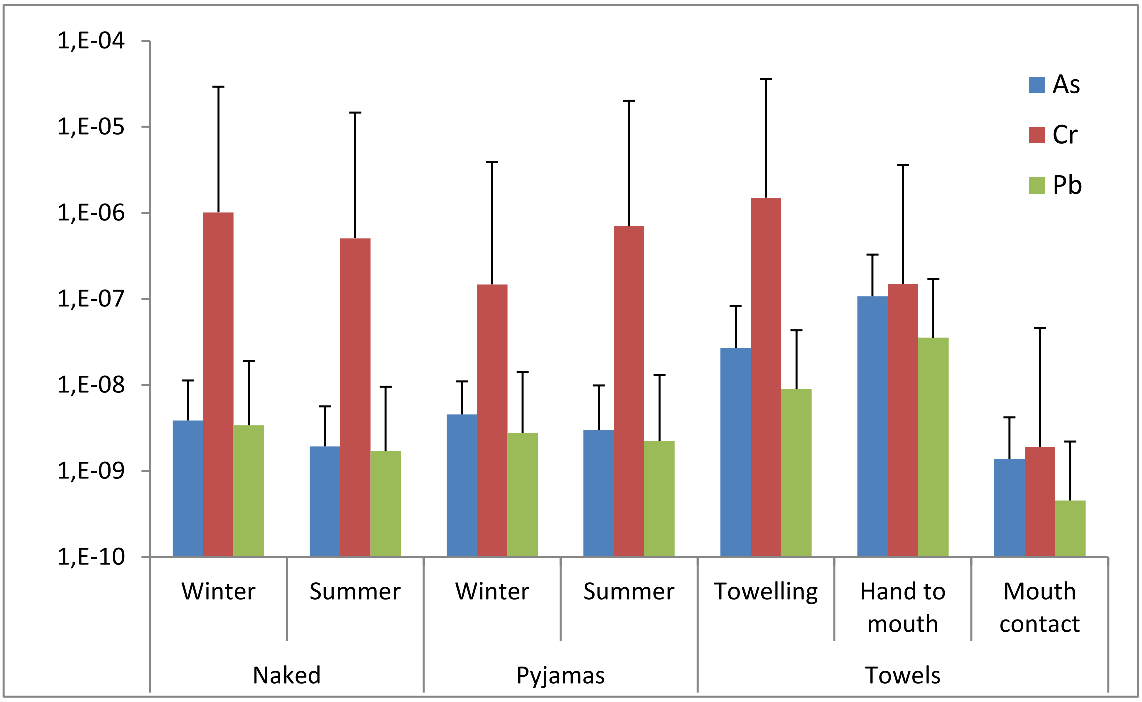

Figure 1. Cancer risk associated to the exposure to trace elements during sleeping (naked or wearing pyjamas) and using towels. Bars show maximum levels.

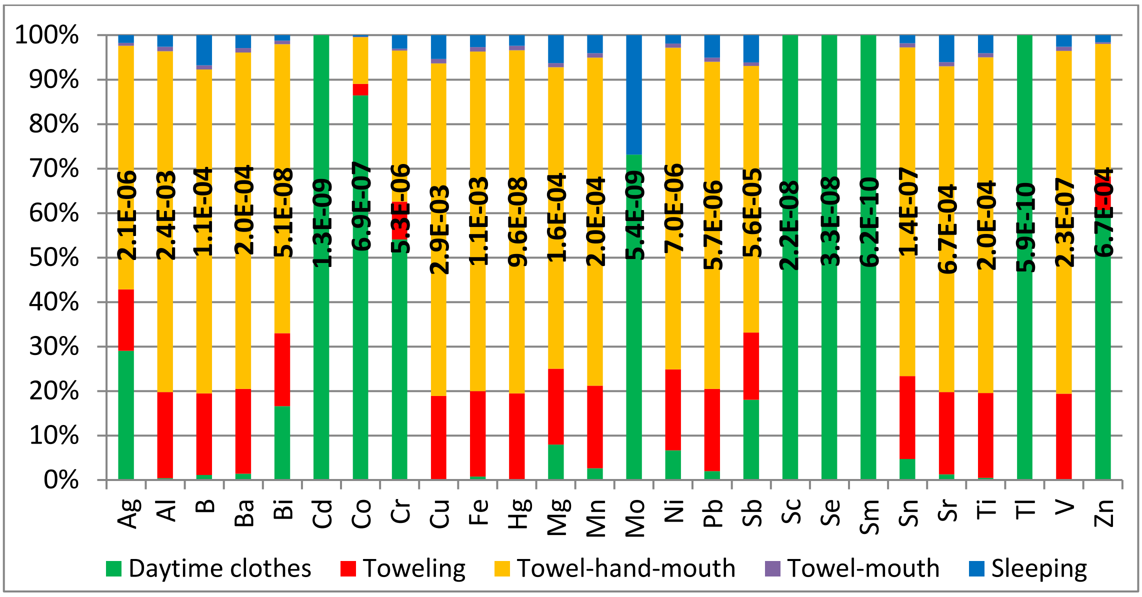

Figure 2. Contribution (in percentage) of different daily activities to the dermal exposure to trace elements after integrating all the scenarios. Numbers indicate the total exposure level in mg/kg/day.