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A review of heavy metals in indoor dust and its human health-risk implications

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Abstract: Indoor dust acts as a media for heavy metal deposition. Past studies have shown that heavy metal concentration in indoor dust is affected by local human activities and atmospheric transport can have harmful effects on human health. Additionally, children are more sensitive to heavy metals due to their hand-to-mouth behaviour and rapid body development. However, limited information on health risks were found in past dust studies as these studies aimed to identify heavy metal concentrations and sources of indoor dust. The objective of this review is to discuss heavy metal concentration and sources influencing its concentration in indoor dust. Accordingly, high lead (Pb) concentration (639.10 μg/g) has been reported in heavy traffic areas. In addition, this review paper aims to estimate the health risk to children from heavy metals in indoor dust via multiple exposure pathways using the health-risk assessment (HRA). Urban areas and industrial sites have revealed high heavy metal concentration in comparison to rural areas. Hazard index (HI) values found in arsenic (As), chromium (Cr) and Pb were 21.30, 1.10 and 2.40, respectively, indicate that non-carcinogenic elements are found in children. Furthermore, most of the past studies have found that carcinogenic risks for As, cadmium (Cd), Cr and Pb were below the acceptable total lifetime cancer risk (TLCR) range (1×10^{-6}–1×10^{-4}). The results of health risk assessment in this review show that carcinogenic risk exists among children. Hence, this proves that future studies need to focus on children's carcinogenic risk in indoor dust studies in order to find out the sources of heavy metals in indoor dust. This review highlights the importance of having the HRA application using bioavailable heavy metal concentration as it provides more accurate health-risk estimation. Moreover, this review is also useful as a reference for policy decision making in protecting children's health.

Keywords: carcinogenic; dust; health risks; indoor; non-carcinogenic.

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Introduction

The United States Environmental Protection Agency (USEPA) has classified indoor air as requiring attention as it is more contaminated in comparison to outdoor air. There has been growing concern on indoor air quality as people spend up to 90% of their time in indoor environments such as homes, schools and offices (1–3). According to Rashed (4) and Turner (5), indoor dust can be defined as fine (≤ 100 μm) settled airborne particles in indoor environments, whereas the pollutants in indoor dust may originate from interior and exterior sources. Studies have shown that indoor dust acts as a carrier of inorganic and organic pollutants such as heavy metals, pesticides, polychlorobiphenyls and polycyclic aromatic hydrocarbons (3, 6–13).

Amongst other pollutants in indoor dust, heavy metals require crucial study due to their non-degradable properties, high toxicity and adverse effects on human (9, 14). Furthermore, heavy metals in dust can enter into the human body through ingestion, inhalation and dermal contact (6, 15–18). Children are also more vulnerable to heavy metals in indoor dust due to their behaviour such as crawling, hand-to-mouth activities and fast growth rate (7, 19, 20). In addition, Olujimi et al. (21) found that the ingestion of dust is the main heavy metal exposure pathway for children as children tend to play on the floor and ingest the dust indirectly. Dust may easily cling to children's skin and be ingested by children unintentionally (21–23). Lastly, the fine dust particles may be inhaled into the lungs of children due to air suspension caused by wind (23). Moreover, studies have shown that heavy metals can cause adverse health effects to children (24–26). The International Agency for Research on Cancer (IARC) has classified aluminium (Al), cobalt (Co), copper (Cu), iron (Fe), nickel (Ni) and

zinc (Zn) as non-carcinogenic elements, whereas arsenic (As), cadmium (Cd), chromium (Cr) and lead (Pb) are classified as both carcinogenic and non-carcinogenic elements. Heavy metals such as As, Cd, Cr and Pb are widespread environmental pollutants which can cause harmful health effects, such as cancers (24, 27). Some examples of carcinogenic effects are respiratory illnesses, cardiovascular deaths, damage to the nervous system and slow growth development (25, 28).

According to the USEPA, the health-risk assessment (HRA) is a model developed to estimate human health risk that is caused by contaminants. Luo et al. (29) stated that the HRA consists of four main components, namely hazard identification, exposure assessment, dose-response assessment and risk characterisation. The hazards from the heavy metals in indoor dust can be identified through data compilation and evaluation of past studies. This helps to determine whether the particular heavy metal exposure may increase the risk of causing human adverse health effects. Exposure assessment can be done by relating the fate of the heavy metal transmission which consists of source, exposure point and receptor. Additionally, dose-response assessment presents the magnitude of the heavy metal exposure and adverse health effects. Lastly, risk characterisation complies all the information gathered from the previous steps and subsequently quantifies the health risks that are posed to humans. Likewise, the hazard quotient (HQ) and lifetime cancer risk (LCR) are used to calculate non-carcinogenic risks and carcinogenic risks, respectively. A HQ value of more than 1 indicates that the heavy metal in dust has potential non-carcinogenic risk to humans which can cause chronic diseases other than cancer, whereas an LCR outside of the acceptable range (1×10^{-6}–1×10^{-4}) indicates potential carcinogenic risk which increases the probability of the person developing cancer over their lifetime. There have been many indoor dust exposure studies conducted in the past (7, 9, 10, 14, 16, 22, 23, 30–34), however, all of these past studies were more concerned in determining sources and heavy metal composition in indoor dust. These studies offered limited information on health risks associated with heavy metal exposure in indoor dust.

Therefore, the objective of this review is to discuss the heavy metal concentration and point out on the sources influencing the concentration of heavy metals in indoor dust. Additionally, this review paper aims to estimate children's health risk (non-carcinogenic and carcinogenic risks) from heavy metals in indoor dust via multiple exposure pathways (ingestion, dermal contact and inhalation) by using the standardised calculation method as proposed by the USEPA. Moreover, the factors of concern in the HRA are also discussed in this review. This review helps to fill in the gaps when reporting the impact of heavy metals in indoor dust on human health. It also helps to alert the public, particularly parents to the dangers of heavy metals in indoor dust by demonstrating the HRA on children. Furthermore, this review can also be used as a reference in making a policy that stresses the protection of children's health and the environment.

Method

This systematic review was completed by searching articles through online electronic databases such as PubMed, Science Direct and Google Scholar between August and December 2015. The search terms included "dust", "heavy metals" and "health risks". The keywords that were used to search for article on indoor dust were "indoor dust or household dust or school dust" AND "heavy metal". As for heavy metal, the keywords used for the search included "indoor dust" AND "heavy metals or metalloid or trace elements". For health risk, the keywords used were "indoor dust" AND "heavy metals" AND "non-carcinogenic or carcinogenic". Figure 1 shows the flow chart used for article selection. The article selection involved two screening process. In the first screening, a total of 118 articles were selected by reading through its title and abstract. Then in the second screening, the contents of selected articles were read thoroughly to ensure the articles

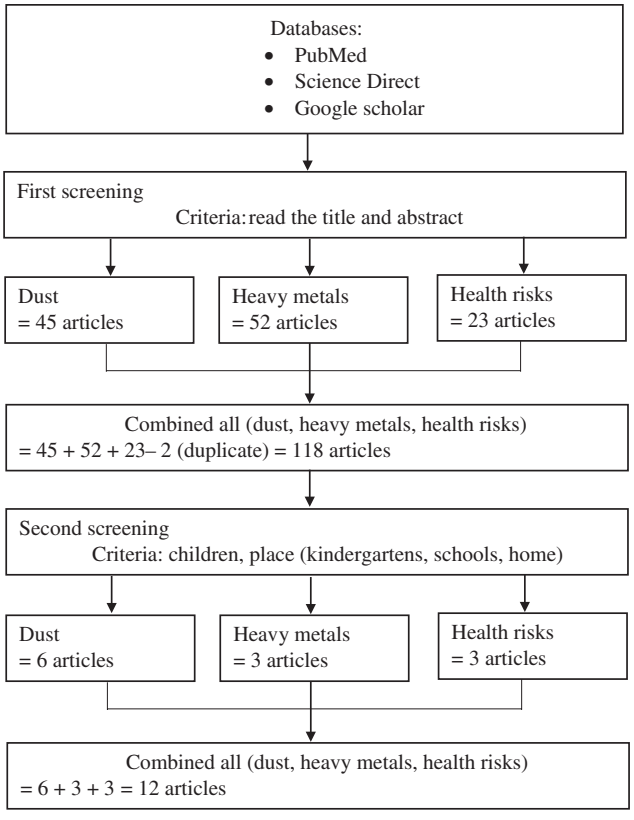

Figure 1: Flow chart of article selection.

met with the criteria such as the studies focused on children and the places of study. There were 12 relevant articles chosen from a total of 118 articles after the second screening process. This review covered the articles that were published in between 1996 and 2015. The data on heavy metal concentration in indoor dust were taken from relevant articles and the unit of heavy metal concentration was standardised as μg/g. These data were compiled to calculate health risks using standardised equations and parameters as shown in 4.0 HRA.

Concentration of heavy metals in indoor dust

Classroom dust and household dust are examples of indoor dust. From the literature review, classroom dust and household dust are the major heavy metal exposure pathway for children and require attention as children spend most of the time in classrooms and at home (7, 16, 23). Table 1 illustrates the heavy metal concentration in indoor dust obtained from past dust exposure studies. The concentration of heavy metals in indoor dust varies depending on the type of local human activities and location. Al-Rajhi et al. (6) reported the highest Pb concentration, 639.10 μg/g, as the study location is exposed to high traffic density and leaded fuel usage in Riyadh, Saudi Arabia. High Pb concentrations were also reported in classroom dust by Tahir et al. (30) in Dungun, Terengganu, Malaysia, Chen et al. (34) in Xi'an, China and Popoola et al. (16) in Lagos, Nigeria, which stressed the need to pay attention to the heavy metal contamination in children's study environments as Pb is a human carcinogen. All of the high Pb concentrations were reported in the indoor dust collected from urban areas which encounter heavy traffic and rapid growth of industrialisation. As a result, automobile emission has also become a main source of heavy metals in indoor dust as shown in past studies (6, 10, 30).

Consequently, the heavy metal concentration in indoor-settled dusts can vary greatly between rooms of a given house and among geographic locations (37). Tahir et al. (30), Lu et al. (36) and Chen et al. (34) have revealed a high Zn concentration in classroom dust with 738.00 μg/g in nurseries that are located close to industrial sites in Dungun, Terengganu, Malaysia; 462.60 μg/g in nurseries in Xi'an, China and 461.50 μg/g in kindergartens and elementary schools in Xi'an, China, respectively. However, Kurt-Karakus (35) reported the highest Zn concentration in dust collected in offices and homes in Istanbul, Turkey, which are 1970.00 μg/g and 832.00 μg/g, respectively. This may be due to the dustiness and ventilation of the building that can cause a different heavy metal concentration in indoor dust (16). Moreover, Darus et al. (14) reported a high concentration of Al (1229.58 μg/g) and Fe (4225.33 μg/g) in Shah Alam (Malaysia) nursery schools, while Latif et al. (23) found at a high Fe concentration (4801.00 μg/g) in a preschool located in Bandar Baru Bangi and another, in Kajang, Selangor (Malaysia). Latif et al. (23) also discovered that wind-blown dust from surface soil and road dust were the main contributors of heavy metal contents found in indoor dust.

Furthermore, most of the studies have demonstrated that the surroundings of industrial areas were the areas that have the highest heavy metal concentrations as shown by Hassan (10) in household dust located in Cairo, Egypt and Tahir et al. (30) in classroom dust in Dungun, Terengganu (Malaysia). The surrounding areas of industrial sites have reported high heavy metal concentrations due to restricted air flow caused by tall surrounding buildings and a high density population, which contributed to the vehicle emission. In addition, Hassan (10) found a high concentration of Al, Fe and Zn at house entryways. This may be due to footsteps carrying outdoor dust into an indoor environment. Additionally, Hassan (10) also revealed that heavy metal concentrations of Pb, Ni, Cd, Co, Cu and Cr increased when the size of dust particles decreased. This is because a smaller dust particle has a larger surface area which comes into contact with heavy metals in the environment, therefore resulting in high heavy metal concentrations in small dust particles (31).

Health-risk assessment

HRA can be defined as risk characterisation of the potential adverse health effects of human exposure to contaminants (29). The IARC has classified the carcinogens into five categories to indicate whether the agents can cause cancer, which include Group 1 (carcinogenic to humans), Group 2A (probably carcinogenic to humans), Group 2B (possibly carcinogenic to humans), Group 3 (not classifiable as carcinogenic to humans) and Group 4 (probably not carcinogenic to humans). From the IARC agents' classification, As, Cd, Cr and Pb are classified as potential non-carcinogenic and carcinogenic elements, whereas other heavy metals (Al, Co, Cu, Fe, Ni and Zn) are treated as non-carcinogenic elements. According to the *Exposure Factors Handbook* (38), the average daily dose (ADD) (mg/kg/day) of heavy metals via ingestion, dermal contact and inhalation can be estimated using the following equations, respectively:

$$\mathrm{ADD}_{\mathrm{ingest}} = \frac{\mathrm{C} \times \mathrm{IngR} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}, \quad [1]$$

Table 1: Heavy metal concentration (μg/g) in indoor dust from past dust exposure studies.

Types of indoor dust	Location	Heavy metal concentration in indoor dust (μg/g)										Reference
		Al	As	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn	
Public community centres	Riyadh, Saudi Arabia	n.a	n.a	2.00	n.a	69.20	271.10	n.a	52.90	639.10	547.10	Al-Rajhi et al. (6)
Nurseries and kindergartens	Hong Kong	n.a	n.a	8.48	n.a	n.a	247.38	n.a	n.a	199.96	2293.56	Tong and Lam (22)
Nurseries	Dungun, Terengganu, Malaysia											Tahir et al. (30)
– Industrial		n.a	n.a	n.a	n.a	n.a	71.00	n.a	n.a	116.00	738.00	
– Town		n.a	n.a	n.a	n.a	n.a	20.00	n.a	n.a	51.00	558.00	
– Village		n.a	n.a	n.a	n.a	n.a	42.00	n.a	n.a	67.00	337.00	
Nurseries	Shah Alam, Malaysia	1229.58	n.a	n.a	n.a	16.88	30.19	4225.33	9.00	31.24	148.71	Darus et al. (14)
Household dust (living room)	Cairo, Egypt											Hassan (10)
– Urban		1524.90	n.a	4.52	3.83	77.63	121.76	2691.50	77.69	321.96	190.00	
– Residential		2835.00	n.a	1.73	2.75	78.40	122.75	1857.45	31.63	181.26	124.78	
– Residential near to industrial area		4290.00	n.a	1.08	5.40	103.85	121.10	921.90	14.66	266.00	131.94	
Household dust (staircase)	Cairo, Egypt											Hassan (10)
– Urban		2422.50	n.a	4.24	3.42	69.79	156.25	1675.00	72.50	270.50	180.00	
– Residential		3742.50	n.a	0.79	1.90	55.30	147.50	2174.50	29.55	146.50	150.90	
– Residential near to industrial area		6650.00	n.a	0.68	3.98	120.13	175.00	3317.00	13.23	148.00	338.55	
Household dust (entryway)	Cairo, Egypt											Hassan (10)
– Urban		2541.50	n.a	4.75	4.25	85.45	168.00	3845.00	82.65	338.90	197.50	
– Residential		4725.00	n.a	1.83	3.06	63.12	168.75	2653.50	33.15	190.80	158.15	
– Residential near to industrial area		7150.00	n.a	1.14	6.00	132.75	167.50	1317.00	15.60	280.00	334.95	
Household dust	Istanbul, Turkey											Kurt-Karakus (35)
– Office		n.a	n.a	1.80	16.00	254.00	513.00	n.a	471.00	192.00	1970.00	
– Home		n.a	n.a	0.80	5.00	55.00	156.00	n.a	263.00	28.00	832.00	
Nurseries	Lagos, Nigeria	n.a	n.a	0.09	n.a	10.53	n.a	n.a	n.a	23.89	n.a	Popoola et al. (16)
Kindergartens and elementary schools	Xi'an, China	n.a	13.20	n.a	43.40	149.20	70.80	n.a	34.60	180.90	461.50	Chen et al. (34)
Preschools	Bandar Baru Bangi and Kajang, Malaysia											Latif et al. (23)
– Classroom floor		n.a	n.a	0.23	n.a	11.90	n.a	4801.00	n.a	253.50	144.90	
– Interior walls		n.a	n.a	0.32	n.a	120.80	n.a	1865.00	n.a	5.80	236.10	
Nursery schools	Xi'an, China	n.a	14.50	n.a	43.30	159.70	74.20	n.a	36.20	176.20	462.60	Lu et al. (36)
Schools and homes	Hunan, China	n.a	486.80	6.42	7.43	60.06	102.83	n.a	1.09	105.95	285.40	Cao et al. (18)
Primary schools	Sri Serdang, Malaysia	n.a	n.a	1.73	n.a	n.a	57.41	n.a	n.a	34.17	n.a	Praveena et al. (12)

n.a: Data not available.

$$\mathrm{ADD}_{\mathrm{dermal}} = \frac{\mathrm{C} \times \mathrm{SA} \times \mathrm{AF} \times \mathrm{ABS} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}, \quad [2]$$

$$\mathrm{ADD}_{\mathrm{inhale}} = \frac{\mathrm{C} \times \mathrm{InhR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}}, \quad [3]$$

where C is the concentration of heavy metals (mg/kg); IngR, the ingestion rate (mg/day); SA, the surface area of the skin exposed to heavy metal (cm^2); AF, the skin adherence factor (mg/cm^2/day); ABS, the dermal absorption factor (mg/cm^2); InhR, the inhalation rate (m^3/day); PEF, the particle emission factor (m^3/kg); EF, the exposure frequency (days/year); ED, the exposure duration (year); BW, the body weight (kg); AT, the averaging time (days); and CF, the conversion factor. The parameters of the ADD, reference dose (RfD) and cancer slope factor (CSF), which were obtained from the *Exposure Factors Handbook* (38), Integrated Risk Information System (39) and USDOE (40), were shown in Table 2. Additionally, the risks can be classified as non-carcinogenic risks and carcinogenic risks. Both non-carcinogenic and carcinogenic risk exposure for children will be calculated using HQ and LCR, respectively.

For non-carcinogenic risk, the HQ for children during a lifetime can be calculated by dividing the ADD from each exposure pathway by a specific RfD as shown in Eq. 4, whereas ADD is the average daily dose and RfD is the estimated maximum permissible risk posed to humans through daily exposure. Subsequently, the calculated HQ for all three exposure pathways (ingestion, dermal contact and inhalation) was summed to obtain the HI as shown in Eq. 5. In the event of $HI \leq 1$, then adverse health effects would be unlikely to occur. However, potential non-carcinogenic effects would occur when $HI > 1$ as this indicates that there is significant non-carcinogenic risk that is posed to human health.

$$\mathrm{HQ} = \mathrm{ADD} / \mathrm{RfD}, \quad [4]$$

$$\mathrm{HI} = \mathrm{HQ}_{\mathrm{ingest}} + \mathrm{HQ}_{\mathrm{dermal}} + \mathrm{HQ}_{\mathrm{inhale}}. \quad [5]$$

For carcinogenic risk, the LCR of children caused by potential carcinogen exposure over a lifetime can be calculated using Eq. 6, for ADD and SF is the slope factor for cancer. Equation 7 shows the TLCR that adds up all LCRs calculated for ingestion, dermal contact and inhalation.

Table 2: Values for parameters, RfD and CSF used in children's health-risk assessment calculations via ingestion, dermal contact and inhalation exposure pathways.

Parameter	Symbol	Value	Reference
Heavy metal concentration in indoor dust	C	Refer to the value in past studies	–
Ingestion rate	IngR	200 mg	USEPA (38)
Exposure duration	ED	6 years	USEPA (38)
Exposure frequency	EF	350 days	USEPA (38)
Average body weight	BW	15 kg	USEPA (38)
Averaging time for non-carcinogenic	$AT_{non\text{-}carcinogenic}$	ED × 365 days	USEPA (38)
Averaging time for carcinogenic	$AT_{carcinogenic}$	70 × 365 days	USDOE (39)
Conversion factor	CF	1×10^{-6} kg/mg	USEPA (38)
Surface area of skin	SA	2800 cm^2	USEPA (38)
Skin adherence factor	AF_{dust}	0.2 mg/cm^2/day	*Exposure Factors Handbook* [USEPA (38)]
Dermal absorption factor (chemical specific)	ABS	0.01 mg/cm^2	*Exposure Factors Handbook* [USEPA (38)]
Inhalation rate	InhR	7.6 m^3/day	USEPA (38)
Particle emission factor	PEF	1.36×10^9 m^3/kg	USEPA (38)
Reference dose of aluminium	RfD_{Al}	1.000 mg/kg/day	USDOE (39)
Reference dose of arsenic	RfD_{As}	0.0003 mg/kg/day	USEPA (40)
Reference dose of cadmium	RfD_{Cd}	0.0010 mg/kg/day	USEPA (40)
Reference dose of cobalt	RfD_{Co}	0.0200 mg/kg/day	USDOE (39)
Reference dose of chromium	RfD_{Cr}	0.0030 mg/kg/day	USDOE (39)
Reference dose of copper	RfD_{Cu}	0.0371 mg/kg/day	USEPA (40)
Reference dose of iron	RfD_{Fe}	0.7000 mg/kg/day	USEPA (40)
Reference dose of nickel	RfD_{Ni}	0.0200 mg/kg/day	USEPA (40)
Reference dose of lead	RfD_{Pb}	0.0035 mg/kg/day	USEPA (40)
Reference dose of zinc	RfD_{Zn}	0.3000 mg/kg/day	USEPA (40)
Cancer slope factor of arsenic	CSF_{As}	1.5000 mg/kg/day	USEPA (40)
Cancer slope factor of cadmium	CSF_{Cd}	6.3000 mg/kg/day	IRIS USDOE (39)
Cancer slope factor of chromium	CSF_{Cr}	0.5000 mg/kg/day	IRIS USDOE (39)
Cancer slope factor of lead	CSF_{Pb}	0.0085 mg/kg/day	IRIS USDOE (39)

The acceptable range of TLCR for carcinogenic risk is in the range of 1×10^{-6}–1×10^{-4}. If the risk exceeds the range, this implies that carcinogenic risks exist and the potential carcinogenic effect would likely occur.

$$\mathrm{LCR} = \mathrm{ADD}\times\mathrm{SF}, \quad [6]$$

$$\mathrm{TLCR} = \mathrm{LCR}_{\mathrm{ingest}} + \mathrm{LCR}_{\mathrm{dermal}} + \mathrm{LCR}_{\mathrm{inhale}}. \quad [7]$$

Estimation of health risks (non-carcinogenic and carcinogenic) among children due to heavy metal exposure in indoor dust

The major exposure pathway of heavy metals in indoor dust to children is through ingestion, followed by dermal contact and lastly inhalation (19). Table 3 shows the HI values and LCR values which represent non-carcinogenic risks and carcinogenic risks of heavy metals in indoor dust for children via ingestion, dermal contact and inhalation exposure pathways. The highest HI values for heavy metals were 0.0940 for Al (10), 21.3000 for As (18), 0.0844 for Cd (18), 0.0285 for Co (34), 1.10 for Cr (35), 0.182 for Cu (35), 0.0901 for Fe (23), 0.3100 for Ni (35), 2.4000 for Pb (6) and 0.0863 for Zn (35). The HI value for As in the study of Cao et al. (18) was 21.30. This confirmed that the indoor dust was highly contaminated by As (486.80 μg/g) as the study location was nearby a lead-acid battery plant where arsenic was released into the environment during manufacturing.

Tchounwou et al. (27) have stated that exposure to high levels of As concentration can induce skin alterations, cardiovascular diseases, neurologic and neurobehavioural disorders, diabetes, hearing loss and hematologic disorders. In addition, Kurt-Karakus (35) also found non-carcinogenic risk for Cr (HI value of 1.10) in the dust samples that were collected from offices in Istanbul, Turkey. As for Cr, this can be formed naturally in the environment or artificially from industrial activities such as fuel combustion, chrome plating, stainless steel manufacturing and waste incineration (41, 42). Acute health effects of Cr on humans include allergies of the skin and mucous membrane, dermatitis, nasal irritation, nasal ulcers, allergic asthmatic reactions and deficiencies in the immune system and renal system (41–43). Additionally, lung cancer is a chronic health effect of Cr as it causes tissue damage in the lungs (42). Moreover, non-carcinogenic risk was also found in Pb involving studies performed by Al-Rajhi et al.'s (6) in Riyadh, Saudi Arabia and Hassan (10) in Cairo, Egypt. The HI value of Pb in Al-Rajhi et al.'s (6) study was 2.40 which validates that vehicle exhaust emission, usage of leaded fuel and high traffic density were the contributors to the Pb deposition in indoor dust. For Hassan (10), the HI values of Pb in the living room and entryway of homes in urban areas were 1.20 and 1.30, respectively, whereas 1.10 was obtained at the entryway of homes in the residential areas that are located close to industrial sites. The heavy traffic density and usage of leaded gasoline were the external sources of lead deposition in indoor dust. Exposure to Pb can cause damage to the haematologic, renal and neurological systems, reduce children's intelligence and academic performance and decrease hearing ability and sight of children, and cause memory loss and attention deficit disorders (24). The non-carcinogenic risks of heavy metals in indoor dust were basically low in residential areas in comparison to areas with high traffic and areas located close to industrial sites.

Carcinogenic risks that exceed the TLCR acceptable values were found in heavy metals such as As (8.23E-04), Cd (6.39E-07) and Cr (1.43E-04) in the studies conducted by Cao et al. (18), Popoola et al. (16) and Kurt-Karakus (35), respectively. All of these studies were undertaken in high population densities and heavy industrial locations. Long-term exposure to As can cause skin cancer, carcinoma, cancers in lungs, liver, urinary bladder, kidney and colon (27). Additionally, Waalkers (44) stated that Cd can cause lung cancer and induce tumours in liver, stomach, pancreas and urinary bladder. On top of this, high exposure to Cr is a cause of death, lung cancer, kidney damage, respiratory tract damage and damage to reproductive system (45). As for Pb, Tahir et al. (30), Darus et al. (14), Kurt-Karakus (35), Popoola et al. (16), Latif et al. (23) and Praveena et al. (12) revealed that carcinogenic risks existed in children as TLCR values were below the acceptable range (1×10^{-6}–1×10^{-4}). Automobile emissions and industrial activities were the main external sources of Pb (6). Tong and Lam (7) and Popoola et al. (16) also established that the age of buildings was associated with the Pb concentration in indoor dust. The deterioration and peeling of paints on the walls of old buildings settles as indoor dust, thus causing high Pb concentration in indoor dust. Thus, great attention is required for lead exposure in children as its long-term exposure can cause anaemia and renal failure (24).

Factors influencing to HRA

HRA helps to estimate the likelihood of adverse health effects on humans who are exposed to heavy metals in indoor dust. However, there are several limitations of

Table 3: Health risks of non-carcinogenic and carcinogenic risks represented by hazard index and total lifetime cancer risk values, respectively.

Location	Health risks	Al	As	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn	Reference
Riyadh, Saudi Arabia	Non-carcinogenic (HI)	n.a	n.a	2.63E-02	n.a	3.03E-01	9.63E-02	n.a	3.48E-02	**0.24E+01**	2.40E-02	Al-Rajhi et al. (6)
	Carcinogenic (TLCR)	n.a	n.a	1.42E-05	n.a	3.90E-05	n.a	n.a	n.a	6.12E-06	n.a	
Hong Kong	Non-carcinogenic (HI)	n.a	n.a	1.11E-01	n.a	n.a	8.79E-02	n.a	n.a	7.51E-01	1.00E-01	Tong and Lam (22)
	Carcinogenic (TLCR)	n.a	n.a	6.02E-05	n.a	n.a	n.a	n.a	n.a	1.91E-06	n.a	
Dungun, Terengganu												Tahir et al. (30)
– Industrial	Non-carcinogenic (HI)	n.a	n.a	n.a	n.a	n.a	2.52E-02	n.a	n.a	4.36E-01	3.23E-02	
	Carcinogenic (TLCR)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.11E-06	n.a	
– Town	Non-carcinogenic (HI)	n.a	n.a	n.a	n.a	n.a	7.10E-03	n.a	n.a	1.92E-01	2.44E-02	
	Carcinogenic (TLCR)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	**4.88E-07**	n.a	
– Village	Non-carcinogenic (HI)	n.a	n.a	n.a	n.a	n.a	1.49E-02	n.a	n.a	2.52E-01	1.48E-02	
	Carcinogenic (TLCR)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	**6.42E-07**	n.a	
Shah Alam, Malaysia	Non-carcinogenic (HI)	1.62E-02	n.a	n.a	n.a	7.40E-02	1.07E-02	7.93E-02	5.91E-03	1.17E-01	6.51E-03	Darus et al. (14)
	Carcinogenic (TLCR)	n.a	n.a	n.a	n.a	9.51E-06	n.a	n.a	n.a	**2.99E-07**	n.a	
Cairo, Egypt (living room)												Hassan (10)
– Urban	Non-carcinogenic (HI)	2.00E-02	n.a	5.93E-02	2.51E-03	3.40E-01	4.33E-02	5.05E-02	5.11E-02	**0.12E+01**	8.32E-03	
	Carcinogenic (TLCR)	n.a	n.a	3.20E-05	n.a	4.37E-05	n.a	n.a	n.a	3.08E-06	n.a	
– Residential	Non-carcinogenic (HI)	3.73E-02	n.a	2.27E-02	1.81E-03	3.43E-01	4.36E-02	3.49E-02	2.08E-02	6.81E-01	5.47E-03	
	Carcinogenic (TLCR)	n.a	n.a	1.23E-05	n.a	4.42E-05	n.a	n.a	n.a	1.74E-06	n.a	
– Residential near to industrial area	Non-carcinogenic (HI)	5.64E-02	n.a	1.42E-02	3.55E-03	4.55E-01	4.30E-02	1.73E-02	9.63E-03	9.99E-01	5.78E-03	
	Carcinogenic (TLCR)	n.a	n.a	7.67E-06	n.a	5.85E-05	n.a	n.a	n.a	2.55E-06	n.a	
Cairo, Egypt (staircase)												Hassan (10)
– Urban	Non-carcinogenic (HI)	3.18E-02	n.a	5.57E-02	2.24E-03	3.06E-01	5.55E-02	3.15E-02	4.76E-02	0.10E+01	7.89E-03	
	Carcinogenic (TLCR)	n.a	n.a	3.01E-05	n.a	3.93E-05	n.a	n.a	n.a	2.59E-06	n.a	
– Residential	Non-carcinogenic (HI)	4.92E-02	n.a	1.04E-02	1.25E-03	2.42E-01	5.24E-02	4.08E-02	1.94E-02	5.50E-01	6.61E-03	
	Carcinogenic (TLCR)	n.a	n.a	5.61E-06	n.a	3.12E-05	n.a	n.a	n.a	1.40E-06	n.a	
– Residential near to industrial area	Non-carcinogenic (HI)	8.74E-02	n.a	8.94E-03	2.62E-03	5.26E-01	6.22E-02	6.23E-02	8.69E-03	5.56E-01	1.48E-02	
	Carcinogenic (TLCR)	n.a	n.a	4.83E-06	n.a	6.77E-05	n.a	n.a	n.a	1.42E-06	n.a	
Cairo, Egypt (entryway)												Hassan (10)
– Urban	Non-carcinogenic (HI)	3.34E-02	n.a	6.24E-02	2.79E-03	3.74E-01	5.97E-02	7.22E-02	5.43E-02	**0.13E+01**	8.65E-03	
	Carcinogenic (TLCR)	n.a	n.a	3.37E-05	n.a	4.81E-05	n.a	n.a	n.a	3.24E-06	n.a	
– Residential	Non-carcinogenic (HI)	6.21E-02	n.a	2.40E-02	2.01E-03	2.77E-01	5.99E-02	4.98E-02	2.18E-02	7.17E-01	6.93E-03	
	Carcinogenic (TLCR)	n.a	n.a	1.30E-05	n.a	3.56E-05	n.a	n.a	n.a	1.83E-06	n.a	
– Residential near to industrial area	Non-carcinogenic (HI)	9.40E-02	n.a	1.50E-02	3.94E-03	5.82E-01	5.95E-02	2.47E-02	1.03E-02	**0.11E+01**	1.47E-02	
	Carcinogenic (TLCR)	n.a	n.a	8.09E-06	n.a	7.48E-05	n.a	n.a	n.a	2.68E-06	n.a	
Istanbul, Turkey												Kurt-Karakus (35)
– Office	Non-carcinogenic (HI)	n.a	n.a	2.37E-02	1.05E-02	**0.11E+01**	1.82E-01	n.a	3.10E-01	7.21E-01	8.63E-02	
	Carcinogenic (TLCR)	n.a	n.a	1.28E-05	n.a	**1.43E-04**	n.a	n.a	n.a	1.84E-06	n.a	
– Home	Non-carcinogenic (HI)	n.a	n.a	1.05E-02	3.29E-03	2.41E-01	5.54E-02	n.a	1.73E-01	1.05E-01	3.65E-02	
	Carcinogenic (TLCR)	n.a	n.a	5.68E-06	n.a	3.10E-05	n.a	n.a	n.a	**2.68E-07**	n.a	
Lagos, Nigeria	Non-carcinogenic (HI)	n.a	n.a	1.19E-03	n.a	4.61E-02	n.a	n.a	n.a	8.97E-02	n.a	Popoola et al. (16)
	Carcinogenic (TLCR)	n.a	n.a	**6.39E-07**	n.a	5.93E-06	n.a	n.a	n.a	**2.29E-07**	n.a	
Xi'an, China	Non-carcinogenic (HI)	n.a	5.78E-01	n.a	2.85E-02	6.54E-01	2.52E-02	n.a	2.27E-02	6.79E-01	2.02E-02	Chen et al. (34)

Table 3 (continued)

Location	Health risks	Al	As	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn	Reference
	Carcinogenic (TLCR)	n.a	2.23E-05	n.a	n.a	8.40E-05	n.a	n.a	n.a	1.73E-06	n.a	
Bandar Baru Bangi and Kajang, Malaysia												Latif et al. (23)
– Classroom floor	Non-carcinogenic (HI)	n.a	n.a	3.02E-03	n.a	5.21E-02	n.a	9.01E-02	n.a	9.52E-01	6.35E-03	
	Carcinogenic (TLCR)	n.a	n.a	1.63E-06	n.a	6.70E-06	n.a	n.a	n.a	2.43E-06	n.a	
– Interior walls	Non-carcinogenic (HI)	n.a	n.a	4.21E-03	n.a	5.29E-01	n.a	3.50E-02	n.a	2.18E-02	1.03E-02	
	Carcinogenic (TLCR)	n.a	n.a	2.27E-06	n.a	6.80E-05	n.a	n.a	n.a	**5.55E-08**	n.a	
Xi'an, China	Non-carcinogenic (HI)	n.a	6.35E-01	n.a	2.85E-02	7.00E-01	2.64E-02	n.a	2.38E-02	6.62E-01	2.03E-02	Lu et al. (36)
	Carcinogenic (TLCR)	n.a	2.45E-05	n.a	n.a	9.00E-05	n.a	n.a	n.a	1.69E-06	n.a	
Hunan, China	Non-carcinogenic (HI)	n.a	**2.13E+01**	8.44E-02	4.88E-03	2.63E-01	3.65E-02	n.a	7.16E-04	3.98E-01	1.25E-02	Cao et al. (18)
	Carcinogenic (TLCR)	n.a	**8.23E-04**	4.56E-05	n.a	3.83E-05	n.a	n.a	n.a	1.01E-06	n.a	
Sri Serdang, Malaysia	Non-carcinogenic (HI)	n.a	n.a	2.27E-02	n.a	n.a	2.04E-02	n.a	n.a	1.28E-01	n.a	Praveena et al. (12)
	Carcinogenic (TLCR)	n.a	n.a	1.23E-05	n.a	n.a	n.a	n.a	n.a	**3.27E-07**	n.a	

n.a: Data not available. HI, Hazard index; TLCR, Total lifetime cancer risk. Bold: Values that are exceeded the acceptable level; HI more than one and TLCR is in between the range of 1×10^{-6}–1×10^{-4}.

HRA as HRA only estimates the magnitude of health risks and does not diagnose a specific disease. Therefore, in order to obtain a precise health-risk estimation, there are some factors that need to be considered. Health-risk estimation in this study was accomplished using standardised parameters that were obtained from the USEPA. Thus, the exact health risk values were influenced by body weight, ingestion rates (IngR), inhalation rates (InhR) and averaging time (non-carcinogenic and carcinogenic risks) of each country. Accordingly, future research will be required to obtain these parameters based on the study area or country in order to obtain accurate health-risk estimation.

Heavy metal concentration in indoor dust can be obtained through the total heavy metal digestion method and bioavailability test. The total heavy metal digestion method usually involves the use of strong acid, including the aqua regia method (combination of HNO_3 and other types of acid such as H_2SO_4 and H_2O_2) and nitric acid extraction methods (46). However, Luo et al. (29) revealed that the total heavy metal concentration from the acid digestion method may overestimate the actual health risk due to the maximum heavy metals soluble in strong acids compared to bioavailable heavy metal concentration which represents the actual fraction of heavy metals that is absorbed by the human gastrointestinal tract. According to Turner (5), bioavailability can be described as the proportion of contaminants or chemicals that can be absorbed by the human body and moved to the systemic circulation which may have toxic effects on the body later. In practice, bioavailability of heavy metals can be analysed using the in vivo experiment and in vitro digestion models. In vivo experiments involving humans or experimental animals that have similar metabolic and anatomical structure of human can contribute to accurate bioavailability of heavy metals (5, 47). However, in vivo experiments involve expensive, time consuming, laborious and ethical issues. Conversely, the rapid, simple, time effective and cost effective in vitro digestion model can provide more perceptions such as effects of heavy metals towards organs in a modified model without killing in a short time of period compared to human and animal studies (48). Therefore, the in vitro digestion model provides a more accurate health-risk estimation as it mimics the processes of the human digestive system, from the mouth, to the stomach and to the small intestine (49). From the review conducted by Yuswir et al. (50), the physiologically based extraction test (PBET) is the most accurate in vitro digestion model in determining bioavailable heavy metal as it includes all three compartments (mouth, stomach and small intestine) as compared to the simplified bioavailability extraction test (SBET) which only

involves the stomach compartment. Incorporation of the bioavailability of heavy metal concentration in HRA will help to obtain accurate health risks caused by the heavy metal together with approximate values of other parameters (IngR, InhR and averaging time) from each country.

Conclusion

Indoor dust can have health effects in humans as it is the accumulation of settled heavy metals from the environment and humans spend more time indoors than outdoors. In addition, children are more susceptible to heavy metals as compared to adults due to their hand-to-mouth behaviour and rapid growth rate. Pb concentrations in indoor dust were found to be in the range of 5.80–639.10 μg/g in areas with heavy traffic and usage of leaded fuel in all the conducted studies. The highest concentration for Al, As, Cd, Co, Cr, Cu, Fe, Ni and Zn in past studies were observed to be 7150.00 μg/g, 486.80 μg/g, 8.48 μg/g, 43.40 μg/g, 254.00 μg/g, 513.00 μg/g, 4801.00 μg/g, 471.00 μg/g and 2293.56 μg/g, respectively. Past studies also indicated that areas in the vicinity of urban and industrial sites have higher heavy metal concentration in indoor dust in comparison to rural and village areas. The heavy metal concentration in indoor dust was altered by the building's dustiness and ventilation. In addition, this review also estimates health risk by adopting the data on heavy metal concentration that was collected from past studies using standard values of the USEPA. HI values for As, Cr and Pb were reported at 21.30, 1.10 and 2.40, respectively, in the areas which are nearby heavy industries and heavy traffic. These HI values were more than 1 which indicated that non-carcinogenic risks existed for children in the respective past studies. Carcinogenic risks of As, Cd, Cr and Pb were found in some of the past studies as most of the results were below the acceptable TLCR range (1×10^{-6}–1×10^{-4}). In order to obtain precise health-risk prediction, parameters such as body weight, IngR, InhR and averaging time need to be collected from each country. The PBET is capable of estimating the amount of heavy metal that is absorbed by the human body and is crucial to be included in the HRA for more accurate health-risk estimation in future studies as total heavy metal concentration may overestimate the health risks. The inclusion of HRA in future studies assists in contributing health-risk information on certain heavy metals in indoor dust as well as increasing the government and public awareness towards the severity of air pollution.

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