



## Pollution Characteristics and Human Health Risks to Heavy Metals Exposure in Street Dust of Kathmandu, Nepal



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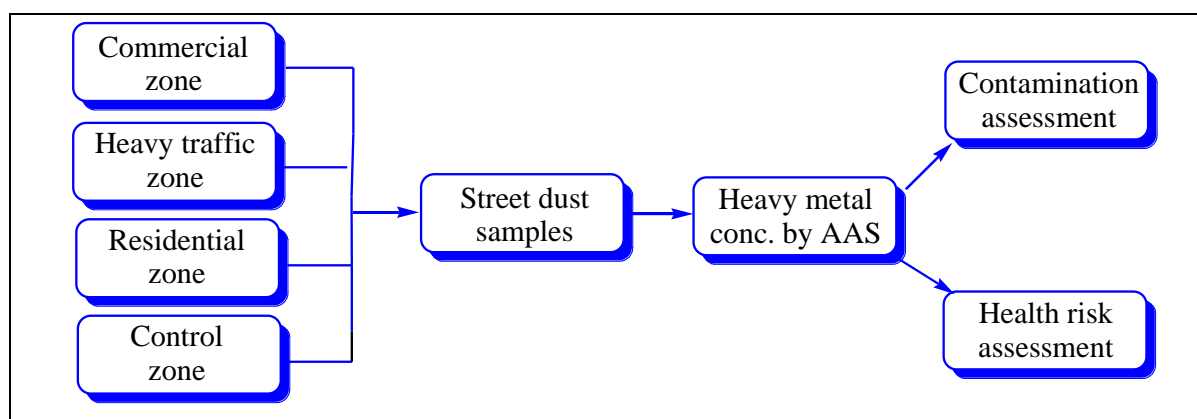
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### ABSTRACT

In this work, a total of thirty four (N=34) street dust samples were collected from four different land use zones viz., commercial, heavy traffic, residential and control (undisturbed) areas of Kathmandu, Nepal. The dust samples were analyzed for four different heavy metals (Cd, Cr, Ni, and Pb) by using the flame atomic absorption spectrophotometer (FAAS). The total organic carbon (TOC) and pH of the samples were also measured. The selected land use zones revealed their relative order based on the concentration of the elements as heavy traffic>commercial>residential>control. The average concentration of the Cd, Cr, Ni, and Pb were found to be 0.69, 77.4, 68.9, and 63.9 mg/kg (dry basis), respectively. The results of the present study were also compared against the heavy metals concentration in street dust with previous studies across the world. High amount of Ni (122.2 mg/kg), Cr (94.8 mg/kg), Pb (74.4 mg/kg), and Cd (0.84 mg/kg) was observed in heavy traffic zone compared to other land use zones. Results revealed that the street dust from the commercial and residential zones contained high concentration of Cr whereas the heavy traffic zone was mainly affected by the Ni. In addition, the dust samples from all land use zones showed alkaline nature and contained variable amount of TOC. The inter-parameter relationship expressed by Pearson's correlation coefficient indicated their common sources of emission as well as similar fate and characteristics. A single pollution index such as contamination factor (CF) and geo-accumulation index (Igeo) revealed different classes of metal contamination in street dust of Kathmandu. The average level of metal contamination in street dust of Kathmandu was found to be 3.94, 2.64, 1.97, and 1.94 for Ni, Cr, Cd, and Pb, respectively. Health risk assessment modeling study of the HMs in street dust indicated no non-carcinogenic risks for the receptors; however, ingestion was found to be the most potential pathway for the HMs exposure and toddlers as the most likely to be a vulnerable group.

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## GRAPHICAL ABSTRACT



## Introduction

The quality of the urban environment throughout the world is changing rapidly as a result of haphazard urbanization, industrialization and accelerated development of the social economy [1,2]. Street dust is a medium of transportation and distribution of pollutants in the surface environment and hence acts as an important indicator for characterizing urban environmental quality [3,4]. Street dust is comprised of silica ( $\text{SiO}_2$ ), organic pollutants and trace amount heavy metals such as Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn [5-7]. Also, it may contain mould spores, animal dander, pollen, and pollen fragments. The particles and associated metals, particularly with fine dust remain suspended in air for longer under certain meteorological conditions. Besides, it can possibly get re-suspended due to the street dust emissions and wind, resulting in an important source of atmospheric air pollution [8].

Dust particles are subjected to the complex mixing processes which occur during various on-street activities. Therefore, the composition of dust may vary from place to place [9]. Studies reveal diverse sources of these deposited solid particles including atmospheric deposition, erosion of surrounding soil and anthropogenic activities such as industrial, urban, and traffic-related activities [10-12]. As for the traffic related particles, the potential sources of the

contamination on the ground surfaces are from tire abrasion products, brake pad dust, combustion exhaust, road surface paint, lubricating oil, and pavement wear [13]. The proper evaluation of the constituents of the dust particles is, therefore required in order to determine the contributing sources.

Street dust has become a burning issue in recent decades, mainly because of toxic heavy metals contamination and  $\text{PM}_{10}$  emission from vehicular movement [14,15]. They act as a temporary sink for these toxic contaminants that can have a direct impact on human health because they can be transferred into the human body by three different pathways *viz.*, ingestion, dermal absorption and inhalation [16,17]. Therefore, the urban inhabitants might no longer be free from health risk since half of the world's population resides in urban areas. Rout *et al.* [18] reported acute and chronic toxicity of heavy metals that can damage central and peripheral nervous systems, blood composition, lungs, kidneys, liver, and even death. Thus, many researchers around the world have intensively investigated the composition, sources and potential health risk of urban street dust [19-23].

Kathmandu, a metropolitan city in Nepal, is one of the most densely populated cities in the country accounting for around 20,000 people per  $\text{km}^2$ . The city is not large enough to have developed public transports such as metro, light

railway or tram except taxies, micro-vans, gas tempos and minibuses etc. As a consequence, many people use private two or four wheelers for their transportation resulting in abundant road traffic which is considered as the major cause of atmospheric contamination in the city center. Furthermore, an increasing number of light and heavy vehicles every year are contributing atmospheric deposition of toxic pollutants in Kathmandu. Because of the topography of Kathmandu valley, growing population, haphazard urbanization and increasing vehicle density, the city has been facing worse situation of atmospheric pollution.

Although there are extensive studies on heavy metals contaminated street dust, majority of them are concerned with either developing or developed countries having long industrial histories [8, 22-29]. Very little assessment in the related areas has been made in developing country like Nepal [30-32]. Due to the accelerated industrialization and urbanization, more than 50% of the world's population lives in urban areas and these environments are known as the main habitats for humans. Kathmandu city is no exception in terms of rapid urban and industrial development during the last decade that has led to the degradation of outdoor and indoor air qualities. As heavy metals are usually transported and emitted in particulate forms, studies of outdoor and indoor dusts are good indicators of heavy metal accumulation. In heavily impacted cities like Kathmandu, there is an urgent need to assess health risk due to toxic metal exposure for population. Health risk assessment will prove to be a useful tool to pinpoint the severity of various toxic metals in indoor as well as outdoor dust. Therefore, extensive studies on heavy metals contamination of soil and dust have been performed during the last decades due to their effects on humans and environmental health. However, there is very limited investigation on health risk assessment of the potentially toxic metals in street dust from different land use zones of Kathmandu. Based on the

forementioned facts, this study therefore aims to investigate the occurrence, profile and pollution level of heavy metals (HMs) in street dust from different land use zones of Kathmandu. Further, non-carcinogenic health risk assessment among three different receptor groups due to HMs exposure in street dust at different land use zones was also estimated. The finding of this study will expand our knowledge on HMs contamination and provide useful information to local policy makers to manage health risk. The present study may therefore be considered as a novel work in the related area in Nepalese context.

## Experimental

### *Study area and selection of sampling sites*

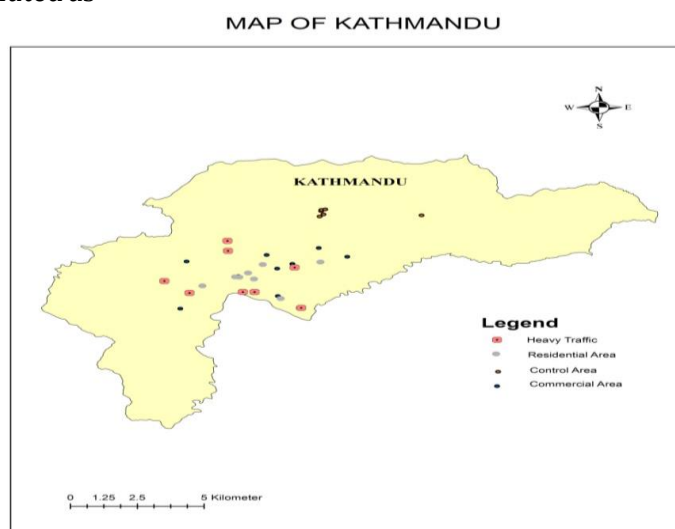
Four different land use zones *viz.*, commercial, heavy traffic, residential and undisturbed (control) areas of Kathmandu (Figure 1) were selected for collection of street dust samples. The control area is based on the low population density and low traffic areas. The selection of sampling sites for street dust measurements were based on different domain anthropogenic activities as briefly described in Table 1. Kathmandu is the first metropolitan city in Nepal that spreads over 50 sq. km. area at elevation of 1400m from mean sea level (MSL) with population of 1 million [33]. It is by far the largest urban agglomerate in Nepal, accounting for 20% of the urban.

Initially, a field survey was made to enlist a number of potential sampling sites and categorize them under the commercial, heavy traffic road, and residential zones. From the category of each land use zone, 30 % of the total sampling sites were finally selected for dust sample collection using a simple lottery method. This method of sampling was justified for the present study because each of the initially selected sampling sites had an equal chance of participation in the study. Therefore, the number of sampling sites

under the commercial, heavy traffic road, and residential zones finally reached to 10, 8, and 10, respectively (Table 1). As for control area, altogether 6 sampling sites within Shivapuri area were selected at an equi-distance of 100 m from the initial point of site selection. The selection of Shivapuri as the control zone was based on the fact that the area is unpolluted as

well as undisturbed particularly due to sparse residential with low population density and limited anthropogenic activities. Our field observations also revealed no evidence of anthropogenic activities in the past as well and no such signals of disturbances were observed during the sampling period.

**Figure 1.** Map of the study area and sampling sites in Kathmandu district



**Table 1.** Description of sampling sites across Kathmandu district

Land use zone	No. of samples (n) analyzed	Name of sampling sites	Activities at the sampling sites
Commercial	10	Kalimati, New road, Bagbazar, Boudha, Durbarmarg, Kamalpokhari, Baneshwor, Kalanki, Ason and Koteswor	High traffic load, high anthropogenic activities, densely populated area, hospitals, educational institutions, super markets, big departmental stores, hotels, mechanical and automobile workshops <i>etc.</i>
Heavy Traffic Road	8	Ratnapark, Chabahil, Maitighar, Koteswor, Tripureswor, Teku, , Gongabu and Kalanki	Heavy traffic density, bus parks, business complexes on either sides, hospitals, commercial buildings, cinema halls, huge anthropogenic activities <i>etc.</i>
Residential	10	Gairidhara (Naxal), Baluwatar, Jorpati, Hadigaun, Ason, Kirtipur, Kasthamandap, Chahabil, Kapan and Baneshwor	medium traffic load, medium anthropogenic activities, medium departmental stores and cluster residential area
Undisturbed (control)	6	Shivapuri	low traffic load, low anthropogenic activities, sparse residential and undisturbed area

### *Sample collection*

A total of 34 street dust samples were collected from the sampling sites (Figure 1) during dry season (February to March, 2019) to avoid rain washing of heavy metals. The sample collection was carried out by sweeping an area of about 1 m<sup>2</sup> from the paved roads using a brush and plastic dustpan. The amount of dust collected from each site was about 250–500 g. To avoid re-suspension of the finest particles during sampling, the sweeping was made slow and collected directly into zipper polythene bags and transported to laboratory. Samples were not collected adjacent to site-specific pollution sources. To minimize cross contamination during sampling, surgical gloves were used in hand. In laboratory, extraneous matter such as small pieces of brick, paving stone, leaves and other debris were removed from the collected samples. Then, the samples were dried in an oven at 35 °C for 3 days and mechanically sieved through 2 mm sized metal free sieve. Until further analysis, sub-samples were weighed and stored in polyethylene flasks in a cool and dry place.

### *Chemicals and apparatus*

All reagents of analytical grade were purchased from commercial sources and used without further purification: HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, potassium dichromate, ferrous ammonium sulphate, sodium fluoride, diphenylamine indicator *etc.*, are from Sigma-Aldrich, USA. All the standard solutions (1000 ppm) for Cd, Cr, Ni and Pb, and standard reference materials (NIST SRM 1648) were certified and obtained from FLUKA AG, Switzerland. A glass electrode digital pH meter (Model 101, ESICO International) was used for pH measurement. Flame atomic absorption spectrophotometer (SOLAAR M5 Dual Automizer, 180-900nm, Thermo Elemental, UK) was used for determination of the analytes.

### *Digestion and heavy metal analysis*

Heavy metals (Cd, Cr, Ni and Pb) in dust samples were determined as per a standard method [24]. For this, 1.0 g of each stock sample was weighed in an acid washed beaker and 10 mL conc. nitric acid was added to it. The sample was then digested over the hot plate at low temperature. Digestion process was continued until acid volume was reduced to 1-2 mL. Whenever needed more acid was added to carry out complete leaching of metals from the sample. After complete digestion, the interior of the beaker was washed with about 10 mL double distilled water. The digested sample was filtered through medium textured Whatman filter paper collecting the filtrate in 25 mL volumetric flask. The beaker was washed with small portions of distilled water adding the washings into the same funnel and collecting filtrate into the same volumetric flask. The final volume was then made with distilled water and mixed well to homogenize the sample. Cd, Cr, Ni and Pb were determined in the digested samples by the atomic absorption spectrophotometer using air-acetylene flame. All the glassware and plastic vessels were treated with dilute (1:1) nitric acid for 24 h and then rinsed with double distilled water before use. The instrumental parameters were those recommended by the manufacturer. 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). In order 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 2.5, 2.0, 2.7, and 2.8% for Cd, Cr, Ni and Pb respectively and can be considered satisfactory for analysis of dust samples. The detection limits were 0.1, 1.0,

0.1, and 0.1 mg/kg for Cd, Cr, Ni, and Pb, respectively.

#### *Determination of total organic carbon (TOC) and pH*

Total organic carbon in dust samples was determined by titrametric method as per Walkey & Black method [34]. Accordingly, 1.0 g of each stock sample was weighed and transferred to a dried 500 mL conical flask. To this, 10 mL of 1N K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> solution and 20 mL of conc. H<sub>2</sub>SO<sub>4</sub> were mixed by gentle swirling. The flask was kept in hot air-oven for about 30 min at 150 °C. After the reaction was over, the contents were diluted with 200 mL of distilled water and added 0.2 g of sodium fluoride and 1 mL of diphenylamine indicator. The sample was titrated with 0.4 N ferrous ammonium sulphate (FAS) until the color of the solution changed from black to brilliant green at the end point. A blank was also run with same quantity of the chemicals without sample.

pH of dust samples was determined in 1:5 dust suspensions following standard methods for examination of water and waste water (APHA) with modification as necessity [35]. Accordingly, 20 g of each sample was weighed in a beaker and added 100 mL of distilled water to it. The mixture was stirred magnetically for an hour. The pH of the unfiltered dust suspension was recorded using the digital pH meter. Before recording, the pH meter was calibrated as per instruction manual.

#### *Estimation of pollution indicators*

Contamination factor (CF) was used to assess the degree of metal pollution and the probable contribution of anthropogenic sources [24,36,37]. The contamination factor (CF) was suggested by Håkanson [38] (Equation 1).

$$CF = \frac{C_s}{C_b} \quad (1)$$

Where, C<sub>s</sub> is the measured concentration of the examined metal in street dust and C<sub>b</sub> is the geochemical background concentration or reference value of the metal or the background value (control) of heavy metals in the uncontaminated dust. The contamination is classified into four groups as follows: low (CF<1), moderate (1≤CF<3), considerable (3≤CF<6) and very high (6≤CF). Furthermore, the contamination level of heavy metals in street dust is assessed by using the Geo-accumulation Index (I<sub>geo</sub>), as introduced by Muller [39]. I<sub>geo</sub> is calculated using the Equation 2.

$$I_{geo} = \log_2 \left[ \frac{C_s}{1.5 \times C_b} \right] \quad (2)$$

The constant 1.5 is the background matrix correction factor due to lithological variability.

The I<sub>geo</sub> values are classified according to Muller in seven classes, as follows: I<sub>geo</sub>≤0= practically unpolluted; 0<I<sub>geo</sub>≤1 = unpolluted to moderately polluted; 1<I<sub>geo</sub>≤2= moderately polluted, 2<I<sub>geo</sub>≤3 = moderately to heavily polluted; 3<I<sub>geo</sub>≤4 = heavily polluted; 4 < I<sub>geo</sub> ≤ 5 = heavily to extremely polluted and I<sub>geo</sub> ≥ 5 = extremely polluted.

#### *Statistical analysis*

Descriptive statistics such as frequency, percentage, mean and standard deviation were used wherever applicable. Correlation analyses among the dust properties and metals were performed with SPSS v.19.0 (SPSS Inc., Chicago, USA).

#### *Health risk assessment model*

Health risk assessment estimates the total exposure to the heavy metals (HMs). Ingestion, dermal absorption and inhalation are the three important pathways of HMs exposure to the human. For the present study, the HRA model was applied to three receptors

viz., toddlers, children and adults. Levels of HMs entry through the three routes of exposure were individually calculated for risk assessment following Equations 3–7 and receptor parameters are presented in Table 2. The equation and receptor parameters used in the present study are based on US Environmental Protection Agency (USEPA) [40] and Ontario (Canada) Ministry of the Environment (OME) protocols [41].

The chronic daily intakes (CDIs) for three different routes of exposure can be calculated using Equations 3–5. Estimated daily intake dose for each receptor group on per body weight basis was expressed as  $\mu\text{g}/\text{kg}/\text{day}$ .

$$\text{CDI}_{\text{ingest}} = \frac{C_{\text{dust}} \times \text{IR} \times \text{AT}}{\text{BW} \times \text{LT}} \quad (3)$$

Where,  $C_{\text{dust}}$  is the concentration of the metal in dust ( $\text{mg}/\text{kg}$ ); IR is the ingestion rate of dust ( $\text{g}/\text{day}$ ); AT is the average time of exposure ( $\text{yr}$ ); BW is body weight ( $\text{kg}$ ); and LT is the average lifetime (70 yr).

$$\text{CDI}_{\text{dermal}} = \frac{C_{\text{dust}} \times \text{SA} \times \text{DA} \times \text{DUC} \times \text{AT}}{\text{BW} \times \text{LT}} \quad (4)$$

Where, SA is the exposed surface area for dust ( $\text{m}^2$ ); DA is the dermal adhesion rate for dust ( $\text{mg}/\text{cm}^2$ ); and DAU is the dermal uptake coefficient.

$$\text{CDI}_{\text{inhalation}} = \frac{C_{\text{dust}} \times \text{AI} \times \text{AT} \times \frac{1}{\text{PEF}}}{\text{BW} \times \text{LT}} \quad (5)$$

Where, AI is the air intake/ inhalation rate ( $\text{m}^3/\text{day}$ ); and PEF is the particulate emission factor ( $1.32 \times 10^9 \text{ m}^3/\text{kg}$ ).

The hazard quotient (HQ) is used to estimate the non-carcinogenic risks of HMs in street dust of different exposures. It is the ratio of the CDI and the specific reference dose (RfD) and can be estimated using Equation 6.

$$\text{HQ} = \frac{\text{CDI}}{\text{RfD}} \quad (6)$$

The reference doses are defined as the maximum allowable level of metals that will not pose any deleterious effects on human health during life time. Generally, there are three RfDs (Table 3) for three different exposure pathways as follows: reference dose ( $\text{RfDo}$ ,  $\mu\text{g}/\text{kg}/\text{day}$ ) for ingestion,  $\text{RfD}_{\text{ABS}}$  ( $\text{RfD}_{\text{ABS}} = \text{RfDo} \times \text{ABS}_{\text{GI}}$ ,  $\mu\text{g}/\text{kg}/\text{day}$ ) for dermal contact and reference dose ( $\text{RfCi}$ ,  $\mu\text{g}/\text{m}^3$ ) for inhalation as suggested by USEPA IRIS (U.S. Environmental Protection Agency's Integrated Risk Information System) [42].  $\text{ABS}_{\text{GI}}$  is the fraction of the pollutant absorbed in the gastrointestinal tract in the critical toxicity study (unit less). For all the elements, the HQ value  $\leq 1.00$  indicates that the risk through the selected exposure pathway is within safe level.

The total risk of specific HMs through multiple exposure routes is expressed as the hazard index (HI). The total risks from the exposure to HMs in dust can be calculated using Equation 7.

$$\text{HI} = \sum \text{HQ}_i \quad (7)$$

Where,  $i$  = different exposure pathways.

Non-carcinogenic risk is low when the HI value is  $<1$  and as HI increases, the magnitude of risk increases, too [16]. Estimation of cancer risks to human is not included in the present study. The specific and constant parameters [40, 41] used in this health risk assessment is given Table 2.

The reference dose of the elements (Table 3) used in the present study were adapted from USEPA [43].

## Results and discussion

### Heavy metal concentrations in dust

Results of heavy metals in street dust samples collected from the selected sites in Kathmandu are presented in Table 4. The data were grouped according to the sampling locations as commercial, heavy-traffic, residential and control zones.

**Table 2.** Receptor parameters used for characterization of human exposure from dust

Parameter	Units	Toddler	Child	Adult
Age	Years	0.6-5	6-12	21-70
Average time (AT)	Years	4.5	7.0	50.0
Body weight (BW)	Kg	16.5	32.9	70.7
Soil Ingestion Rate (IR)	g/day	0.1	0.1	0.02
Dermal Adhesion rate (DA)	mg/cm <sup>2</sup>	0.02	0.02	0.07
Surface area exposed (SA)	m <sup>2</sup>	0.344	0.586	1.03
Air Intake (AI)	m <sup>3</sup> /day	5.0	12.0	50.0

CDI chronic daily intake ( $\mu\text{g}/\text{kg day}$ ); C concentration of metal in dust ( $\text{mg}/\text{kg}$ ); LT life time (70 yrs); DUC dermal uptake co-efficient (0.01); BA Bioaccumulation factor (0.01); Particulate emission factor (PEF) ( $1.32 \times 10^9 \text{ m}^3/\text{kg}$ )

**Table 3.** Reference dose of elements for three different pathways

Elements	RfD <sub>ingest</sub> ( $\mu\text{g}/\text{kg}/\text{day}$ )	RfD <sub>dermal</sub> ( $\mu\text{g}/\text{kg}/\text{day}$ )	RfCi <sub>inhale</sub> ( $\mu\text{g}/\text{m}^3$ )	ABS <sub>GI</sub>
Cd	1.0	0.025	0.01	0.025
Cr	3.0	0.039	0.028	0.013
Ni	20.0	0.8	0.09	0.04
*Pb	3.5	3.5	0.3	1.00

\*For Pb, the PTWI has been withdrawn by JECFA [44], however, previous RfD has been used for calculation purpose

Table 4 showed that different land use zones based on metal concentration in street dust indicated the order as heavy traffic>commercial>residential>control. The mean concentrations of Cd, Cr, Ni and Pb (mean of all land uses) in the dust samples were 0.69, 77.4, 68.9 and 63.9  $\text{mg}/\text{kg}$  respectively. The values were significantly higher than those of the control zone. The mean concentration of heavy metals for the commercial and residential land use zones followed the order of abundance as  $\text{Cr} > \text{Pb} > \text{Ni} > \text{Cd}$ . On the other hand, heavy traffic zone exhibited the elemental order by their abundance as  $\text{Ni} > \text{Cr} > \text{Pb} > \text{Cd}$ . The control zone showed the metals in the order of their abundance as  $\text{Pb} > \text{Cr} > \text{Ni} > \text{Cd}$ . Each land use showed some variation in the concentrations of Cd, Cr, Ni and Pb. Similar to our findings, Rout *et al.* [28] also reported higher concentration of Cr and Pb in commercial zone. Among the land use types, heavy traffic zone recorded the highest concentration of

Cd, Cr, Ni and Pb under the present investigation. However, cadmium exhibited significantly low concentration in all land use cases in consistent with the findings of Faiz *et al.* [45] who concluded that the street dust generally contained lower levels of Cd than other metals.

As for inter land-use variation, concentration of Cd was higher in heavy traffic zone (0.84  $\text{mg}/\text{kg}$ ) compared to other sites (0.35–0.74  $\text{mg}/\text{kg}$ ). The mean level of Cd (0.69  $\text{mg}/\text{kg}$ ) as observed in the present study was comparable with the values (Table 5) reported from Jharia (India) [18] and Kuala Lumpur (Malaysia) [47] but was much lower than Isfahan (Iran) [48]. Cd levels in street dust reported from Queensland (Australia) [15], Toronto (Canada) [27] and Beijing (China) [46] were lower than the present study. 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 street dust [49]. The anthropogenic sources of cadmium in street dust are reportedly the wear and tear as well as burning of vehicle tyres [30,50]. Cadmium is also used as an attendant substance of the zinc oxide in rubber matrix. The Cd enrichment in street dust in heavy traffic and commercial zones of Kathmandu may probably be due to Cd released from lubricant and wear and tear from vehicular tyres in the narrow and congested streets. 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 in residential areas of Kathmandu. Likewise, Cr content (Table 4) in the dust samples from heavy traffic zone (94.8 mg/kg) is higher than other zones (29.3-79.8 mg/kg). The overall mean concentration of the metal (77.4 mg/kg) is comparable with the previous data for Jharia, India (75.5 mg/kg), reported by Rout *et al.* [18]. This value is significantly lower than reported from Toronto (Canada) [27] and Beijing (China) [46] but is higher than Queensland (Australia) [15] and Kuala Lumpur (Malaysia) [47]. The source of Cr in street dust is believed to be chrome plating of some motor vehicle parts [51].

**Table 4.** Heavy metal concentration (mg/kg), TOC (%) and pH in street dust (Mean  $\pm$  SD) from different land use zones of Kathmandu

Land use zone	Statistical parameter	Cd	Cr	Ni	Pb	TOC	pH
Commercial zone (n=10)	Mean	0.74 $\pm$ 0.11	79.3 $\pm$ 8.9	53.8 $\pm$ 10.1	67.3 $\pm$ 12.1	2.22 $\pm$ 0.15	7.8 $\pm$ 0.6
	Range	0.56 - 0.91	60.3 - 92.8	38.9 - 69.0	51.2 - 86.4	1.61 - 2.72	7.0 - 8.5
Heavy traffic zone (n=8)	Mean	0.84 $\pm$ 0.12	94.8 $\pm$ 17.6	122.2 $\pm$ 22.6	74.4 $\pm$ 7.0	2.57 $\pm$ 0.38	7.9 $\pm$ 0.2
	Range	0.69 - 0.95	78.6 - 120.4	84.6 - 149.6	98.5 - 179.8	2.12 - 3.52	7.0 - 10.0
Residential zone (n=10)	Mean	0.50 $\pm$ 0.06	58.2 $\pm$ 12.1	30.8 $\pm$ 6.8	50.2 $\pm$ 8.5	1.78 $\pm$ 0.16	7.8 $\pm$ 0.3
	Range	0.39 - 0.61	44 - 72.4	22.6 - 37.9	38.8 - 64.9	0.91 - 3.15	7.0 - 8.1
Kathmandu District	Mean of all land uses	0.69	77.4	68.9	63.9	2.04	7.8
Control zone (n=6)	Mean	0.35 $\pm$ 0.09	29.3 $\pm$ 6.3	17.5 $\pm$ 5.8	32.9 $\pm$ 3.5	0.92 $\pm$ 0.12	7.5 $\pm$ 0.2
	Range	0.24 - 0.48	10.0 - 14.6	11.8-25.2	18.5-30.4	0.82 - 1.15	7.4 - 8.0

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

Cities/ Countries	Cd	Cr	Ni	Pb	References
Kathmandu/ Nepal	0.69	77.4	68.9	63.9	Present study
Queensland/ Australia	0.51	14.8	7.9	32.5	Gunawardane <i>et al.</i> [15]
Jharia/ India	0.78	75.4	66.0	67.8	Rout <i>et al.</i> [18]
Toronto/ Canada	0.05	197.9	185.6	182.8	Nazzal <i>et al.</i> [27]
Beijing/ China	0.39	102.0	24.9	77.4	Li <i>et al.</i> [46]
Kuala Lumpur/ Malaysia	0.7	53.8	28.6	144.3	Munim <i>et al.</i> [47]
Isfahan/ Iran	2.14	-	66.6	393.3	Soltani <i>et al.</i> [48]

Anthropogenically, Cr occurs by the burning of oil and coal, petroleum from ferro-chromate refractory material, pigment oxidants, catalyst, chromium steel, fertilizers, oil well drilling and metal plating tanneries. Besides, chromium is also released into the environment through sewage and fertilizers [52].

Table 4 shows Ni concentration comparatively higher in heavy-traffic zone (122.2 mg/kg) than other sites (17.5–53.8 mg/kg) like those of Cd and Cr. The mean metal concentration (68.9 mg/kg) is significantly lower than the value reported from Toronto (Canada) [27]. However, the concentration is comparable with the values from Jharia (India) [18] and Isfahan (Iran) [48] but is higher than Queensland (Australia) [15], Beijing (China) [46] and Kuala Lumpur (Malaysia) [47]. The source of Ni in street dust is believed to be corrosion of cars [10,50]. 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 source of Ni in high-traffic zone of Kathmandu is probably due to its release by corrosion of these components over the lifetime of the vehicle [24,53].

Similarly, Pb level is also higher in the same land use (74.4 mg/kg) as compared to other zones (32.9–67.3 mg/kg). The mean concentration of Pb (63.9 mg/kg) in this study is higher than reported from Queensland (Australia) [15] but is significantly lower than the values from Toronto (Canada) [27], Beijing (China) [46], Kuala Lumpur (Malaysia) [47] and Isfahan (Iran) [48]. Pb is used in the manufacture of pesticides and fertilizers, paints and dyes, batteries, petrol additive, and explosives [54]. 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 [37]. High concentration of Pb in Nepalese dust environment may be connected with

vehicular activities, especially from vehicles frequently coming for filling of fuel including coal related sources to some extent [18].

#### *Relationship with TOC and pH*

The inter-parameter relationship is frequently expressed by Pearson's correlation coefficient that indicates their potential sources [55]. The obtained correlation matrix is presented in Table 6.

Results revealed positive correlation among HMs and with TOC and pH as well although the extent of relationship is different. Strong correlations ( $p < 0.05$ ) were evident for the pairs Cr and Ni (0.898) and Cd and Pb (0.796) indicating probably similar characteristics, fate and share common origins of emission. According to Amato *et al.* [12], Cd, Ni, and Cr can be derived from gasoline, lubricants, vehicle parts and tire and brake wear.

Table 4 reveals the alkaline nature of street dust from all land use zones. The alkaline nature of the dust samples reflects the richness of carbonate salts [56]. pH can affect the adsorption states of heavy metals on the surface of dust and change the occurrence form of heavy metals [57]. Besides, the alkaline nature of dust may be due to the alkaline substances in aging road and building materials [58]. Results revealed positive correlation between HMs and pH indicating that this dust property can enhance adsorption of metals to dust particles. Similarly, the % TOC in dust samples in this study varied from 0.92% in dust of control zone to 2.57% in heavy traffic zone (Table 4). The results are in agreement with Acosta *et al.* [59] who also reported higher OC content in dust samples of heavy traffic zone. TOC content in dust samples in this study showed positive correlation with HMs (Table 6). The elevated level of TOC indicates that dust is an important sink of organic material in Kathmandu. Accordingly, TOC significantly influences the fate and behavior of HMs in dust.

**Table 6.** Pearson's correlation coefficients among heavy metals and with TOC and pH

	TOC	pH	Cd	Cr	Ni	Pb
TOC	1.00					
pH	0.254	1.00				
Cd	0.524	0.425	1.00			
Cr	0.475	0.448	0.121	1.00		
Ni	0.588	0.543	0.198	0.898*	1.00	
Pb	0.456	0.512	0.796*	0.321	0.154	1.00

\*The correlation is significant at the 0.05 level

**Table 7.** Contamination factor (CF) and geo-accumulation index (Igeo) of heavy metals in different land use zones, Kathmandu

Heavy metals	Contamination factor (CF)		
	Commercial	Heavy traffic	Residential
Cd	2.11	2.40	1.43
Cr	2.71	3.24	2.00
Ni	3.07	6.98	1.76
Pb	2.05	2.26	1.53

Heavy metals	Geo-accumulation index (Igeo)		
	Commercial	Heavy traffic	Residential
Cd	0.43	0.49	0.29
Cr	0.55	0.65	0.40
Ni	0.62	1.41	0.35
Pb	0.41	0.46	0.31

### Estimation of pollution indicators

Contamination factor (CF) and geo-accumulation (Igeo) as the single pollution index [38] was used to evaluate contamination level in street dust samples of Kathmandu. The contamination factor (CF) indicates the amount of anthropogenically introduced metal in street dust with respect to the natural concentration. Such assessment of heavy metals is most important for the human survival [60]. Tables 7-9 show the contamination factor and geo-accumulation index and their classifications based on the metal contamination levels.

Results revealed that the heavy traffic zone demonstrated the highest metal contamination factor in its' street dust followed by commercial and residential

zone (Table 7). Among the metals, Ni recorded the highest level of contamination in heavy traffic zone followed by commercial and residential zones. The contamination factors for Ni, Cr, Cd and Pb in the heavy traffic zone are in the order as 6.98, 3.24, 2.40, and 2.26, respectively. Commercial zone also showed higher level of Ni contamination similar to heavy traffic zone while residential recorded higher contamination factor for Cr. Lead demonstrated the lowest contamination level for heavy traffic and commercial zones except for residential. As for classification of pollution index based on metal contamination factor (Table 8), all three land use zones viz., heavy traffic, commercial and residential demonstrated moderate level of contamination ( $1 \leq CF < 3$ ) for Cd and Pb whereas commercial and

residential showed the same pollution category for Cr and residential alone for Ni. On the other hand, considerable level ( $3 \leq CF < 6$ ) of Cr and Ni pollution was recorded for heavy traffic and commercial zones respectively. Above all, heavy traffic zone exhibited a very high level of contamination ( $6 \leq CF$ ) for Ni. Higher degree of contamination is often a matter of worry because of tremendous anthropogenic activities that occur at these sites during rush hours of the day. Long term exposure within the neighborhood can lead to adverse health effects particularly on children, pregnant women and the aged, all known to be vulnerable [61].

The average level of metal contamination in street dust of Kathmandu calculated from the ratio of the average metal concentration of all land uses (:) the metal concentration of control site is presented in Figure 2.

Considering the mean of all land uses and contamination factor thereafter, it may be concluded that dust of Kathmandu is enriched considerably by the metals in the order as

Ni(3.94)>Cr>(2.64)>Cd(1.97)>Pb(1.94).

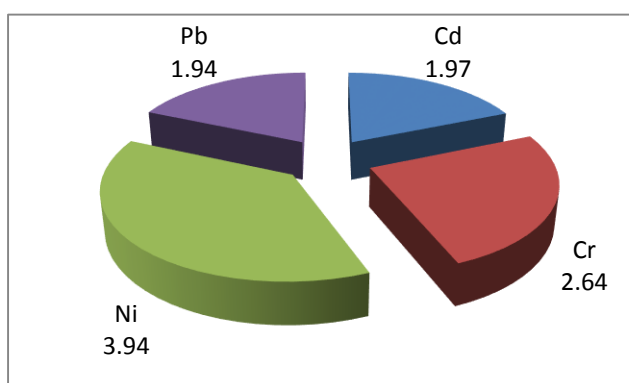
The Cd and Pb enrichment in Kathmandu dust as revealed by the present study is comparable with the findings of Shakyia *et al.* [32] who also reported enrichment factor of Cd (1.5) and Pb (1.6) in street dust. The metal enrichment may be due to accelerated anthropogenic activities in Kathmandu with time factor.

Geo-accumulation index (Igeo) is the indicator used to assess the presence and intensity of anthropogenic contaminant deposition on surface soil [60]. This index of potential contamination is calculated by the normalization of one metal concentration in the topsoil with respect to the concentration of a reference element. Table 7 showed the highest Igeo values for all metals in heavy traffic zone followed by commercial and residential. Heavy traffic zone showed Igeo values for Ni, Cr, Cd and Pb in the decreasing order as 1.41, 0.65, 0.49, and 0.46 respectively and the same Igeo order was found for the metals in commercial zone.

**Table 8.** Classification of pollution index based on contamination factor values in different land use zones, Kathmandu

Land use	Pollution index (Contamination factor)			
	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, Pb	Cr	Ni
Residential	-	Cd, Cr, Ni, Pb	-	-

**Figure 2.** Average metal contamination level in street dust of Kathmandu district



On the other hand, residential zone showed higher Igeo value for Cr subsequently followed by Ni, Pb and Cd. While heavy traffic and commercial zones exhibited lowest Igeo values for Pb, residential zone recorded lowest Igeo value for Cd among the land use types. As for classification of pollution level based on the Igeo values (Table 9), all the land use types demonstrated a category of unpolluted to moderately polluted level ( $0 < I_{geo} \leq 1$ ) for Cd, Cr, Ni and Pb except the Igeo value for Ni that showed the moderately polluted level ( $1 < I_{geo} \leq 2$ ) in heavy traffic zone. Several works were focused on identification of possible levels of pollution using mathematical models such as index of geo-accumulation (Igeo), enrichment factors (EF), contamination factor and degree of contamination [23,26,62,63]. Similar to our findings, the models indicated various levels of metal contamination in street dust. They also reported traffic emission, automobiles and other anthropogenic activities as the potential sources of the metal contamination.

#### Health risk assessment

The results of health risk assessment due to HMs exposure in street dust, for three different receptor groups viz., toddlers,

children and adults in the studied land use zones are presented in Tables 10-12.

Results revealed the vulnerability of exposure through ingestion in the order as toddlers > children > adults. This same receptor order is also true for all HMs and land-use cases. The finding is in agreement with Rou *et al.* [18] who also reported toddlers as the most vulnerable age group. Their findings predicted potential health risk to toddlers and children. Besides, the results obtained in the present study are also in agreement with previously published research data [4,25,64]. Their studies reported ingestion of dust particles as the main exposure risk pathway in a receptor followed by dermal contact and inhalation in consistent with our findings. For heavy traffic zone, the chronic daily intake of HMs by toddlers was found to be in the order as Ni > Cr > Pb > Cd. The remaining two receptor groups also followed the same elemental order. Accordingly, chronic daily intake for Ni through dust ingestion from heavy traffic zone was found to be  $4.8 \times 10^{-2}$ ,  $3.7 \times 10^{-2}$  and  $2.5 \times 10^{-2}$   $\mu\text{g}/\text{kg}/\text{day}$  for toddlers, children and adults respectively (Table 10). These intake values are extremely below the reference dose (RfD) of 20.0  $\mu\text{g}/\text{kg}/\text{day}$  for Ni (Table 3) and hence may be considered as negligible.

**Table 9.** Classification of pollution based on Geo-accumulation index in different land use zones, Kathmandu

Pollution index	Commercial	Heavy traffic	Residential
(1): ( $I_{geo} \leq 0$ )	-	-	-
(2): ( $0 < I_{geo} \leq 1$ )	Cd, Cr, Ni, Pb	Cd, Cr, Pb	Cd, Cr, Ni, Pb
(3): ( $1 < I_{geo} \leq 2$ )	-	Ni	-
(4): ( $2 < I_{geo} \leq 3$ )	-	-	-
(5): ( $3 < I_{geo} \leq 4$ )	-	-	-
(6): ( $4 < I_{geo} \leq 5$ )	-	-	-
(7): ( $I_{geo} \geq 5$ )	-	-	-

1): Practically unpolluted; (2): Unpolluted to moderately polluted; (3): Moderately polluted; (4): Moderately to heavily polluted; (5): heavily polluted; (6): heavily to extremely polluted and (7): Extremely polluted

**Table 10.** Chronic daily intake ( $\mu\text{g/kg/day}$ ) and exposure risk of heavy metals for receptors in different land use zones, Kathmandu

Land use zone	Heavy metals	Receptors								
		Toddlers			Children			Adults		
		CDI <sub>ingest</sub>	CDI <sub>dermal</sub>	CDI <sub>inhale</sub>	CDI <sub>ingest</sub>	CDI <sub>dermal</sub>	CDI <sub>inhale</sub>	CDI <sub>ingest</sub>	CDI <sub>dermal</sub>	CDI <sub>inhale</sub>
Commercial zone	Cd	$2.9 \times 10^{-4}$	$2.1 \times 10^{-6}$	$1.1 \times 10^{-11}$	$2.2 \times 10^{-4}$	$2.8 \times 10^{-5}$	$2.0 \times 10^{-11}$	$1.5 \times 10^{-4}$	$1.6 \times 10^{-5}$	$2.9 \times 10^{-10}$
	Cr	$3.1 \times 10^{-2}$	$2.0 \times 10^{-7}$	$1.1 \times 10^9$	$2.4 \times 10^{-2}$	$2.6 \times 10^{-7}$	$2.2 \times 10^{-9}$	$1.6 \times 10^{-2}$	$1.5 \times 10^{-6}$	$1.8 \times 10^{-6}$
	Ni	$2.1 \times 10^{-2}$	$1.4 \times 10^{-5}$	$7.9 \times 10^{-10}$	$1.6 \times 10^{-2}$	$1.9 \times 10^{-5}$	$1.4 \times 10^{-9}$	$1.1 \times 10^{-2}$	$1.1 \times 10^{-4}$	$2.1 \times 10^{-8}$
	Pb	$2.6 \times 10^{-2}$	$1.8 \times 10^{-5}$	$9.9 \times 10^{-10}$	$2.0 \times 10^{-2}$	$2.3 \times 10^{-5}$	$1.8 \times 10^{-9}$	$1.4 \times 10^{-2}$	$1.4 \times 10^{-4}$	$7.3 \times 10^{-9}$
Heavy traffic zone	Cd	$3.2 \times 10^{-4}$	$2.5 \times 10^{-5}$	$1.2 \times 10^{-11}$	$2.5 \times 10^{-4}$	$3.3 \times 10^{-5}$	$2.3 \times 10^{-11}$	$1.6 \times 10^{-4}$	$1.9 \times 10^{-5}$	$3.2 \times 10^{-10}$
	Cr	$3.6 \times 10^{-2}$	$2.2 \times 10^{-7}$	$1.4 \times 10^9$	$2.8 \times 10^{-2}$	$2.9 \times 10^{-7}$	$2.6 \times 10^{-9}$	$1.9 \times 10^{-2}$	$7.0 \times 10^{-4}$	$1.3 \times 10^{-6}$
	Ni	$4.8 \times 10^{-2}$	$3.2 \times 10^{-5}$	$1.8 \times 10^9$	$3.7 \times 10^{-2}$	$4.3 \times 10^{-5}$	$3.3 \times 10^{-9}$	$2.5 \times 10^{-2}$	$2.5 \times 10^{-4}$	$4.6 \times 10^{-8}$
	Pb	$2.9 \times 10^{-2}$	$2.0 \times 10^{-5}$	$1.1 \times 10^9$	$2.3 \times 10^{-2}$	$2.6 \times 10^{-5}$	$2.1 \times 10^{-9}$	$1.5 \times 10^{-2}$	$1.5 \times 10^{-4}$	$2.8 \times 10^{-8}$
Residential zone	Cd	$1.9 \times 10^{-4}$	$1.5 \times 10^{-5}$	$7.4 \times 10^{-12}$	$1.5 \times 10^{-4}$	$2.0 \times 10^{-5}$	$1.4 \times 10^{-11}$	$1.0 \times 10^{-4}$	$1.2 \times 10^{-5}$	$1.9 \times 10^{-10}$
	Cr	$2.2 \times 10^{-2}$	$1.3 \times 10^{-7}$	$8.6 \times 10^{-10}$	$1.7 \times 10^{-2}$	$1.8 \times 10^{-7}$	$1.6 \times 10^{-9}$	$1.2 \times 10^{-2}$	$1.1 \times 10^{-6}$	$7.9 \times 10^{-7}$
	Ni	$1.1 \times 10^{-2}$	$8.2 \times 10^{-6}$	$4.5 \times 10^{-10}$	$9.4 \times 10^{-3}$	$1.1 \times 10^{-5}$	$8.5 \times 10^{-10}$	$6.2 \times 10^{-3}$	$1.1 \times 10^{-4}$	$1.1 \times 10^{-8}$
	Pb	$1.9 \times 10^{-2}$	$1.3 \times 10^{-5}$	$7.4 \times 10^{-10}$	$1.5 \times 10^{-2}$	$1.7 \times 10^{-5}$	$1.8 \times 10^{-9}$	$1.0 \times 10^{-2}$	$1.0 \times 10^{-4}$	$1.9 \times 10^{-8}$

On the contrary, this elemental order was noted to be different for residential and commercial both of which demonstrated the order as  $\text{Cr} > \text{Pb} > \text{Ni} > \text{Cd}$ . Cadmium was found as the least daily intake metal in all types of land use activities and by all receptors. While the chronic daily intake for Cr through dust ingestion from residential zone was estimated to be  $2.2 \times 10^{-2}$ ,  $1.7 \times 10^{-2}$  and  $1.2 \times 10^{-2}$   $\mu\text{g/kg/day}$  for toddlers, children and adults respectively, commercial zone exhibited chronic daily intake of Cr as  $3.1 \times 10^{-2}$ ,  $2.4 \times 10^{-2}$  and  $1.6 \times 10^{-2}$   $\mu\text{g/kg/day}$  respectively for the same receptors. These intake values from both residential and commercial zones were several orders below the tolerable limit of  $3.0 \mu\text{g/kg/day}$  for Cr (Table 3). Among the land uses, the exposure risk was found to be in the order as heavy traffic > commercial > residential for all HMs cases. Apparently, the most sensitive group is the toddler group in all land use cases, because of their hand-to-mouth activity, the behavior of mouthing non-food objects and repetitive hand/finger sucking during outdoor activities, through which dust can be readily ingested [64–66]. It is obvious that the increase in exposure frequency and/or the ingestion rate can result in the adverse effects to toddler. Therefore, the potential health risk for toddlers due to the exposure to street dust cannot be ruled out [67]. In addition, considering the lower body weight of children, the metals intake ( $\text{mg/kg-bodyweight/day}$ ) of a child is believed to be

greater than that of an adult [68]. Thus, the hazard health risk for children exposed to street dust metals is thought to be greater than that of adults.

Hazard quotient values (HQs) for the receptor groups based on the metal concentrations are given in Table 11. Results revealed that the HQ values were found to be all less than the safe level ( $=1$ ). This indicates no non-carcinogenic risks from the HMs to all receptors in the present study. In other words, the risks are within the safe level in consistent with the findings of Bourliva *et al.* [22] and Sun *et al.* [29] who also reported HQ values less than safe level ( $=1$ ) for different receptor groups based on total metal concentrations for the street dust. In addition, Rout *et al.* [28] also reported the hazard quotient values (HQs) less than 1.0 indicating no risks to people from heavy metals such as Cr, Ni and Pb. However, it may be noted from Table 11 that HQ<sub>ingest</sub> value was relatively higher for toddlers followed by children and adults. The same order was demonstrated by all receptors from all types of land-use activities (Table 11). Likewise, HQ values for the HMs followed the same order in all receptors, and land use zones as  $\text{Cr} > \text{Ni} > \text{Pb} > \text{Cd}$ . The lowest value of HQ for Cd was found in all receptors and land uses.

In our present study, Cd, Cr, Ni, and Pb revealed a HI value  $< 0.1$  for all the receptors and land use zones indicating that they are far to pose threats (Table 12). Nevertheless, the health

risk may be higher for toddlers and children who are more prone to contact with street dusts in sufficiently large doses. Therefore, the potential health risk for them due to the exposure to the street dust cannot be ruled out [67]. Although the HQs and HIs values for the HMs in this study are  $<1.0$ , the physical dust may have human health effects. Besides, water and food may be potential routes for metal intakes. Furthermore, Amato *et al.* [14] and Gertler *et al.*

[69] have pointed out street sweepers as victims in view of the potential increase in airborne particle concentrations during the manual sweeping. Taxi drivers may also be at health risk due to the long-term exposure to the street dust. Amato *et al.* [14] have reviewed the effectiveness of street sweeping, water washing, and dust suppressants as some of the strategies for enhancing hygiene and controlling adverse health effects.

**Table 11.** Hazard Quotient (HQ) and exposure risk of heavy metals for receptors in different land use zones, Kathmandu

Land use zone	Heavy metals	Receptors								
		Toddlers			Children			Adults		
		HQ <sub>ingest</sub>	HQ <sub>dermal</sub>	HQ <sub>inhale</sub>	HQ <sub>ingest</sub>	HQ <sub>dermal</sub>	HQ <sub>inhale</sub>	HQ <sub>ingest</sub>	HQ <sub>dermal</sub>	HQ <sub>inhale</sub>
Commercial zone	Cd	$2.9 \times 10^{-4}$	$8.0 \times 10^{-5}$	$1.9 \times 10^{-9}$	$2.2 \times 10^{-4}$	$1.1 \times 10^{-4}$	$3.7 \times 10^{-9}$	$1.5 \times 10^{-4}$	$6.2 \times 10^{-5}$	$5.0 \times 10^{-8}$
	Cr	$1.0 \times 10^{-2}$	$2.8 \times 10^{-4}$	$4.1 \times 10^{-8}$	$8.0 \times 10^{-3}$	$3.7 \times 10^{-4}$	$7.8 \times 10^{-8}$	$5.3 \times 10^{-3}$	$2.2 \times 10^{-3}$	$1.1 \times 10^{-6}$
	Ni	$1.1 \times 10^{-3}$	$1.8 \times 10^{-5}$	$3.2 \times 10^{-8}$	$8.0 \times 10^{-4}$	$2.4 \times 10^{-5}$	$5.9 \times 10^{-8}$	$5.5 \times 10^{-4}$	$1.4 \times 10^{-4}$	$8.3 \times 10^{-7}$
	Pb	$7.4 \times 10^{-3}$	$3.4 \times 10^{-5}$	$2.8 \times 10^{-10}$	$5.7 \times 10^{-3}$	$4.5 \times 10^{-5}$	$5.3 \times 10^{-10}$	$4.0 \times 10^{-3}$	$2.6 \times 10^{-4}$	$7.3 \times 10^{-9}$
Heavy traffic zone	Cd	$3.2 \times 10^{-4}$	$9.0 \times 10^{-5}$	$2.1 \times 10^{-9}$	$2.5 \times 10^{-4}$	$1.2 \times 10^{-4}$	$4.1 \times 10^{-9}$	$1.6 \times 10^{-4}$	$7.0 \times 10^{-5}$	$5.7 \times 10^{-8}$
	Cr	$1.2 \times 10^{-2}$	$3.4 \times 10^{-4}$	$5.0 \times 10^{-8}$	$9.5 \times 10^{-3}$	$4.5 \times 10^{-4}$	$9.4 \times 10^{-8}$	$6.4 \times 10^{-3}$	$2.6 \times 10^{-3}$	$1.3 \times 10^{-6}$
	Ni	$8.3 \times 10^{-3}$	$4.1 \times 10^{-5}$	$7.2 \times 10^{-8}$	$6.5 \times 10^{-3}$	$5.4 \times 10^{-5}$	$1.4 \times 10^{-7}$	$4.3 \times 10^{-3}$	$3.2 \times 10^{-4}$	$1.9 \times 10^{-6}$
	Pb	$2.4 \times 10^{-3}$	$3.8 \times 10^{-5}$	$3.3 \times 10^{-10}$	$1.9 \times 10^{-3}$	$5.0 \times 10^{-5}$	$5.8 \times 10^{-10}$	$1.2 \times 10^{-3}$	$2.9 \times 10^{-4}$	$8.1 \times 10^{-9}$
Residential zone	Cd	$1.9 \times 10^{-4}$	$5.4 \times 10^{-5}$	$1.3 \times 10^{-9}$	$1.5 \times 10^{-4}$	$7.2 \times 10^{-5}$	$2.4 \times 10^{-9}$	$1.0 \times 10^{-4}$	$4.2 \times 10^{-5}$	$3.4 \times 10^{-8}$
	Cr	$7.6 \times 10^{-3}$	$2.1 \times 10^{-4}$	$3.1 \times 10^{-8}$	$5.9 \times 10^{-3}$	$2.8 \times 10^{-4}$	$5.8 \times 10^{-8}$	$3.9 \times 10^{-3}$	$1.6 \times 10^{-3}$	$8.0 \times 10^{-7}$
	Ni	$5.6 \times 10^{-3}$	$1.0 \times 10^{-5}$	$3.8 \times 10^{-8}$	$4.4 \times 10^{-3}$	$1.4 \times 10^{-5}$	$3.4 \times 10^{-8}$	$2.9 \times 10^{-3}$	$8.0 \times 10^{-5}$	$4.7 \times 10^{-7}$
	Pb	$5.9 \times 10^{-4}$	$2.5 \times 10^{-5}$	$2.1 \times 10^{-10}$	$4.7 \times 10^{-4}$	$3.4 \times 10^{-5}$	$3.9 \times 10^{-10}$	$3.1 \times 10^{-4}$	$2.0 \times 10^{-4}$	$5.5 \times 10^{-9}$

**Table 12.** Hazard Index (HI) for receptors in different land use zones, Kathmandu

Land-use	Heavy metals	Hazard Index (HI)		
		Receptors		
		Toddlers	Children	Adults
Commercial Zone	Cd	$3.7 \times 10^{-3}$	$3.3 \times 10^{-4}$	$2.7 \times 10^{-4}$
	Cr	$1.0 \times 10^{-2}$	$8.4 \times 10^{-3}$	$7.5 \times 10^{-3}$
	Ni	$9.1 \times 10^{-3}$	$8.2 \times 10^{-3}$	$6.9 \times 10^{-4}$
	Pb	$7.4 \times 10^{-3}$	$5.7 \times 10^{-3}$	$4.3 \times 10^{-3}$
Heavy Traffic zone	Cd	$4.1 \times 10^{-3}$	$3.7 \times 10^{-3}$	$8.6 \times 10^{-4}$
	Cr	$1.2 \times 10^{-2}$	$1.0 \times 10^{-2}$	$9.0 \times 10^{-3}$
	Ni	$8.3 \times 10^{-3}$	$6.6 \times 10^{-3}$	$4.6 \times 10^{-3}$
	Pb	$2.3 \times 10^{-3}$	$2.0 \times 10^{-3}$	$1.5 \times 10^{-3}$
Residential zone	Cd	$2.4 \times 10^{-4}$	$2.2 \times 10^{-4}$	$1.2 \times 10^{-4}$
	Cr	$7.8 \times 10^{-3}$	$6.2 \times 10^{-3}$	$5.5 \times 10^{-3}$
	Ni	$5.6 \times 10^{-3}$	$4.4 \times 10^{-3}$	$3.0 \times 10^{-3}$
	Pb	$6.2 \times 10^{-4}$	$5.6 \times 10^{-4}$	$5.1 \times 10^{-4}$

## Conclusion

In this study, we analyzed the concentration of heavy metals (Cd, Cr, Ni and Pb), TOC and pH in dust samples from different land use zones of

Kathmandu and evaluated their pollution levels. Besides, the study also focused on assessment of health risk due to the HMs exposure in street dust to three different receptor groups *viz.*,



toddlers, children and adults from different land use zones. The selected land use zones showed their relative order based on concentration of the elements as heavy traffic>commercial>residential>control.

The average concentrations of Cd, Cr, Ni and Pb in dust samples of Kathmandu were found to be 0.69, 77.4, 68.9 and 63.9 mg/kg respectively. Based on the mean concentrations of HMs, Kathmandu street dust may be considered to be moderately polluted when compared with previous studies across the world. Among the land use zones, dust samples from heavy traffic zone showed the highest Ni (122.2 mg/kg), Cr (94.8 mg/kg), Pb (74.4 mg/kg) and Cd (0.84 mg/kg) contents. The commercial and residential zones were mainly affected by Cr in their dust samples. Besides, dust samples also revealed alkaline nature with different TOC values in the land use zones.

With a view to evaluate the HMs contamination levels in different land use zones, a category of single pollution index *viz.*, contamination factor (CF) and geo-accumulation index (Igeo) was used in the present study. While the commercial and heavy traffic zones recorded the highest CF and Igeo values for Ni, residential zone demonstrated the same for Cr. Accordingly, the CF ranged from a class of moderate to very high metal contamination level for different land use zones. Likewise, the Igeo values ranged from unpolluted to moderately polluted level with respect to the analyzed HMs for different land use zones. However, the average level of metal contamination in street dust of Kathmandu was found to be 3.94, 2.64, 1.97 and 1.94 for Ni, Cr, Cd and Pb, respectively.

Heavy metals can be generated in street dust both from natural and anthropogenic sources. Their entry in the food chain indicates a geochemical risk because of their toxicity to human health, especially to the occurrence of bioaccumulation phenomena. Results revealed dust ingestion as the major pathway contributing to exposure risk in all land use zones of

Kathmandu. The hazard quotient (HQ) and hazard index (HI) values for the HMs studied were far below threshold values indicating no non-carcinogenic risks from these elements for the receptor groups. However, toddlers appeared likely to be the vulnerable group because of their behaviour of mouthing non-food objects and repetitive hand/finger sucking during outdoor activities. Eventually, the present study may be expected to provide baseline information for local policy makers in order to address environmental pollution and manage health risk due to ingestion, dermal absorption and inhalation of HM pollutants in street dust.

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### Disclosure statement

No potential conflict of interest was reported by the authors.

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