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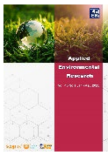

Research Article

Metal Contamination in Household Dust and Their Health Risk Assessment: A Study in Two Malaysian Cities

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Abstract

Investigating the composition of household dust can provide crucial insights into potential environmental and health implications. This study aimed to determine the concentration of selected metals in 30 household floor dust samples collected from two cities in Peninsular Malaysia, namely Melaka and Butterworth. The samples were collected using nylon socks attached to a vacuum cleaner nozzle during January-February 2021. All samples were sieved through a 200-µm sieve, acid-digested with aqua regia, and analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Mean metal concentrations decreased in the order of Fe>Al>Mg>Zn>Mn>Ba>Cu>Cr>Pb. Cd was not detected in any samples. The median concentrations of Al, Ba, and Mg from Melaka were significantly higher than those from Butterworth. Hazard indexes for all metals were less than one, indicating a low noncarcinogenic risk of exposure to occupants via inhalation, dust ingestion, and skin absorption. Statistical analyses revealed that the levels of metals in household dust were influenced by factors such as the location and age of the house, the presence of air conditioning, and the time since the last paint. This study highlights the presence of metals in indoor settings of different cities in Malaysia, providing fundamental data for future research in the field.

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Introduction

Indoor dust refers to fine (≤100 µm) settled or airborne particulate materials observed in an indoor environment [1]. Dust particles vary in size, with small particles being able to float in the air and enter human lungs, whereas large particles are heavy and tend to sink to the ground. Indoor dust can come from both interior and exterior sources. Tobacco smoke, cooking fumes, building, and furnishing materials are common interior sources of indoor dust [2–3]. Outdoor soil and street dust can enter homes through windows, vents, doors, pets and by adhering to residents' clothing and footwear. The composition of household dust differs considerably depending on geographical locations and rooms [4]. Household dust also acts as a reservoir for various inorganic and organic contaminants, such as heavy metals, flame retardants and polycyclic aromatic hydrocarbons [3, 5–6], making it a significant source of toxic substance exposure for humans, particularly young children.

Because of their non-biodegradability, toxicity, and health concerns, heavy metals in household dust have received great attention. People nowadays spend most of their time indoors, whether at home, work, or school. Contaminants from dust can enter the human body via inhalation, ingestion, and skin contact. Toddlers and children are more vulnerable to metals in dust because of their hand-to-mouth behavior, crawling on the floor, and smaller body size [3, 7]. Previous studies have revealed that the condition and location of a building, nearby human activities, and outdoor sources have significant impact on the level of metals in indoor dust [8–12].

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Metals concentration in indoor dust, source identification and health risk assessment have been attempted in many areas across the world, including Sydney, Australia [13], Ottawa, Canada [14], Istanbul, Turkey [15], and China [9]. Several studies have been conducted in Malaysia, primarily in nurseries and elementary schools' buildings [16–21], as well as other urban, semi-urban and rural areas [12, 22–24]. However, differences in city characteristics, such as industrial activity and population density, may have a major influence on metal levels and distribution in indoor dust. Therefore, it is crucial to investigate metal concentrations in indoor dust and the associated health risks to home inhabitants in different locations.

The objectives of this study focus on determining the concentrations of 10 selected metals (Al, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Pb and Zn) in indoor dust collected in Butterworth and Melaka, Malaysia. The potential sources or factors that may have influenced the presence of metals in the dust were identified using statistical analysis. The health risk of exposure to these metals through dust ingestion, inhalation and dermal uptake were also evaluated.

Materials and methods

1) Background of the study area

Butterworth (5.4380°N, 100.3882°E), the city center of Seberang Perai, is located in the Penang state on the northwest coast of Peninsular Malaysia. It served as the main logistical hub of northern Malaysia, as well as the home to the third busiest seaport in the country, the Port of Penang. As of 2020, it has a total population of 80 378 residents [25]. Butterworth's economy is also driven by heavy manufacturing, particularly at the Mak Mandin Industrial Estate where food processing, tin, steel, and metal fabrication factories are situated. Melaka City (also spelled Malacca) (2.1896°N, 102.2501°E) is the capital of Melaka state and has a population of 62 175 inhabitants [26]. It is situated on the southwestern coast of Peninsular Malaysia. Being one of the oldest towns in Malaysia, Melaka was formerly a well-known historic trading post that later developed into a prospering commercial center. The economy of Melaka City is largely based on tourism, besides being a manufacturing hub, with many domestic and foreign investors producing a wide range of goods for both domestic and international markets. Currently, there are 23 industrial zones located in the suburbs, including Batu Berendam, Ayer Keroh, Taman Tasik Utama, Cheng, and Tanjung Kling.

2) Sample collection

Household dust was collected from 30 homes in Butterworth (n=15) and Melaka (n=15) during the months of January and February 2021 (Figure 1). A standard vacuum cleaner with a clean nylon sock fitted into the suction nozzle was used to collect floor dust samples. The suction head was washed with deionized water and air-dried between samples. The nylon sock was then sealed in a plastic bag and brought to the laboratory. A questionnaire was used to obtain general information on household conditions, including age and location of the building, frequency of ventilation, number of occupants, air conditioning, frequency of vacuuming, time when the last paint was applied, smoking, keeping pets, and wearing shoes indoors.

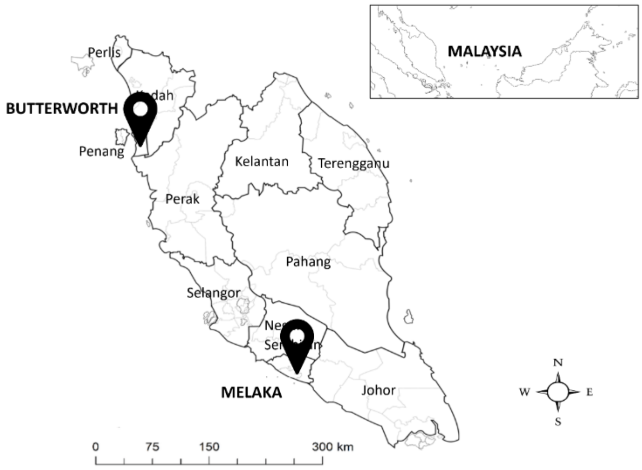

Figure 1 A map showing the study area.

3) Chemicals and materials

Analytical grade hydrochloric acid (37%), nitric acid (65%) and hydrogen peroxide (30%) were purchased from R&M Chemicals. Deionized water was obtained from a Milli-Q water purification unit. Multi-element Calibration Standard solution was purchased from Perkin Elmer. Stainless steel test sieve with mesh size 200-µm was used to remove foreign objects from dust samples.

4) Sample preparation and analysis

Sample preparation and analysis were performed according to Tay and Zakaria [27]. In short, 200 µm-sieved dust sample was acid digested with aqua regia solution and hydrogen peroxide in a water bath for 30-45 min. The solution was then filtered, diluted to 50 mL with 2% HNO_3 solution and stored at 4°C until instrumental analysis. The concentrations of metals were measured using an inductively coupled plasma mass spectrometer (Perkin Elmer Nexlon 300X ICP-MS). Multi-element Calibration Standard solution purchased from Perkin Elmer was used to prepare calibration standards. All statistical analyses (Spearman rank correlation, Principal Component Analysis, Mann Whitney *U* test and Kruskal-Wallis *H* Test) were performed using OriginLab software. In all statistical studies, the significance level was set at α = 0.05.

5) Quality assurance (QA) and quality control (QC)

All glassware and plasticware used to prepare the samples were pre-cleaned with detergent, soaked in a 5% nitric acid (HNO_3) solution overnight, then rinsed with deionized water. Powderless gloves were worn throughout the laboratory. One reagent blank and one standard reference material® 2584 (SRM2584, Trace Elements in Indoor Dust, NIST) were included in each batch of digestion. The average of blank concentrations was used to correct the reported results. SRM analysis revealed excellent recoveries for Cr (80.4%), Mn (88.5%), Zn (98.7%), Mg (116%) and Fe (103%). Satisfactory recoveries were obtained for Al (61.8%), Cu (75.0%) and Pb (70.8%), whereas the recoveries for Cd and Ba were relatively low (45.4% and 41.5%, respectively). Detection limits were calculated as the mean of blanks plus three times the standard deviation of all blanks run throughout analysis. The method detection limits were determined to be 10.39 mg kg^{-1} for Al, 5.51 mg kg^{-1} for Cr, 0.23 mg kg^{-1} for Mn, 0.71 mg kg^{-1} for Cu, 1.08 mg kg^{-1} for Zn, 0.02 mg kg^{-1} for Cd, 0.42 mg kg^{-1} for Ba, 0.10 mg kg^{-1} for Pb, 29.2 mg kg^{-1} for Mg and 13.4 mg kg^{-1} for Fe.

6) Health risk assessment

Residential exposure to metals and health risk associated with indoor dust were assessed according to the US EPA Exposure Factors Handbook [28]. The exposure doses through dust ingestion, inhalation and dermal contact were calculated by Eqs. 1–3:

$$ADD_{ing} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad \text{(Eq. 1)}$$

$$ADD_{inh} = \frac{c \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad \text{(Eq. 2)}$$

$$ADD_{der} = \frac{C \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad \text{(Eq. 3)}$$

where ADD is exposure dose (mg kg^{-1} day^{-1}). The input parameters for estimation of ADD were obtained from US EPA Exposure Factors Handbook [28] and were summarized in Table 1.

Following the calculation of the ADDs for the three exposure pathways, hazard quotients (HQs) were used to estimate the noncarcinogenic risk of metals in household dust using Eq. 4. A hazard index (HI) which is equal to the total of HQ of a particular metal via all exposure pathways, was calculated using Eq. 5.

$$HQ = \frac{ADD}{RfD} \quad \text{(Eq. 4)}$$

$$HI = \sum HQ = \sum HQ_{ing} + \sum HQ_{inh} + \sum HQ_{der} \quad \text{(Eq. 5)}$$

where RfD is the reference dose of metal (mg kg^{-1} day^{-1}). The RfD values used are 0.003 for Cr, 0.14 for Mn, 0.02 for Ni, 0.3 for Zn, 0.04 for Cu, 0.001 for Cd, 0.2 for Ba, 0.004 for Pb, and 0.7 for Fe [29]. For Al, the RfD is 1 [30]; whereas for Mg, the RfD was set at 11 due to no RfD value available and the optimal daily intake between 7–10 mg kg^{-1} day^{-1} [31].

Table 1 Input parameters for the estimation of AAD through dust ingestion, dermal contact and inhalation

Parameter	Symbol	Unit	Value	
			Adult	Children
Mean concentration of metal in household dust	C	mg kg^{-1}	-	-
Ingestion rate of contaminated dust	IngR	mg day^{-1}	30	60
Exposure frequency	EF	day $year^{-1}$	350	350
Exposure duration	ED	year	30	6
Body weight	BW	kg	70	15
Average time	AT	-	ED×365 day	ED×365 day
Inhalation rate	IngR	m^3 day^{-1}	15.2	7.6
Inhalation factor for the respirable particles	PEF	m^3 kg^{-1}	1.36×10^9	1.36×10^9
Surface area of the skin exposed to pollutants	SA	cm^2	5700	2800
Skin adherence factor	AF	mg cm^{-2} h^{-1}	0.07	0.7
Dermal absorption factor	ABS	-	0.001	0.001

Results and discussion

1) Metals in household dust

The metal concentrations in household dust from Butterworth and Melaka cities are presented in Table 2. Cd levels were below the detection limit in all samples. The absence of Cd detection could be due to its absence in the dust samples, or it might result from a relatively lower recovery of Cd during acid digestion (SRM recovery of 45.4%). In general, the mean metal concentration decreased in the following order: Fe>Al>Mg>Zn>Mn >Ba>Cu>Cr>Pb, which is consistent with previous study conducted in Simpang Renggam, Johor, Malaysia [22]. High quantities of Fe and Al in household dust samples were expected as they are among the main components of the earth's crust and are used in various human activities, including manufacturing, construction, and machinery production. These elements can be released through weathering, dispersed, or transported by wind. The median concentrations of Al, Ba and Mg in Melaka (5280, 80.2 and 2600 mg kg^{-1}, respectively) were significantly higher than in Butterworth (3,580, 24.9 and 918 mg kg^{-1}, respectively) (Mann Whitney U test, p = 0.009, 0.02 and 0.0096, respectively), which could be attributed due to higher traffic density and ongoing construction activities, including road widening, building construction, and old building renovation, particularly prevalent in the in historic city of Melaka. Additionally, advanced industrial development in the southern peninsular Malaysia may contribute to these differences. Street dust analysis has revealed that Al and Mg are predominant elements [32], while Ba may be released into the environment through the use of Ba-contained paints, coatings, alloys and other construction materials during old building renovation [33]. The presence of Pb in 9 out of 30 household dust could be due to the usage of leaded petrol prior to 1990s, resuspension of street dust by wind and anthropogenic activities, as well as the usage of lead-based paint in old houses. A combination of regulatory measures to ban the usage of leaded petrol, as well as reduced use in consumer products, has likely contributed to lower concentrations of Pb in household dust compared to other metals.

The concentrations of Al, Ba, Cr, Cu, Mn, Pb, and Zn in this study are low to moderate when compared to cities in Canada, Australia, China, Saudi Arabia, Japan, and Turkey as well as other locations in Malaysia (Table 3). The mean concentration of Mg in Melaka (3,450 mg kg^{-1}) is comparable to that found in Japan (4,000 mg kg^{-1}) [34], but much lower than that found in Ottawa, Canada (9,830 mg kg^{-1}) [35]. Fe was detected at a higher level in this study than in previous Malaysian studies [12, 22], but at a lower level than in Ottawa, Canada [35].

2) Statistical analyses

Spearman rank correlation was performed to evaluate the correlation between metals (Table 4). Strong correlation was relatively found between Fe and Mn (r=0.764), which is consistent with the findings of Chattopadhyay, Lin and Feitz [13] (r=0.84). Cu, Mn, and Fe were found to be positively correlated with other metals (0.401<r<0.764), suggesting that these metals come from common sources such as automobile emissions, soil, or road dust. Studies from Hong Kong [7] , Anhui rural, China [39], Simpang Renggam, Johor, Malaysia [22] and Seberang Perai, Penang, Malaysia [24], also reported a strong positive correlation between Zn-Cu (0.183<r<0.819) [7, 24, 39], Cr-Cu (0.23<r<0.93) [22, 39], Fe-Cr (r=0.790) [22], Cu-Mn (r=0.194) [7], Pb-Cu (r=0.653) [7] and Zn-Mn pairs (r=0.531) [7] in indoor dust.

Table 2 Metal concentrations in household dust samples from Melaka and Butterworth (mg kg^{-1})

	Melaka (n = 15)					Butterworth (n = 15)				
	min	median	max	mean	DF	min	median	max	mean	DF
Al	1,820	5,420	6,660	5,120	100	139	3,580	6,700	3,440	100
Cr	<5.51	8.22	157	25.4	80	<5.51	<5.51	125	26.3	47
Mn	<0.23	64.9	416	82.8	80	<0.23	63.7	313	82.4	80
Cu	<0.71	40.3	754	136	73	<0.71	<0.71	520	67.4	40
Zn	72.7	411	1,260	453	100	<1.08	230	2,660	496	93
Cd	<0.02	<0.02	<0.02	-	0	<0.02	<0.02	<0.02	-	0
Ba	<0.42	80.2	131	72.9	87	<0.42	24.9	235	45.1	60
Pb	<0.10	<0.10	24.9	5.21	33	<0.10	<0.10	54	5.16	27
Mg	874	2,600	7,920	3,450	100	21.7	918	5,720	1,780	100
Fe	3,340	9,290	18,700	9,710	100	218	9,010	77,300	12,400	100

Note: DF = Detection frequency (%)

Table 3 Metal concentrations in household dust samples compared to other studies

Reference	Location	Mean concentrations (mg kg^{-1})									
		Al	Cr	Mn	Cu	Zn	Ba	Pb	Mg	Fe	Cd
This study	Butterworth, Penang, Malaysia (n = 15)	3,440	26.3	82.4	67.4	496	45.1	5.16	1,780	12,600	<0.02
	Melaka, Malaysia (n = 15)	5,120	25.4	82.8	136	453	72.9	5.21	3,450	9,710	<0.02
Tay et al. [22]	Simpang Renggam, Johor, Malaysia (n = 7)	5,100	35.6	503	80.8	809	183	24.2	2,300	8,500	0.027
Latif et al. [12]	Kajang & Bandar Baru Bangi, Malaysia (n = 30)	n.a.	n.a.	n.a.	n.a.	0.43	n.a.	0.85	270	0.69	0.19
Wahab et al. [24]	Seberang Perai, Malaysia (n = 9)	n.a.	n.a.	n.a.	6.84	33.8	n.a.	39.5	n.a.	n.a.	n.a.
Salem et al. [36]	Jeddah, Saudi Arabia (n = 20)	n.a.	46.7	197	94.1	489	161	n.a.	n.a.	n.a.	0.54
	Al-Qunfudah, Saudi Arabia (n = 20)	n.a.	34.6	306	36.8	107	68.6	n.a.	n.a.	n.a.	0.07
Hejami et al. [14]	Toronto, Canada (n = 67)*	n.a.	42	58	136	386	71	36	n.a.	n.a.	1.7
Doyi et al. [37]	Sydney, Australia (n = 224)	n.a.	90.0	220	272	1876	n.a.	299	n.a.	n.a.	n.a.
Cheng et al. [38]	Chengdu, China (n = 90)	n.a.	82.7	n.a.	161	675	n.a.	123	n.a.	n.a.	2.37
Liu et al. [11]	China (n = 38)	n.a.	19.8	n.a.	16.9	166	n.a.	40.7	n.a.	n.a.	2.29
Yoshinaga et al. [34]	Japan (n = 100)	15,700	67.8	226	304	920	208	57.9	4,000	10,000	1.02
Kurt-Karakus [15]	Istanbul, Turkey (n = 31)	n.a.	55	136	156	832	n.a.	28	n.a.	n.a.	0.80
Rasmussen et al. [35]	Ottawa, Canada (n = 48)	26,000	86.7	270	206	717	492	406	9,830	14,100	6.46

Note: n.a. = data not available
*median concentration

Table 4 Correlation matrix for metal concentrations

	Al	Cr	Mn	Cu	Zn	Ba	Pb	Mg	Fe
Al	1	0.279	0.620*	0.453*	0.547*	0.206	0.320	0.559*	0.567*
Cr		1	0.401*	0.406*	0.320	0.173	0.449*	0.102	0.454*
Mn			1	0.599*	0.764*	0.382*	0.563*	0.398*	0.764*
Cu				1	0.606*	0.457*	0.374*	0.446*	0.607*
Zn					1	0.435*	0.443*	0.309	0.761*
Ba						1	0.275	0.159	0.454*
Pb							1	0.233	0.529*
Mg								1	0.276
Fe									1

Note: *Correlation is significant at the 0.05 level (2-tailed).

Principal component analysis (PCA) was used to identify the most likely sources of metals in dust. Two significant principal components, accounting for 50.52% of the total variances, were extracted (Table 5). PC1 accounted for 34.39% of the total variance with high loadings of Ba, Cu, Fe, Mn, and Zn. The second principal component (PC2) was dominated by Al, Cr, Mg and Pb. Previous studies have linked Fe, Zn and Cu to specific industries [10, 40], whereas Ba, Cu, Mn and Zn have been linked to vehicle wear and tear [40-42], indicating that PC1 was attributed due to industrial and traffic sources. Al and Mg are primarily generated from natural sources (such as earth crust sources from outdoors) and are transferred inside the house by people and ventilation [8]. These elements can also be contributed by building materials, particularly sand and cement used during renovation. Purple wall paint has been linked to high concentrations of Zn and Pb [8]. Cr might come from corrosion of metal objects and building materials. Hence, PC2 might be linked to outdoor dusts and considered as a combination of natural and anthropogenic sources.

Table 5 Principal component analysis of variables

Parameter	Coefficients of PC1	Coefficients of PC2
Al	0.393	0.174
Cr	0.179	0.478
Mn	0.510	-0.047
Cu	0.430	-0.079
Zn	0.279	-0.447
Ba	0.133	-0.301
Pb	0.266	0.476
Mg	0.196	0.345
Fe	0.403	-0.311
Eigenvalue	3.103	1.452
Variance explained (%)	34.49	16.13
Cumulative % variance	34.49	50.61

3) Influence of household conditions and personal behaviors on metal concentrations

The relationship between household dust metal concentration and potentially influencing factors was investigated using Mann Whitney *U* test and Kruskal-Wallis *H* test (Table 6). Results showed that facing the main traffic street had an important effect on Zn content in household dust (Mann Whitney U test, $p = 0.023$), which might be linked to tire abrasion, brake wear, as well as corrosion of automotive parts and road equipment [38, 42]. In addition, the Mann Whitney U test revealed that the median concentration of Mn in households with air-conditioning (48.7 mg kg^{-1}) was significantly lower than in those without (114 mg kg^{-1}) ($p = 0.009$). This finding is contrary to that of Kurt-Karakus [15], who reported that the presence of air conditioning was linked to higher median Cd, Cr, Cu, and Mn concentrations. One possible explanation is that the presence of air conditioning leads to lower ventilation rates through windows, reducing the chances of outdoor dust transportation into indoor environment. The concentrations of Mn and Zn were significantly higher in older houses (age >20 years) (Kruskal-Wallis *H* test, $p = 0.019$ and 0.025, respectively). Given the age of the houses in the current study (83.3% of them were >11 years old) and the last paint time for 60% of the houses was more than 5 years, flaking paint off the wall could be a significant contributor to metals in household dust [43].

It has been hypothesized that smoking is the primary cause of the high metal contents in indoor dust due to the amounts of Cd, Cu, Ni, Zn and Pb in cigarettes [38, 44-45]. This does not appear to be the case here, as our results showed no significant differences between the median concentrations of these elements, except for Mg. Households with smoking activities showed a higher level of Mg (4,250 mg kg^{-1}) than that without smoking (2,120 mg kg^{-1}) (Mann Whitney U test, $p = 0.012$). This finding could be due to the limited statistical power of this study as only a small number of samples were included. On the other hand, ventilation frequency, vacuuming frequency, wearing shoes indoors and number of occupants had no effect on metal levels in household dust (Mann Whitney *U* test and Kruskal-Wallis *H* test, p>0.05). Similar finding was also reported by Liu et al. [11] in a study across China. This result, however, contradicts the findings of Kurt-Karakus [15], who discovered that number of occupants was the most significant factor associated with metal concentrations.

4) Health risk assessment

A health risk assessment was carried out to estimate the non-carcinogenic risk posed to the occupants via three different routes (ingestion, inhalation, and dermal uptake). The HI values of metals decreased in the following order: Fe>Al>Cr>Zn>Cu>Pb>Ba>Mn>Mg (Table 7). Among the metals investigated in this research, Fe is the most significant contributor to the cumulative non-carcinogenic risk due to its high concentration in indoor dust. Household dust ingestion appears to be the most important metal exposure pathway, followed by skin contact and inhalation. The HI values associated with each metal were lower than the safe limit of one for both adults and children, indicating a low risk of exposure to metals in household dust. The HI values for children, on the other hand, were nearly an order of magnitude greater than those for adults.

Table 6 Associations between median household dust metal concentration (mg kg^{-1}) and the potentially influencing factors

Factor	n	Al	Cr	Mn	Cu	Zn	Ba	Mg	Fe
Facing main traffic street									
Yes	14	5,060	5.82	74.7	70.5	585	56.6	2,500	9,330
No	16	4,370	5.59	48.5	0.00	223	60.7	2,120	7,820
p-value[a]		0.647	0.881	0.243	0.087	0.023*	0.769	1.00	0.803
Air-conditioned									
Yes	22	4,370	5.82	48.7	21.0	272	60.7	2,340	7,600
No	8	5,000	11.9	114	32.9	542	56.5	2,490	9,860
p-value[a]		0.290	0.980	0.009*	0.713	0.140	0.813	0.870	0.052
Last painted									
5 years ago	12	5,420	6.79	63.1	35.4	415	68.6	2,570	8,720
>5 years ago	18	3,710	2.82	65.2	6.74	256	45.7	2,120	9,190
p-value[a]		0.028*	0.845	0.932	0.982	0.363	0.593	0.300	0.966
Age of house									
1-10 years	5	4,620	5.78	62.4	40.3	283	92.3	2,260	7,500
11-20 years	11	3,580	0.00	30.4	0.00	178	6.60	2,120	7,360
>20 years	14	5,040	16.3	93.3	23.7	515	52.1	2,470	10,100
p-value[a]		0.350	0.274	0.019*	0.391	0.025*	0.580	0.843	0.078
Numbers of occupants									
1-2	6	5,950	2.93	90.3	90.7	618	58.6	2,500	11,000
3-4	10	5,050	16.0	78.0	40.1	288	61.6	2,940	8,260
5	14	3,970	4.23	57.0	2.98	311	56.6	1,690	8,500
p-value[a]		0.088	0.306	0.269	0.279	0.210	0.786	0.188	0.416
Ventilation frequency									
Everyday	17	4,910	7.72	57.2	34.5	283	46.1	1,840	7,700
Occasionally	13	5,130	5.78	84.5	5.96	442	89.5	2,580	9,370
p-value[a]		0.572	0.607	0.313	0.861	0.194	0.198	0.379	0.391
Vacuuming frequency									
Twice a week	10	4,950	5.18	60.5	0.00	349	58.4	1,520	8,360
Once a week or less	20	4,855	5.82	65.2	37.2	362	59.0	2,500	9,330
p-value[a]		0.613	0.946	1.00	0.302	0.322	0.824	0.262	0.509
Smoking allowed									
No	25	4,620	7.72	64.9	7.51	406	53.8	2,120	9,370
Yes	5	5,130	5.78	62.4	40.3	283	92.3	4,250	8,140
p-value[a]		0.158	0.318	0.202	0.467	0.194	0.348	0.012*	0.478
Shoes allowed									
No	26	4,950	6.79	64.3	6.74	288	58.4	2,470	8,580
Yes	4	5,180	2.89	188	300	832	59.1	2,050	13,600
p-value[a]		0.261	0.165	0.188	0.260	0.064	0.439	0.451	0.165

Note: [a] p-value for comparing mean metal concentrations by Mann Whitney U test or Kruskal-Wallis H test.
[*] Difference between data set is significant at the 0.05 level.

Table 7 Hazard quotients and hazard index from metal exposure to household dust

	Adults					Children				
	HQ_{ing}	HQ_{inh}	HQ_{der}	HI	Risk	HQ_{ing}	HQ_{inh}	HQ_{der}	HI	Risk
Al	5.86E-03	2.18E-06	7.80E-05	5.94E-03	N	5.47E-02	5.10E-06	1.79E-03	5.65E-02	N
Cr	3.54E-03	1.32E-06	4.71E-05	3.59E-03	N	3.31E-02	3.08E-06	1.08E-03	3.42E-02	N
Mn	2.42E-04	9.03E-08	3.22E-06	2.46E-04	N	2.26E-03	2.11E-07	7.39E-05	2.34E-03	N
Zn	1.04E-03	3.89E-07	1.39E-05	1.06E-03	N	9.75E-03	9.08E-07	3.19E-04	1.01E-02	N
Cu	6.50E-04	2.42E-07	8.64E-06	6.59E-04	N	6.07E-03	5.65E-07	1.98E-04	6.26E-03	N
Ba	3.47E-04	1.29E-07	4.61E-06	3.51E-04	N	3.24E-03	3.01E-07	1.06E-04	3.34E-03	N
Pb	5.33E-04	1.99E-07	7.09E-06	5.40E-04	N	4.98E-03	4.63E-07	1.63E-04	5.14E-03	N
Mg	9.76E-05	3.64E-08	1.30E-06	9.90E-05	N	9.11E-04	8.49E-08	2.98E-05	9.41E-04	N
Fe	6.54E-03	2.44E-06	8.70E-05	6.63E-03	N	6.10E-02	5.69E-06	4.27E-04	6.15E-02	N

5) Limitations of study

Our study has significant limitations. For example, only 15 household dust samples from each city were included in the study (total sample = 30), leading to limited statistical power for detecting differences between groups and relations of interest. Dust samples were collected using nylon socks attached to the nozzle of a conventional vacuum cleaner, hence the sampling technique might have missed some of the very fine dust particles. Open vessel acid digestion with aqua regia solution has limited maximum digestion temperature, as well as potential loss of volatile elements, giving unsatisfactory recoveries especially for Cd and Ba. As a result, the digestion method employed in this study may have underestimated the total element concentration in Melaka and Butterworth's household dust. Future studies involving a higher number of samples, applying a more efficient dust sampling method, and employing closed vessel digestion are recommended.

Conclusion

The present study investigated the concentrations of Al, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Pb and Zn in 30 household dust samples from Melaka and Butterworth, Malaysia. Results revealed that household dust was primarily composed of Fe, Al, Mg and Zn. Statistical analyses suggest that metal levels were influenced by transportation of street dust into indoor environments, along with the impact of human activities such as painting and air-conditioning. Health risk assessment indicated a low risk of exposure to these metals through contact with household dust. Future research investigating metal contamination in dust particles of various sizes from different indoor environments could offer a more comprehensive understanding of exposure through inhalation, dust ingestion and dermal uptake.

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