Non-carcinogenic and Carcinogenic Risk Assessment of Heavy Metals Exposure to Indoor Dust in Kathmandu, Nepal

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Abstract

The present study was carried out to assess the contamination of heavy metals in indoor household dust of Kathmandu, Nepal, and its adverse effect on the indoor environment and human health. The concentrations of four heavy metals (Cd, Cr, Ni, and Pb) in a total of ninety-three ($N = 93$) indoor dust samples collected from four different types of land use zones *viz.*, commercial, heavy traffic, residential, and control (undisturbed) of Kathmandu were determined by the flame atomic absorption spectrophotometer (FAAS). The mean concentrations of Cd, Cr, Ni, and Pb in indoor dust samples over the study zones were 0.89, 158.1, 113.3, and 65.3 mg/kg, respectively. The land use zones showed the various degree of metal contamination in indoor dust ranging from moderate to considerable level. PLI showed a high pollution load in the monitored locations, indicating an alarming condition and the urgent need for immediate remedial actions. Hazard quotient (HQ) values indicated ingestion as the major pathway of indoor dust heavy metal exposure to children while the inhalation pathway remained dominant in adults. Hazard index (HI) values showed no probable non-carcinogenic risk of the heavy metals present in the indoor dust of Kathmandu. For carcinogenic health risk, TLCR values were found within the acceptable safe limit indicating no cancer risk for both the receptor groups.

Keywords: Indoor dust, heavy metals, health risk, contamination assessment, Kathmandu

Introduction

In Kathmandu, the rapid growth in urbanization and industrialization has increased the risk of pollution due to dust particles in the indoor environment across different land use zones. Dust, a common air pollutant produced from various natural as well as anthropogenic activities, consists of solid particulate matter with fine particles [1]. Indoor air pollution with dust and other contaminants particularly toxic heavy metals may emanate from infiltration of outdoor pollutants, vehicle emission or through incense burning, smoking, furniture, and building materials or may result from occupants' activities [2]. Both outdoor and indoor dust are important indicators of environmental contamination from the atmospheric deposition that receive varying inputs of anthropogenic metals from various stationary and mobile sources such as vehicular traffics, industrial activities, power plants, residential fossil fuel burning, waste incineration, construction, and demolition activities and re-suspension of contaminated soil [3, 4]. They are significant contributors to pollution in an urban environment.

Dust particles re-suspend in the atmosphere under certain meteorological conditions and accumulate either on roadsides or outdoor ground surfaces [5]. The most polluting heavy metals in the urban environment including As, Cd, Co, Cu, Ni, Zn, and

Pb, could be released *via* street dust to the underlying soil contaminating groundwater through rainwater or seepage [6]. Consequently, the natural biogeochemical cycle of the ecosystem is disrupted causing substantial risks to human health [7]. Therefore, heavy metals in dust particles require crucial study due to their peculiar characteristics such as non-biodegradable and persistent nature, long biological half-life, and their potential toxic effects on humans [8,9].

Dust particles less than 100 µm size are more likely to stick on human skin and are harmful pollutants [10]. They can enter into the human body through three potential pathways *viz.,* ingestion, dermal contact, and inhalation [11]. Heavy metals in dust particles are likely to affect children *via* ingesting dust through finger sucking and mouthing non-food objects [12]. It has been reported that people spend up to 90% of their time in indoor environments such as homes, schools, and offices [13,14]. The United States Environmental Protection Agency (USEPA) [13] has therefore raised special concern on indoor air because of its' more contaminating nature than outdoor air. According to WHO [15], nearly 4 million people die prematurely from non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), and lung cancer, attributable to household air pollution from inefficient cooking practices. Among them, inhalation of particulate matter (soot) causes nearly half of deaths among children less than 5 years of age due to pneumonia.

Kathmandu is the capital and largest municipality of Nepal which spreads over an area of 50.7 km². The average elevation is 1,400 meters above sea level in the bowl-shaped Kathmandu Valley in central Nepal. The total population of Kathmandu city was 975,543 in the 2011 national census with an annual growth rate of 6.12% to the population figure of 2001 and projected to reach 1,319,597 by 2021. The local vehicular fleet has increased rapidly in recent years and the number of vehicles has exceeded 1.1 million in Kathmandu. The city, one of the fastest-growing metropolitan areas in South Asia with a 4 percent growth rate per year, has faced the unprecedented challenges of rapid urbanization and modernization at a metropolitan scale. Rapid urbanization and economic development in Kathmandu have resulted in a decline in its environmental quality. According to the WHO's Ambient Air Pollution Database [16], Kathmandu recorded the annual average $PM_{2.5}$ concentration of 49 µg/m³ in 2013, the value being 4.9 times higher than the maximum permissible limit recommended by WHO [17]. The levels of indoor and outdoor pollution in Kathmandu are therefore at great risk. Hence, the main objectives of this study are to (a) determine heavy metal contamination in indoor dust from different land-use zones across Kathmandu, (b) assess contamination level due to heavy metal accumulation in indoor dust, and (c) evaluate non-carcinogenic and carcinogenic health risks of heavy metals exposure to indoor dust in two receptor groups (children and adults) from the study areas.

Materials and Methods

Sampling

A total of 93 indoor household dust samples were collected from four different types of land use zones *viz.* commercial, heavy traffic, residential, and control (undisturbed area) in Kathmandu. The sampling sites were carefully selected to isolate the effect of metal discharges from different anthropogenic activities. For this, an initial field survey was made to enlist several potential sampling sites and categorized them under the above four major zones. The categorizations of sampling sites into four different land-use zones for indoor dust measurements were based on different domain activities in Kathmandu such as industrial, traffic load and population density, commercial, non-commercial and other anthropogenic activities. The sampling sites for indoor dust collection from different zones across Kathmandu are located using the GIS mapping method (Fig. 1).

From each land use category which was consecutively numbered for sampling indoor dust, 30 percent were selected following a simple lottery method. Accordingly, the number of sampling sites for the present study reached 9, 8, and 9 for commercial, heavy traffic, and residential zones respectively. The selection of control zone for background value was based on the sparse residential with low population density and limited anthropogenic activities. Our field observations also revealed no evidence of such domain activities in the past and during the sampling period as well. At the control zone, 5 sampling sites were selected for sample collection maintaining equidistance from one another. In this way, a total of 93 indoor dust samples (three households replicate from each sampling site) from adjacent to the roadside were collected during the dry season (February-March, 2020). Dust samples were collected by gently sweeping an area of about 1 m² from the residential
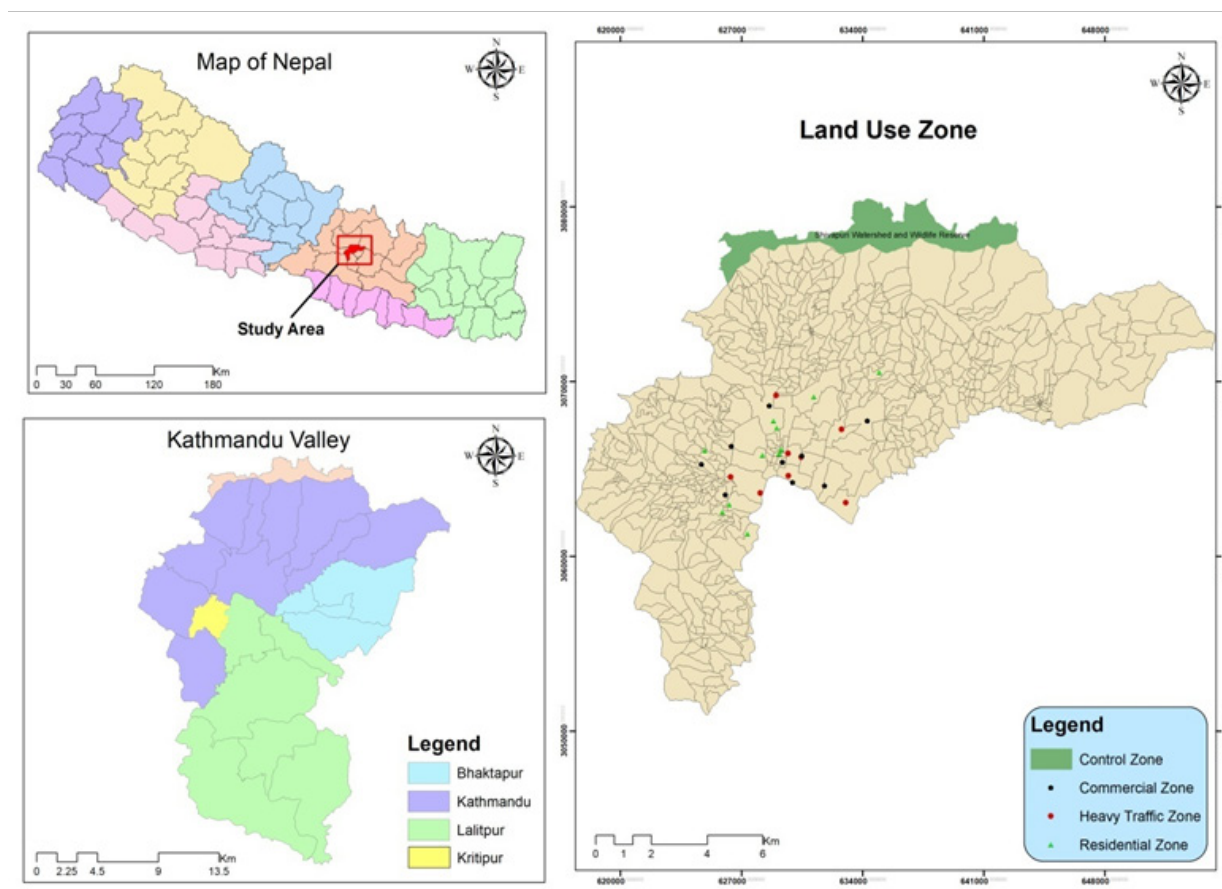
Figure 1: *Location of the sampling sites representing different land-use zones in Kathmandu*

floor, lamp covers, un-cleaned windowsills, and ceiling fans using a brush and plastic dustpan and transferring about 250 g of dust to self-sealing plastic bags and mixed as one sample to avoid comparison between the samples. The samples were well-labeled before transport to the laboratory. To avoid re-suspension of the finest particles during sampling, the sweeping was made slow and collected directly into plastic bags.

Sample preparation and analysis of heavy metals
In the laboratory, all samples were air-dried naturally for 3 weeks and then sieved initially through a 500-µm mesh to remove pieces of stones, cigarette butts, dead organisms, and other unwanted fragments. Indoor dust with diameters below 100 µm could be easily transported by re-suspension and accumulated from atmospheric deposition [18]. According to Shilton *et al.* [19], the finest particles of indoor dust can absorb high concentrations of heavy metals and remain airborne for a prolonged duration. Therefore, all dust samples were sieved through a sieve of 75 µm size for metal analysis. For determination of metal content, an aliquot of 0.5 g of dust sample was subjected to acid digestion using 10 mL concentrated HNO_3 and 2 mL 70% $HClO_4$ over the hot plate at low temperature [20]. The digestion process was continued till the volume became 1-2 mL, cooled, and then filtered through Whatman filter paper (No. 42) collecting the filtrate in a 25 mL volumetric flask. The interior of the beaker was washed two times with about 10 mL double distilled water, transferred into the funnel, and collected the filtrate into the same volumetric flask. The flask was mixed well to homogenize the sample and then the final volume was made with double distilled water. The samples were stored in the refrigerator at 4 °C before analysis or when not in use. The standard solutions of each heavy metal under investigation were prepared and used for calibration. The concentrations of four heavy metals (Cd, Cr, Ni, and Pb) were determined by the flame atomic absorption spectrophotometer (SOLAAR M5 Dual Atomizer, 180-900nm, Thermo Elemental, UK) using an air-acetylene flame.

Reagents, standards, and quality control
All chemicals and reagents used in this study were of analytical grade and procured from Sigma-Aldrich, USA. The standard solutions (1000 mgL^{-1}) for Cd, Cr, Ni, and Pb, and standard reference materials (NIST SRM 1648) were certified and procured from FLUKA AG, Switzerland. The reagents and calibration standards were prepared by successive dilution using double distilled water. All the glassware was treated with dilute (1:1) nitric acid for 24 h and then rinsed with double distilled water before use. Quality assurance and quality control were assessed through the standard laboratory methods for the reliability of the analytical data. This process included the use of standard operating procedures for calibration techniques, analysis of reagent blanks, matrix spikes, replicates as well as preparation of standards. All analyses were carried out in triplicate, and the detection limit was determined as three times the standard deviation of the mean. The precision and analytical accuracy were checked by analysis of standard reference materials (NIST SRM 1648). The recovery percentage of metal concentrations from the reference materials was 98% (Cd), 97% (Cr), 98% (Ni), and 98% (Pb). To determine the precision of the analytical process, few samples from the sampling sites were analyzed by three times. The standard deviation for the pretested samples was calculated to be 2.1, 2.3, 2.6, and 2.5% for Cd, Cr, Ni, and Pb respectively, and can be considered satisfactory for the analysis of dust samples. The detection limits were found to be 0.1, 1.0, 0.1, and 0.1 mg/kg for Cd, Cr, Ni, and Pb respectively.

Assessment of heavy metal contamination

Contamination factor and pollution load index
To evaluate the level of contamination in an indoor environment, monitored through indoor dust, contamination factor (C^if) and pollution load index (PLI) were determined. Hakanson [21] reported four classes of contamination factor index (C^if) to evaluate the metal contamination levels. The metal contamination levels were classified as low for $C^if < 1$, moderate for $1 \leq C^if < 3$, considerable for $3 \leq C^if < 6$, and very high for $C^if \geq 6$. The factor C^if can be calculated by Eq. 1:

$$C^if = \frac{C_s^i}{C_b^i} \dots\dots\dots\dots\dots\dots(1)$$

where, C^is represents the mean concentration of heavy metal i in the sample, and C^ib denotes the reference concentration of heavy metal i. The metal concentration of indoor household dust from the control zone was considered as background value due to the unavailability of information for the background concentrations of metals in indoor dust.

The mutual pollution effect at different sampling sites by different metals was calculated using the pollution load index (Eq. 2). PLI is the geometric mean of the C^if values for the n metals [22].

$$PLI = \left(C^1f \times C^2f \times C^3f \dots\dots\dots\dots \times C^if\right)^{1/i} \dots\dots\dots\dots\dots.(2)$$

where i is the number of heavy metals, and C^if is the contamination factor calculated by Eq.1. The PLI method can simply assess the site quality by identifying three classifications, *viz.*, no pollution for PLI < 1, deterioration of site quality for PLI > 1, and baseline levels of pollutants for PLI = 1 [22].

Human health risk assessment (HRA)
Risk assessment of human health is an important tool and extensively implemented for characterizing heavy metals along with their exposure pathways (Ingestion, dermal contact, and inhalation) in urban environments. The methodology used for the health risk assessment was based on the guidelines following the Exposure Factors Handbook of the US Environmental Protection Agency (USEPA) [13,23-25] and Ontario (Canada) Ministry of the Environment (OME) protocols [26].

Non-carcinogenic risk
Average daily dose (ADD) (mg/kg/day) of potentially toxic heavy metals that affect children and adults *via* ingestion (ADD$_{ingest}$), dermal contact (ADD$_{dermal}$), and inhalation (ADD$_{inhale}$) were estimated using the following Eqs. (3–5).

$$ADD(ingest) = \frac{C \times IngR \times EF \times ED \times CF}{BW \times AT} \dots\dots\dots\dots\dots\dots(3)$$

$$ADD(dermal) = \frac{C \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \dots\dots\dots\dots\dots(4)$$

$$ADD(inhale) = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \dots\dots\dots\dots\dots(5)$$

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.

C (exposure-point concentration, mg/kg) in Eqs. (3-5), combined with the values for the exposure factors shown above, is considered to yield an estimate of the "reasonable maximum exposure" [27], which is the upper limit of 95% confidence interval of the mean. The 95% upper confidence limit (UCL) was calculated as shown in Eq. (6).

$$If\ (n \geq 30),\quad UCL = \bar{X} \pm Z\,\frac{\alpha}{2}\left(\frac{\sigma}{\sqrt{n}}\right) \dots\dots\dots 6)$$

where, n = sample quantity, $\bar{X}$ = arithmetic mean concentration, σ = standard deviation, α = 1−(confidence level/100), $Z_{\alpha/2}$ = Z-table value, and UCL= upper confidence limit.

The receptor parameters used in the present study (Table 1) are based on US Environmental Protection Agency (USEPA) [23] and Ontario (Canada) Ministry of the Environment (OME) protocols [26].

Table 1: Receptor parameters for risk assessment models

Factor	Definition	Unit	Receptor	
			Children	Adults
IR_{ingest}	Ingestion rate	g/day	0.1	0.02
IR_{inhale}	Inhalation rate	m³/day	12.0	50.0
PEF	Particle emission factor	m³/kg	1.36×10^9	1.36×10^9
SA	Exposed skin area	m²	0.586	1.03
AF	Skin adherence factor	mg/cm²	0.02	0.07
ABS	Dermal absorption factor	-	0.01	0.01
ED	Exposure duration	year	7.0	50.0
EF	Exposure frequency	day/yr	320	350
BW	Average body weight	kg	32.9	70.7
AT	Average lifetime for heavy metals	day	ED×365	ED×365

The reference dose of the elements (Table 2) for three different pathways and slope factor for different elements used in the present study were adapted from USEPA [25].

Table 2: Reference dose (RfD, mg/kg/day) of elements for three different pathways and slope factor values (SF, (mg/kg/day)⁻¹)

Pathways	Cd	Cr	Ni	Pb
Oral RfD	1.00×10^{-3}	3.00×10^{-3}	2.00×10^{-2}	3.50×10^{-3}
Dermal RfD	5.00×10^{-5}	6.00×10^{-5}	5.40×10^{-3}	5.30×10^{-4}
Inhal. RfD	1.00×10^{-3}	2.86×10^{-5}	2.06×10^{-2}	3.50×10^{-3}
Slope factor (SF)	6.3	0.5	4.4	8.50×10^{-3}

The non-carcinogenic effects of heavy metals were estimated by calculating the hazard quotient (HQ) and hazard index (HI), using Eqs. (7–8):

$$HQ = ADD/RfD \dots\dots\dots\dots(7)$$

$$HI = HQ\ (ingest) + HQ\ (dermal) + HQ\ (inhale) \dots\dots 8)$$

The HQ for children and adults during a lifetime was calculated by dividing the ADD from each exposure pathway by a specific RfD as shown in Eq. (7). Here, ADD is the average daily dose and RfD is the estimated maximum permissible risk posed to the human population (for both children and adults) through daily exposure to a particular metal, without causing a considerable risk of deleterious impacts during a lifetime [28]. According to USEPA [24, 27], no risk of adverse health effects occurs for HQ ≤ 1, and there will be a probability of adverse health effects for HQ > 1.

Hazard index is used to evaluate the potential risk to human health when more than one heavy metal is involved. Hazard index is calculated as the sum of hazard quotients (HQs) as shown in Eq. 8 [28]. There is no risk of non-carcinogenic impacts for HI ≤ 1, and a chance of negative health effects occurs for HI>1 [29].

Carcinogenic risk

According to Li *et al.* [30], lifetime carcinogenic risk (LCR) denotes the probability of an individual developing any type of cancer over a lifetime due to carcinogenic exposures. The LCR of children and adults caused by potential carcinogen exposure over a lifetime is estimated using Eq. (9) for average daily dose (ADD in mg/kg/day) multiplied by the cancer slope factor (SF) for each exposure [31]. Equation (10) shows the total lifetime carcinogenic risk (TLCR) that adds up all LCRs calculated for ingestion, dermal contact, and inhalation.

$$LCR = ADD \times SF \dots\dots\dots(9)$$

$$TLCR = LCR\ (ingest) + LCR\ (dermal) + LCR\ (inhale) \dots\dots(10)$$

The acceptable value of TLCR for carcinogenic risk is in the range of $1 \times 10^{-6} – 1 \times 10^{-4}$ [23]. If the risk exceeds the range, this implies that carcinogenic risks exist and the potential carcinogenic effect would likely occur.

Statistical analysis

An IBM-PC computer was used for all data processing including descriptive statistics such as frequency, percentage, mean and standard deviation. SPSS v.19.0 (SPSS Inc., Chicago, USA) was used to study correlation among the metals.

Results and Discussion
Heavy metal concentrations in indoor dust

Table 3 lists the range and mean of heavy metal concentrations (Cd, Cr, Ni, and Pb) in indoor dust determined at different land-use zones in Kathmandu.

Table 3: *Heavy metal concentration (mg/kg) in indoor dust (Mean ± SD) from different land-use zones of Kathmandu*

Land use zone	Statistical parameter	Cd	Cr	Ni	Pb
Commercial zone (n= 9)	Mean	0.88 ± 0.17	175.4 ± 44.7	132.3 ± 37.6	48.4 ± 20.1
	Range	0.64 –1.12	97.3 – 245.4	75.5 – 188.7	20.8 – 76.3
Heavy traffic zone (n=8)	Mean	1.00 ± 0.22	158.7 ± 48.0	114.2 ± 23.8	97.8 ± 20.5
	Range	0.62 – 1.32	85.5 – 231.8	72.9 – 155.2	65.6 – 130.0
Residential zone (n=9)	Mean	0.80 ± 0.22	140.3 ± 60.1	93.3 ± 17.8	49.6 ± 9.0
	Range	0.63 – 1.15	68.2 – 212.4	68.2 – 118.4	36.8 – 62.5
Kathmandu District	Mean of all land use zones	0.89	158.1	113.3	65.3
Control zone (n=5)	Mean	0.39 ± 0.11	76.3 ± 19.9	32.8 ± 9.6	38.0 ± 10.5
	Range	0.24 – 0.54	50.1– 102.4	20.7 – 45.9	25.3 – 51.0
World's average shale values		0.3	90.0	68.0	20.0

Table 3 also presents the world average shale values of each heavy metal under investigation [32]. The mean concentrations of Cd, Cr, Ni, and Pb in indoor dust samples over the study zones were 0.89, 158.1, 113.3, and 65.3 mg/kg respectively. Chromium retained the highest mean concentration among heavy metals followed by Ni, Pb, and Cd (Table 3). The values were comparably higher than their control zone as well as the world's average shale values. Further, the results revealed that the mean concentration of heavy metals in the dust samples from the commercial, heavy traffic, and residential zones was in the order of Cr>Ni>Pb>Cd. The increase of Cr concentration could be attributed to its use in many alloys, especially stainless steel; therefore, grinding, welding, and also polishing of stainless steel can lead to the discharge of this element into the indoor environment [33]. Anthropogenically, Cr occurs by the burning of oil and coal, chromium steel, metal plating tanneries and also through sewage and fertilizers [34]. Apart from this, the source of Cr and Ni in dust is believed to be from car components, tyre abrasion, lubricants, engine wear, thrust bearing, brake dust, and bearing metals [35]. The highest concentration of Ni was recorded in indoor dust from the commercial zone followed by heavy traffic and residential zones. Nickel is representative metal of anthropogenic activities including machining, coal combustion, metallurgy and so on. The source of Ni in dust is also believed to be from corrosion of cars [36]. The metal is used for plating the outer part of a vehicle, such as the tyre rims or as an alloy for plating the surface of the cylinder and pistons of an engine.

The highest concentration of Pb was observed in the heavy traffic zone followed by residential and commercial zones. Lead is a major pollutant in the indoor environment that is released from combustion of gasoline containing Pb, burning gas for heating, road paints, abrasion of the automobile tyres, engine wear, radiators, leaks, and spills from batteries [37]. Although leaded petrol is banned in many countries today including Nepal, significant archives may still exist in the near-road environment as the low solubility of Pb allows it to have long residence times in the soil column [38].

Although Cd was found in lowest concentration among the heavy metals, heavy traffic zone showed the highest contamination of Cd in its indoor dust samples among the three major land use zones. Cadmium that occurs naturally in combination with zinc is a relatively rare heavy metal. Motor vehicles, car and automobile lubricants and reinforced car tyres with metals (Zn) are the possible source for Cd emissions in dust [39].

Table 4: *Pearson's correlation coefficients among heavy metals*

	Cd	Cr	Ni	Pb
Cd	1.00	0.214	0.218	**0.812***
Cr	0.214	1.00	**0.784***	0.316
Ni	0.218	**0.784***	1.00	0.214
Pb	**0.812***	0.316	0.214	1.00

*The correlation is significant at the 0.05 level.

The anthropogenic sources of Cd in dust are reportedly originated from automotive emissions, corrosion of the brake lining, the wear and tear as well as burning

Table 5: *Comparison of heavy metals concentration in indoor dust in this study with previous studies across the world (mg/kg)*

Cities/Countries	Cd	Cr	Ni	Pb	References
Kathmandu/Nepal	0.89	158.12	113.26	65.27	Present study
Khorramabad/Iran	11.34	11.81	60.19	32.08	Sabzevari & Sobhanardakani [33]
Cairo/Egypt	1.73	78.40	31.63	181.26	Hassan [43]
Anhui/China	-	113.68	38.93	348.73	Lin *et al.* [45]
Istanbul/Turkey	0.8	55.0	263.0	28.0	Kurt-Karakus [46]
Al-Karak city/Jordan	-	65.5	17.9	81.15	Madanat *et al.* [47]
Ebedei/Nigeria	4.8	-	20.15	97.45	Boisa & Odagwe [48]
Bushehr/Iran	5.4	83.5	42.0	93.4	Ardashiri & Hashemi [49]
Colombo/Sri Lanka	-	0.8	-	2.3	Pitawala *et al.* [50]

of vehicle tyres [36,40]. Cadmium is also used as an attendant substance of the zinc oxide in rubber matrix. Besides, domestic use of coal for cooking as well as burning of household refuse and products (batteries, toys, cigarettes, etc.) is another prominent source of Cd.

Table 4 shows correlations among the heavy metals under the present investigation. The positive correlations among the heavy metals indicate their common sources [41] and are frequently expressed by Pearson's correlation coefficient. The strong correlation was observed between Cd and Pb ($r = 0.812$, $p<0.05$), and Cr and Ni ($r = 0.784$, $p <0.05$) implying probably similar characteristics, fate and share common origins of emission. Moreover, the results revealed positive correlations, though not much significant, among the parameters suggesting common contaminant sources.

Although heavy metals in dust could be derived from indoor and outdoor sources, the result of this study indicated major influence from outdoor sources. The possible routes of heavy metals entering the household buildings could be through the open windows for cooling and ventilation [42]. While recognizing the fact that the movement of people in and out from houses also contributes the heavy metals inside the houses, its contribution is obvious from the ambient sources [9]. In addition, Hassan [43] found a high concentration of metals at house entryways due to footsteps carrying outdoor dust into an indoor environment. Besides, the study also revealed increasing concentrations of Pb, Ni, Cd, Co, Cu and Cr with decreasing size of dust particles because a smaller dust particle has a larger surface area and hence can absorb greater amount of metals [43]. Latif *et al.* [44] also found wind-blown dust from surface soil and road dust as the main contributors of heavy metal contents found in indoor dust.

Status of indoor environment (heavy metal pollution) in Kathmandu: Comparison with studies across the world

The mean concentrations of heavy metals in indoor dust in the present study were compared against different cities/countries across the world with a view to evaluate the status of indoor environment due to heavy metal exposure in indoor dust in Kathmandu (Table 5).

The mean level of Cd (0.89 mg/kg) as observed in the present study was comparable with the value reported from Istanbul (Turkey) but was lower than Khorramabad (Iran), Ebedei (Nigeria), Busheher (Iran) and Cairo (Egypt). On the contrary, the present study recorded exceptionally the highest level of Cr in indoor household dust compared to the list of cities/countries under study (Table 6). With the exception of Istanbul (Turkey), the mean level of Ni in the present study was comparatively higher than those reported for Khorramabad (Iran), Anhui (China), Cairo (Egypt), Al-Karak city (Jordan), Ebedei (Nigeria) and Busheher (Iran). Similarly, Pb level was found to be higher than Khorramabad (Iran), Istanbul (Turkey) and Colombo (Sri Lanka) but lower than those reported for Anhui (China), Cairo (Egypt), Al-Karak city (Jordan), Ebedei (Nigeria) and Busheher (Iran). The interplay of sources of metals, land use type, traffic volume, fuel quality, distance from the road, building materials, human habits, populations, etc. in each city determines the metal concentration in dust [51]. Hence, it may be suggested that degree of heavy metals contamination in indoor dust in a particular location or area depends mainly on the level and types of anthropogenic activities there.

Assessment of heavy metal contamination in indoor dust
Contamination factor and pollution load index
The land use-wise distribution of contamination and pollution load in indoor dust by Cd, Cr, Ni and Pb is presented in Table 6 and their classifications based

Table 6: Contamination factor (CF) and pollution load index (PLI) of different land use zones in Kathmandu

Contamination factor (CF)				
Landuse zone	**Heavy metals**			
	Cd	Cr	Ni	Pb
Commercial	2.26	2.30	4.03	1.27
Heavy traffic	2.56	2.08	3.48	2.57
Residential	2.05	1.84	2.85	1.31
Pollution load index (PLI)				
Landuse zone	**PLI value**			
Commercial	5.16			
Heavy traffic	6.90			
Residential	3.75			

The average metal contamination level in Kathmandu which is the ratio of average metal concentration from all land use zones to the metal concentration from control zone is presented in Figure 2.
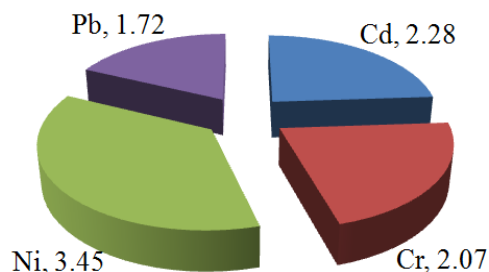

Figure 2: Average metal contamination level in indoor dust of Kathmandu

on contamination levels are shown in Table 7. The contamination factor (CF) indicates the amount of anthropogenically introduced metal in dust with respect to the natural concentration.

Table 6 showed that the contamination factor for Ni was found to be comparatively higher among the metals analyzed in indoor dust and in all land use zones in the order of commercial (4.03) > heavy traffic (3.48) > residential (2.85). Similar trend was also exhibited by all the land use zones for Cr. The heavy traffic zone showed higher contamination factor for Cd (2.56) and Pb (2.57) compared to the rest of the land use zones. Evidently, the commercial and heavy traffic zones showed considerable level of contamination ($3 \leq CF < 6$) for Ni (Table 7) whereas the residential zone exhibited moderate level of contamination ($1 \leq CF < 3$) for the same metal based on their contamination factors. On the other side, the moderate level of contamination ($1 \leq CF < 3$) was observed for Cd, Cr and Pb in indoor dust from the commercial, heavy traffic and residential land use zones.

Based on the average metal concentration from all land use zones and the average contamination level calculated thereafter, it can be concluded that average metal contamination level in indoor household dust from Kathmandu is at considerable level of contamination for Ni (CF = 3.45) and moderate level for Cd (CF = 2.28), Cr (CF = 2.07) and Pb (CF = 1.72) (Figure 2). Accordingly, the average metal contamination level in indoor dust from Kathmandu follows the order of Ni>Cd>Cr>Pb.

Pollution load index (PLI) demonstrates the mutual pollution effect in dust by different metals. Table 6 showed high PLI values indicating high pollution load in all the monitored land use zones. All the land use zones were found to have a category of polluted dust (PLI > 1) based on their PLI classification (Table 7). Results revealed that the heavy traffic zone was found to have a comparatively higher PLI value (6.90) followed by commercial (5.16) and residential (3.75) zone respectively. The high PLI could be attributable to the cumulative concentrations of heavy metals in

Table 7: Classification of pollution indices based on contamination factor and pollution load index of different land use zones in Kathmandu

Pollution index (Contamination factor)				
Land use zone	**Low (CF<1)**	**Moderate ($1 \leq CF < 3$)**	**Considerable ($3 \leq CF < 6$)**	**Very High ($6 \leq CF$)**
Commercial	-	Cd, Cr, Pb	Ni	-
Heavy traffic	-	Cd, Cr, Pb	Ni	-
Residential	-	Cd, Cr, Ni, Pb	-	-
Pollution index (Pollution load index)				
Land use zone	**Polluted dust (PLI >1)**		**Non-polluted dust (PLI < 1)**	
Commercial	(+)		-	
Heavy traffic	(+)		-	
Residential	(+)		-	

all land use zones, implying an alarming condition. The results of the present study are also in agreement with Roy *et al.* [20], Dehghani *et al.* [52] and Mehr *et al.* [53] who also reported high pollution load in dust in their studies highlighting that the highly contaminated areas are mostly affected by pollution from traffic, industries and other indoor and outdoor anthropogenic activities.

Human health risk assessment

The health risks due to heavy metals exposure in indoor dust included non-carcinogenic and carcinogenic. The assessment was done for children and adults as two receptor groups.

Non-carcinogenic risk

Non-carcinogenic risks from the HMs in indoor dust for three different exposure pathways (ingestion, dermal contact and inhalation) were calculated and the individual values of HQ and HI of these HMs for children and adults are presented in Table 8.

but their dermal posed less risk compared to children. Moreover, it was found that ingestion and inhalation routes were found insignificant for Cd exposure both in children and adults while dermal contact for Ni proved to be insignificant route for the same receptor groups based on the HQ values.

The HI values of the HMs for both the receptor groups declined in the order of Cr > Pb > Ni > Cd. Adults displayed higher HI values for Cr, Ni and Pb than children while the HI values were comparable for Cd between them. Among the HMs determined for non-carcinogenic health risk, Cr contributed 95% of the HI in children, while 85% contribution of the HI was found in adults for the same element similar to recent works of Liu *et al.*, [56]. They also reported non-carcinogenic risk due to high concentration of Cr in the road dust of Changsa city of China. Above all, the HI values calculated for Cd, Cr, Ni and Pb (Table 8) for both children and adults were less the

Table 8: Comparison of non-carcinogenic health risks posed by the heavy metals (HMs) in adults and children

Heavy metals	HQ_{ingest}		HQ_{dermal}		HQ_{inhale}		HI	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Cd	2.36×10^{-6}	2.41×10^{-7}	2.76×10^{-6}	1.73×10^{-7}	2.09×10^{-7}	4.43×10^{-6}	5.32×10^{-6}	4.84×10^{-6}
Cr	1.40×10^{-4}	5.02×10^{-3}	4.10×10^{-4}	2.56×10^{-5}	1.29×10^{-3}	2.75×10^{-2}	1.84×10^{-3}	2.75×10^{-2}
Ni	1.50×10^{-5}	1.53×10^{-6}	3.25×10^{-6}	2.03×10^{-7}	1.29×10^{-6}	2.73×10^{-5}	1.95×10^{-5}	2.90×10^{-5}
Pb	4.94×10^{-5}	1.42×10^{-5}	1.90×10^{-5}	1.18×10^{-6}	4.37×10^{-6}	9.28×10^{-5}	7.27×10^{-5}	5.01×10^{-3}

The HQ and HI values of all metals were below 1, demonstrating no risk of non-carcinogenic impacts among children and adults residing in the territory of Kathmandu. The HQ values of the HMs through all the three exposure pathways were found to be in the order of Cr > Pb > Ni > Cd for both the receptor groups. Further, the results also showed that children had comparatively higher HQ values of the HMs for ingestion and dermal contact pathways than adults while HQ values were found higher for inhalation route in adults. The higher HQ values of the HMs in children through ingestion pathway can be attributed to the more vulnerability of children to the toxic substances. In addition, children are also more sensitive to heavy metals in indoor dust due to their behaviour such as hand-to-mouth activities, crawling and fast growth rate [12,54]. Moreover, Olujimi *et al.* [55] also reported ingestion as the main toxic metal exposure route for children as they prefer to play on the house floor and ingest the indoor dust indirectly. Among the HMs, Cr displayed higher HQ for the ingestion and inhalation pathways for adults

maximum permissible value of 1.0 which indicates no non-carcinogenic risks in the receptor groups. The findings are in agreement with the risk assessment conducted by Kurt-Karakus [46], Ardashiri and Hashemi [49], Olujimi *et al.* [55], and Liu *et al.* [56], who also reported the total hazard quotient (ΣHQ) less than the acceptable level of 1, indicating that exposure to heavy metals in indoor dust poses no non-carcinogenic risks to children and adults.

Carcinogenic risk

The calculated LCR values for each exposure pathway and TLCR in children and adults are listed in Table 9.

For children and adults, the LCR values through all the three exposure pathways decreased in the order of Ni > Cr > Cd > Pb. The obtained LCR data suggest that exposure through ingestion in children was comparably a more dangerous route of exposure to these metals followed by dermal contact and inhalation. However, LCR values for adults were found in the order of inhalation > ingestion > dermal contact. Further, it was found that almost all calculated LCR values of the HMs for all the three

Table 9: Comparison of carcinogenic health risks posed by the heavy metals (HMs) in adults and children

Heavy metals	LCR_{ingest}		LCR_{dermal}		LCR_{inhale}		TLCR	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Cd	1.49×10^{-8}	1.52×10^{-9}	8.69×10^{-10}	5.47×10^{-11}	1.32×10^{-9}	2.79×10^{-8}	1.71×10^{-8}	2.95×10^{-8}
Cr	2.10×10^{-7}	2.14×10^{-8}	1.23×10^{-8}	7.70×10^{-10}	1.86×10^{-8}	3.94×10^{-7}	2.41×10^{-7}	4.16×10^{-7}
Ni	1.32×10^{-6}	1.58×10^{-7}	7.74×10^{-8}	4.84×10^{-9}	1.17×10^{-7}	2.48×10^{-6}	1.51×10^{-6}	2.64×10^{-6}
Pb	1.47×10^{-9}	1.50×10^{-10}	8.59×10^{-11}	5.36×10^{-12}	1.30×10^{-10}	2.76×10^{-9}	1.69×10^{-9}	2.92×10^{-9}

exposure routes were less than 10^{-6} indicating falls of the risk factor.

Total lifetime cancer risks (TLCR) for both children and adults also declined in the order of Ni > Cr > Cd > Pb. However, the TLCR values of these metals were comparable between the receptor groups. Further, it was found that Ni and Cr contributed 86% and 14% of the TLCR in adults respectively while similar contribution of Ni (85%) and Cr (14%) was also found in children. The acceptable safe limit of TLCR for carcinogenic risk is in the range of $1 \times 10^{-6} - 1 \times 10^{-4}$ [23]. Since both children and adults did not exceed the risk range, this implies that carcinogenic risks did not exist and the potential carcinogenic effect would unlikely to occur in both the receptor groups. The results of the present carcinogenic risk assessment are also in agreement with Lin *et al,* [45], Kurt-Karakus [46] and Olujimi *et al,* [55] who also reported carcinogenic risk for these heavy metals within the acceptable level (10^{-4}–10^{-6}) for the receptor groups.

The exposure parameters of a population are dominant factor in health risk assessment that greatly vary according to a geographical region and nationality [57,58]. The risk assessment results may not be easily comparable between studies unless there are uniform standards for exposure parameters [59,60]. In this context, Nepal does not possess any standard reference in terms of exposure parameters till today nor does it resemble with many parameters derived from western countries due to differences in race and region. Such unpleasant circumstances may cause large deviations in the health risk assessment, even at greater accuracy of the measured concentrations.

Conclusion

This study presents a comprehensive evaluation of indoor environment in Kathmandu, Nepal by evaluating the distribution of selected heavy metals in indoor household dust from different types of land use zones *viz.*, commercial, heavy traffic, residential and control. The overall mean concentrations of Cd, Cr, Ni and Pb in indoor dust exceeded the control

values as well as the average world's shale values. In indoor dust samples from all land use zones, Cr demonstrated the highest concentration whereas Cd was found to be the lowest of all. The present study recorded exceptionally high Cr content in indoor dust samples compared to other cities/countries.

The indoor environmental status of Kathmandu was assessed on the basis of two pollution indices *viz.*, contamination factor (CF) and pollution load index (PLI). Accordingly, CF values were found to vary from moderate to considerable degree of metal contamination in indoor dust. Of the four types of HMs analyzed, only Ni demonstrated considerable level of contamination in indoor dust samples from commercial and heavy traffic zones. The average metal contamination level in Kathmandu indoor dust was at considerable level for Ni (CF = 3.45) and moderate level for Cd (CF = 2.28), Cr (CF = 2.07) and Pb (CF = 1.72). Similarly, PLI value was greater than 1, implying a category of polluted indoor dust from all land use zones. The metal contamination level in indoor dust samples based on PLI values followed the decreasing order of heavy traffic (PLI = 6.90) > commercial (PLI = 5.16) > residential (PLI = 3.75) zone. The high PLI could be attributable to the cumulative concentrations of heavy metals in all land use zones, implying an alarming condition

An assessment of health risk showed that ingestion was the main exposure pathway for these HMs in children followed by inhalation and dermal contact while adults displayed inhalation as the main route followed by ingestion and dermal contact. For non-carcinogenic health risk, both HQ and HI values were below 1.0 indicating no adverse health risk for both the receptor groups. However, Cr contributed 95% and 85% of the HI in children and adults respectively. For carcinogenic health risk, the calculated values of lifetime cancer risk (LCR) for individual exposure route and total lifetime cancer risk (TLCR) were found within the acceptable safe limit of 1×10^{-6}–1×10^{-4} indicating no cancer risk for both the receptor groups. Nevertheless, Ni prevailed 85% and 86%

as major contributions for TLCR in children and adults respectively. However, the study indicated vulnerability of both the receptor groups to the risks of indoor dust metals. Hence, it can be concluded from the present study that a monitoring plan is necessary to assess potential sources of heavy metals evolution in indoor dust from different land use zones in order to develop proper measures for reducing the exposure risk to human health through all possible routes.

Acknowledgments

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