

RESEARCH ARTICLE

Assessment of metal concentrations and associated health risks in indoor dust from Baling, Kedah, Malaysia

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Abstract - Household dust exposes people to a wide range of chemicals from everyday products and has been linked to respiratory symptoms. This study was conducted to determine the levels of selected metals (Al, Cr, Mn, Ni, Zn, Cu, Cd, Ba, Pb, Mg, and Fe) in household dust samples from seven households in Baling, Kedah, Malaysia. Dust samples collected using vacuum cleaners were acid-digested and analysed using inductively coupled plasma mass spectrometry (ICP-MS). The results showed that the mean concentrations of Al, Cr, Mn, Ni, Zn, Cu, Ba, Pb, Mg, and Fe in the dust samples were 6930, 6.85, 116, 19.2, 553, 77.6, 914, 11.5, 1780, and 5730 mg/kg, respectively. Cd levels were below the detection limit in all samples. Statistical analysis revealed that the use of air conditioners, the age of the house, smoking, and pet ownership contributed to higher metal levels in household dust. The Hazard Quotient (HQ) was used to assess the risk of metal exposure through dust ingestion, inhalation, and dermal absorption. The HQ and Hazard Index (HI) values for both adults and children were found to be less than one, indicating a low risk of exposure to these metals.

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1. Introduction

Dust emissions are a common problem in developing cities with high populations. Dust particles in the atmosphere can be transported and settle in streets, playgrounds, gardens, and indoor environments, including homes and schools. Nowadays, people tend to spend most of their time indoors, leading to concern about their exposure to contaminants, such as metals, through dust ingestion, inhalation, or dermal absorption. Long-term exposure to metal-contaminated dust can cause adverse effects, especially in infants and young children, due to its toxicity and bioaccumulation [1]. At this young age, their organs and brains are developing rapidly and are easily vulnerable to damage or disorder. Heavy metals such as Arsenic (As), Cadmium (Cd), Lead (Pb), Nickel (Ni), Chromium (Cr), and Manganese (Mn) usually led to allergic diseases to human health [2]. Other than that, children's respiratory illnesses, such as asthma, are frequently associated with indoor air quality [3]. Both internal and external sources contribute to the concentration of metals in indoor dust, which is much higher indoors than their natural crustal abundances [4]. Particulate matter from road dust, industrial emissions, soils, lubricant oil, pollutants from building erosion, and airborne or tracked-in particles from cars, clothes, and footwear are examples of external sources of metals. Metals can also be found internally in worn building materials, cosmetics, household appliances, rubber carpets, carpet pigments, and emissions from cooking, heating, and smoking [4]. The concentration of metals in environmental matrices varies depending on geographical location and the sources contributing to it. For example, urban areas tend to have higher concentrations of Pb, Ni, Cu, and Zn than rural regions, primarily due to transportation, vehicle emissions, traffic density, industrial activities, and building erosion [5].

Baling (5.6736° N, 100.9159° E) is a small town in the Malaysian state of Kedah with a population of 146,600. It shares borders with the state of Perak and the southernmost city of Thailand, Betong. Baling is surrounded by hilly terrains and is part of the Bintang Range (Banjaran Bintang), which extends into Perak. Compared with more urbanised areas in the northern region of Peninsular Malaysia, Baling may have lower dust emissions due to its slower rate of industrial development and urbanisation. Previous studies have attempted to determine metal concentrations in dust collected from nurseries and residential buildings across various locations in Malaysia [6-11]. Nevertheless, no comparable study has yet been carried out in the state of Kedah. Therefore, the objectives of this pilot study are to determine the concentration of selected metals, including aluminium (Al), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) in dust samples collected from Baling, Kedah, as well as to estimate the health risk associated with exposure to those metals for both adults and children.

2. Materials and Methods

2.1 Sample Collection and Pre-treatment

Seven vacuum cleaner dust samples were collected from different households of Baling, Kedah in August 2020 (during the period of Recovery Movement Control Order, RMCO/PKPP in Malaysia). Table 1 provides a description of the sampling locations. Dust samples were provided by the residents and transferred into plastic zip-lock bags, sealed, and labelled appropriately. Large objects (plastic objects, sticks, stones, hairs, glass fragments, etc) were removed with plastic tweezers upon arrival at the laboratory and then sieved through a 200 µm sieve.

2.2 Analysis

Chemical analysis techniques have been described elsewhere [12]. In short, before being used, all glass and plasticware were acid-washed. About 0.2 g of the dust sample was acid-digested with 10 mL of H₂O₂: HNO₃ (3:7 v/v) using an UltraWave™ system (Milestone Helping Chemist, Italy). Following digestion, the sample solution was filtered through Whatman cellulose acetate filter paper and diluted to 50 mL with 2% HNO₃. One reagent blank was included for each digestion batch. The concentrations of Al, Cr, Mn, Ni, Zn, Cu, Cd, Ba, Pb, Mg, and Fe were measured using a Perkin-Elmer NexIon 300X inductively coupled plasma – mass spectrometer. Detection limits were calculated as the mean of blanks plus three times the standard deviation of all blanks run throughout analysis. The instrumental detection limits (iDLs) were determined to be 147 µg/L for Al, 3.87 µg/L for Cr, 2.15 µg/L for Mn, 1.98 µg/L for Ni, 0.44 µg/L for Cu, 36.3 µg/L for Zn, 0.03 µg/L for Cd, 4.80 µg/L for Ba, 7.26 µg/L for Pb, 51.7 µg/L for Mg and 224 µg/L for Fe. All statistical analyses (Spearman rank correlation and Mann-Whitney U test) were performed using Microsoft® Excel® for Microsoft 365 MSO. In all the statistical analyses, the significance threshold was set at $\alpha = 0.05$.

Table 1. Description of the sampling sites

Household	B1	B2	B3	B4	B5	B6	B7
Building type	shop house	terrace	semi-D	semi-D	semi-D	terrace	terrace
size of the house (sqft)	~ 1200	~ 1200	~ 1200	> 1300	> 1300	> 1300	> 1300
No. of occupants	5	5	8	4	4	3	6
Age of the building (yr)	9	25	7	5	5	90	37
Facing main traffic street	no	no	no	no	no	no	no
Floor cover	tile	carpet	tile	tile	tile	tile	carpet
Shoes allowed	no	no	no	no	no	no	no
Smoking allowed	yes	yes	no	no	no	yes	no
Air-conditioned	yes	no	yes	yes	yes	no	no
Last painted (yrs ago)	1-5	1-5	> 5	1-5	1-5	< 1	> 5
Ventilation frequency	everyday	everyday	occasionally	everyday	everyday	everyday	everyday
Pets allowed	yes	yes	yes	no	no	yes	no
Vacuuming frequency	twice a week	once a week	once a month	once a week	once a week	twice a week	twice a week

2.3 Health Risk Assessment

In accordance with the USEPA Exposure Factors Handbook (USEPA 2011), the average daily exposure dose (ADD, mg/kg/day) of an element from dust via ingestion, inhalation, and dermal adsorption pathways can be calculated using Eqs. (1-3) respectively.

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

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

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

where C is the concentration of the element (mg/kg), $IngR$ is the ingestion rate of contaminated dust (30 mg/day for adult; 60 mg/day for children), EF is the exposure frequency (350 day/year), ED is the exposure duration (30 years for adult; 6 years for children), BW is the body weight (70 kg for adult; 15 kg for children), AT is the average time ($ED \times 365$ day), $IngR$ is the inhalation rate (15.2 m³/day for adult; 7.6 m³/day for children), PEF is the inhalation factor for the respirable particles (1.36 \times 10⁹ m³/kg), SA is the surface area of the skin exposed to pollutants (5700 cm² for adult; 2800 cm² for children), AF is the skin adherence factor (0.07 mg/cm²/h for adult; 0.7 mg/cm²/h for children) and ABS is the dermal absorption factor (0.001).

The hazard quotient (HQ) and hazard index (HI), which represent the lifetime non-cancer risk, can be calculated using Equations (4) and (5) based on the ADDs from the three exposure routes:

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

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

where RfD (mg/kg/day) is the estimated maximum permissible risk on humans through daily exposure. Unlikely detrimental impacts on human health are indicated by HQ and $HI \leq 1$, but likely adverse health consequences are revealed by HQ and $HI > 1$.

3. Results and Discussion

3.1 Concentration of Metals

Figure 1 summarises the metal concentrations of various metals across different indoor dust samples. Notably, Al was recorded as the most abundant metal in indoor dust samples, with a mean concentration of 6930 mg/kg, followed by Fe (mean = 5730 mg/kg). The Cd level was below the detection limit in all samples. In general, the mean metal concentration decreased in the following order: Al > Fe > Mg > Zn > Ba > Mn > Cu > Ni > Pb > Cr. The dominance of Al and Fe in the dust samples collected is expected, as they are among the most abundant elements in the Earth's crust. These metals might come from natural sources such as soil erosion, be distributed or carried by wind, and be associated with dirt or road dust, or with anthropogenic activities such as industrial emissions, construction, or transportation. The presence of elevated Al and Fe in household dust may also be linked to the infiltration of outdoor dust into the indoor environment [13].

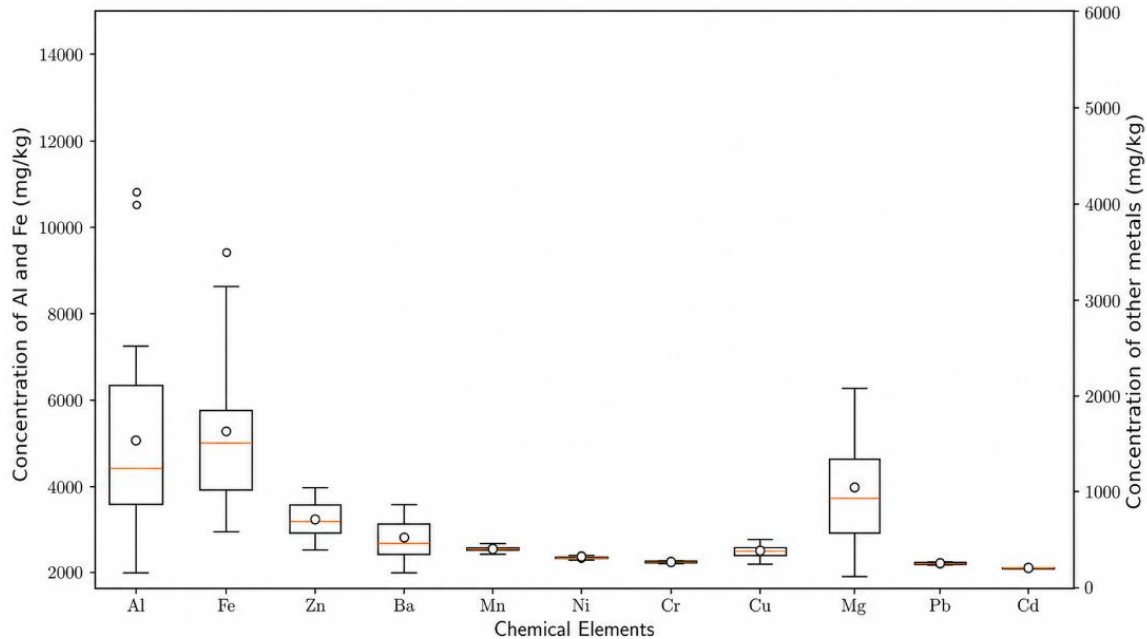


Figure 1. The concentrations of various metals across the samples

Variation in metal concentrations across research areas is usually due to differences in population density and the degree of industrial activity in the respective regions. Comparisons of metals in indoor dust between this study and other studies were summarised in Table 2. Our Al concentration is far lower than that in Canada [14] and Japan [15], but slightly higher than that reported in Simpang Renggam [9], Melaka, and Butterworth [10]. Zn, Ni, Cu, Mn, Mg and Cr concentrations were generally low to moderate compared to those reported in Japan [15], Canada [14], Thailand [16], Mexico [17], Turkey [18, 19] and several locations in Malaysia [9, 10]. This observation could be due to Baling town being less industrialised, which may have more airborne dust from natural sources rather than from industrial pollution. On the other hand, our findings for Zn, Cu and Mg in Baling were much higher than those reported in urbanised Kajang and Bandar Baru Bangi [7] as well as in Seberang Perai [11]. Worn building materials and combustion products from heating, cooking, and smoking could be indoor sources of these metals [20]. Agricultural practices and small-scale metal-related industries, such as metal workshops, automotive repair, or construction activities, could also contribute to increased Zn and Cu levels in Baling. Pb was detected in two samples, which may be related to sources such as construction materials, cleaning and grooming products, computers, printers, gasoline, and paints ([21, 22]).

3.2 Statistical Analysis

Spearman's rank correlation was performed to assess correlations among metals (Table 3). Strong correlations were found among Al and Mn ($r=0.93$), Al and Cu ($r=0.79$), and Al and Fe ($r=0.79$), suggesting that these metals originate from common sources such as soil or road dust. A positive correlation between Fe and Mn ($r=0.82$) is consistent with findings in Melaka and Butterworth, Malaysia [10], and Sydney, Australia [21]. The relationship between household dust metal concentrations and potential influencing factors was investigated using the Mann-Whitney U test (Table 4). Results showed that households with air-conditioning (coincidentally, all of these households are relatively young, between 1-10 years) exhibited a higher median Ba concentration (Mann-Whitney U test, $p<0.05$). This may be due to a homeowner's habit of closing all the windows to maintain a cool environment, which prevents air from circulating throughout the home. Levels of Mn, Mg and Fe were significantly higher in a smoker's household. Additionally, homes with pets had higher median concentrations of Al, Mn, Cu and Fe than homes without pets. Outdoor dust could attach to the pet's paws and body, which were then taken into the house. On the other hand, vacuuming frequency was not associated with metal concentrations in indoor dust in this study, possibly due to the small sample size and limited statistical power.

Table 2. Comparison of heavy metal concentrations in indoor dust between this study and other studies elsewhere

Reference		Al	Cr	Mn	Ni	Zn	Cu	Cd	Ba	Pb	Mg	Fe
This study	Baling, Malaysia (n=7)	6930	6.9	116.0	19.2	553.0	77.6	n.d.	914.0	11.5	1780	5730
Lim, et al. [10]	Butterworth, Penang, Malaysia (n = 15)	5120	25.4	82.8	n.a.	453.0	136.0	n.d.	72.9	5.2	3450	9710
	Melaka, Malaysia (n = 15)	3440	26.3	82.4	n.a.	496.0	67.4	n.d.	45.1	5.2	1780	12400
Tay, et al. [9]	Simpang Renggam, Johor, Malaysia (n = 7)	5090	35.6	503.2	23.6	809.3	80.8	0.0	182.9	24.2	2310	8500
Latif, et al. [7]	Kajang & Bandar Baru Bangi, Malaysia (n = 30)	n.a.	n.a.	n.a.	n.a.	0.43	n.a.	0.19	n.a.	0.85	270	0.69
Wahab, et al. [11]	Seberang Perai, Malaysia (n = 9)	n.a.	n.a.	n.a.	n.a.	33.8	6.84	n.a.	n.a.	39.5	n.a.	n.a.
Salem Ali Albar, et al. [23]	Jeddah, Saudi Arabia (n = 20)	n.a.	46.7	197	n.a.	489	94.1	0.54	161	n.a.	n.a.	n.a.
	Al-Qunfudah, Saudi Arabia (n = 20)	n.a.	34.6	306	n.a.	107	36.8	0.07	68.6	n.a.	n.a.	n.a.
Hejami, et al. [4]	Toronto, Canada (n = 67)*	n.a.	42	58	n.a.	386	136	1.7	71	36	n.a.	n.a.
Doyi, et al. [24]	Sydney, Australia (n = 224)	n.a.	90	220	n.a.	1876	272	n.a.	n.a.	299	n.a.	n.a.
Cheng, et al. [25]	Chengdu, China (n = 90)	n.a.	82.7	n.a.	52.6	675	161	2.37	n.a.	123	n.a.	n.a.
Liu, et al. [26]	China (n = 38)	n.a.	19.8	n.a.	n.a.	166	16.9	2.29	n.a.	40.7	n.a.	n.a.
Yoshinaga, et al. [15]	Japan (n = 100)	15700	67.8	226	59.6	920	304	1.02	208	57.9	4000	10000
Kurt-Karakus [19]	Istanbul, Turkey (n = 31)	n.a.	55	136	263	832	156	0.8	n.a.	28	n.a.	n.a.
Rasmussen, et al. [14]	Ottawa, Canada (n = 48)	26000	86.7	270	62.9	717	206	6.46	492	406	9830	14100
Gul, et al. [18]	Ankara, Turkey (n = 85)	n.a.	23.8	65.9	32.3	264	65.8	0.4	n.a.	27.5	n.a.	n.a.
Andrade, et al. [17]	Mexico (n = 203)	n.a.	n.a.	247	n.a.	1082	208	n.a.	n.a.	50	n.a.	17608
Somsunun, et al. [16]	Chiang Mai and Lamphun, Thailand (n = 100)	n.a.	n.a.	577.6	34.9	408.7	107.3	2.2	n.a.	62.1	n.a.	n.a.

Table 3. Correlation matrix for metal concentrations

	Al	Cr	Mn	Ni	Zn	Cu	Ba	Pb	Mg	Fe
Al	1									
Cr	0.00	1								
Mn	0.93	0.22	1							
Ni	0.25	0.58	0.27	1						
Zn	-0.50	0.07	-0.25	0.02	1					
Cu	0.79	0.48	0.82	0.50	-0.43	1				
Ba	-0.50	0.59	-0.32	0.63	0.64	-0.14	1			
Pb	0.53	-0.09	0.53	0.04	0.13	0.18	-0.13	1		
Mg	0.21	0.89	0.50	0.45	0.25	0.54	0.46	0.27	1	
Fe	0.79	0.26	0.82	0.40	-0.07	0.71	-0.07	0.80	0.54	1

Bold values are significant at the 0.05 level (2-tailed)

Table 4. Associations between median household dust metal concentration (mg kg⁻¹) and the potentially influencing factors

Factor	n	Al	Cr	Mn	Ni	Cu	Zn	Ba	Mg	Fe
Air-conditioned										
Yes	4	4370	7.32	92.6	26.3	66.0	543	168	1800	5820
No	3	8660	0.00	172	6.08	69.7	248	71.7	1790	5440
p-value ^a		0.240	0.362	0.240	0.060	0.500	0.144	0.039*	0.500	0.500
Age of house										
1-10 years	4	4370	7.32	92.6	26.3	66.0	543	168	1800	5820
>10 years	3	8660	0.00	172	6.08	69.7	248	71.7	1790	5440
p-value ^a		0.240	0.362	0.240	0.056	0.500	0.144	0.039*	0.500	0.500
Vacuuming frequency										
Twice a week	3	5180	15.0	94.6	24.6	66.5	248	111	1980	5440
Once a week or less	4	7380	2.92	116	21.2	67.6	511	114	1740	5820
p-value ^a		0.362	0.144	0.362	0.430	0.362	0.240	0.362	0.240	0.362
Smoking allowed										
Yes	3	8660	15.0	172	24.6	69.7	343	111	1980	7810
No	4	3330	2.92	79.1	21.2	64.2	416	114	1650	4670
p-value ^a		0.079	0.144	0.039*	0.298	0.144	0.500	0.500	0.039*	0.039*
Pets allowed										
Yes	4	9930	10.4	157	26.3	71.8	296	104	1890	7350
No	3	3100	0.00	67.6	17.8	62.9	678	131	1600	4600
p-value ^a		0.017*	0.144	0.017*	0.108	0.017*	0.144	0.362	0.079	0.017*

3.3 Health Risk Assessment

Figure 2 displays the HQs determined for adults and children across three exposure pathways. The HQ values for ingestion (HQ_{ing}) are notably higher than those for inhalation (HQ_{inh}) and dermal uptake (HQ_{der}) across all metals for both adults and children. This suggests that dust ingestion is the primary route of exposure to dust-borne metals, particularly for children. The HQ computed for each metal ranged from 5.77×10⁻⁸ to 0.089 for children and 2.47×10⁻⁸ to 9.50×10⁻³ for adults. Al has the highest HQ. The HI values for non-carcinogenic effects decreased in the following order: Al>Zn>Ba >Pb>Fe>Cr>Mn>Ni>Cu>Mg (Table 5). All HQ and HI values for both adults and children are less than 1, indicating that exposure to metals through dust ingestion, inhalation, and dermal uptake does not pose a significant health risk under current exposure conditions. Although individual HQ values are below the risk threshold, cumulative exposure to multiple metals could still pose long-term health concerns, especially for vulnerable populations. Continuous monitoring of metal levels in household dust, along with measures to reduce exposure, could be recommended as a precautionary approach.

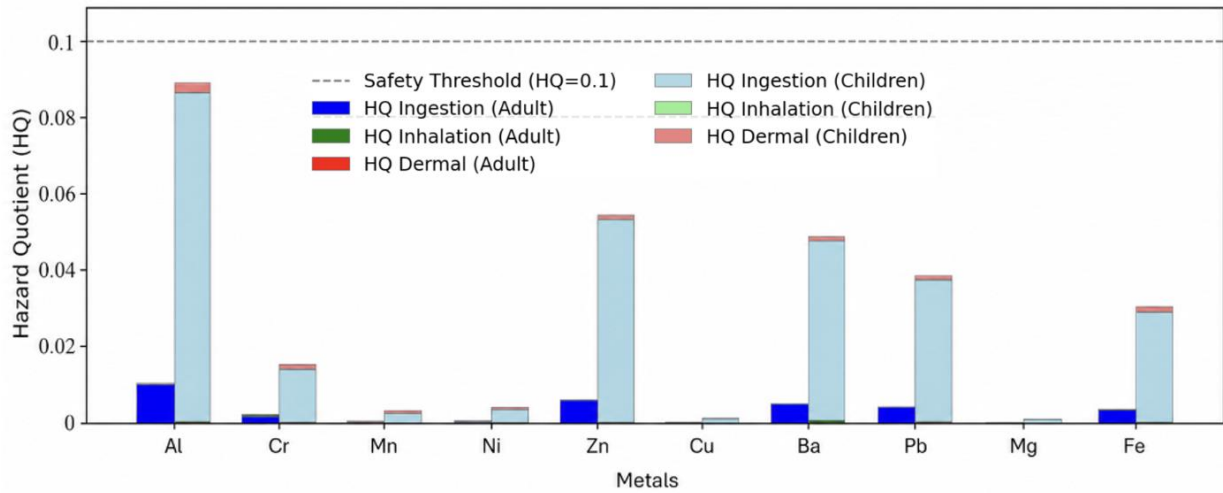


Figure 2. Hazard quotient (HQ) values for dust ingestion, inhalation, and dermal uptake between adults and children across various metals found in indoor dust

Table 5. Non-carcinogenic risks (HI) of metals in indoor dust

Elements	Adult	Children
Al	9.62E-03	9.15E-02
Cr	1.67E-03	1.58E-02
Mn	3.45E-04	3.28E-03
Ni	4.01E-04	3.57E-03
Zn	5.76E-03	5.47E-02
Cu	1.08E-04	1.02E-03
Ba	5.44E-03	5.17E-02
Pb	4.20E-03	4.00E-02
Mg	6.73E-05	6.40E-04
Fe	3.41E-03	3.24E-02

4. Conclusions

In this study, seven house dust samples were taken from Baling, Kedah, and their contents of Al, Cr, Mn, Ni, Zn, Cu, Cd, Ba, Pb, Mg, and Fe were examined. The results show that the samples' average heavy metal concentrations were in the following decreasing order: Al > Fe > Mg > Ba > Zn > Mn > Cu > Ni > Pb > Cr, whereas Cd was below the detection limit in all samples. The use of air conditioners, pet ownership, and smoking are examples of personal behaviours that may affect the concentration of metals in indoor dust. Health risk assessments revealed negligible risk of exposure to these metals through dust ingestion, inhalation and dermal uptake.

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Declaration of Competing Interest

The author declares no conflicts of interest.

CRedit Authorship Contribution Statement

N.H. Md Yusuff: Formal analysis, Data curation, Writing - original draft
 J.H. Tay: Conceptualisation, Investigation, Supervision, Writing – review & editing

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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