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Chemical Associations of Lead, Cadmium, Chromium, Nickel and Zinc in Household Dust of Kathmandu Metropolitan Area

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Abstract

Dust samples were collected from roadside houses of seven major locations in Kathmandu metropolitan area and trace element compositions was determined by atomic absorption spectrophotometer (AAS). Results show significant concentrations of Zn, Pb, Ni, Cr and Cd in the test household dusts as compared to the undisturbed (control) area. The mean concentrations of all the studied locations were found to be 76.2 mg/kg for Zn, 40.6 mg/kg for Pb, 29.9 mg/kg for Cr, 23.9 mg/kg for Ni and 8.2 mg/kg for Cd, respectively. Increase in these trace metals in the dust can most likely be attributed to rapid urbanization, increased vehicle emissions to the atmosphere and other anthropogenic sources. Elevated Zn abundance in household dust probably originates from traffic sources. Besides, enrichment factor reveals that the household dust was most severely affected by Cd in almost all the locations. Also, correlations between metal levels in dust samples for all the metals were investigated.

Keywords**:** Environment; Heavy metals; Household dust; Kathmandu metropolitan area; Enrichment factor.

Introduction

Solid matter, composed of soil, anthropogenic metallic constituents, and natural biogenic materials is called dust [1]. Household or street dust often contains a range of toxic metals with the composition and concentration being seldom constant [2]. This is because of changes during weathering, the relatively short residence time in the environment, and because the residence time is directly related to climate [3,4]. Of the three materials, soil, sediments and dust (which derive primarily from the earth's crust and with which human beings come into contact), dust is the most pervasive. It is also the material that is now recognized as a significant source of trace metals in the urban environment. In some instances, the dust may represent a significant pollutant source. Moreover, three main factors known to influence the level of trace elements in dust have been reported as road traffic (automobiles), industry and weathered materials. The effect of the road traffic on trace metal contents of dust samples have been investigated for various purposes such as agricultural studies and different pollution studies [5,6].

Kathmandu, the capital of Nepal forms the core of the nation’s most populous urban region. Like many cities of the developing world, the city has been facing rapid population expansion including poor infrastructure and squatter settlements, with severe environmental consequences including air, water and other forms

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of pollution. The number of vehicles in the country has grown 15 times in the last two decades. According to Department of Transport Management (DoTM), number of vehicles has reached 11,26,763 in the first eight months of the current fiscal year from 75,141 in 1989-90. Over 72 per cent of all the vehicles ply in the central development region [7]. Hence, the major polluting source of many trace elements in Kathmandu has become automobiles [8,9].

Many of heavy metals such as Cr, Cd, Cu, Fe, Pb, Hg, Zn etc., are considered toxic to living organisms and even trace metals considered essential for life can be toxic when present at excessive levels that impair important biochemical processes and pose a threat to human health, plant growth and animal life [10]. It has also been suggested that dust can be an important source of metal intake for young children due to inadvertent ingestion of the dust [2,3]. Consequently, in recent years, public and scientific attention has increasingly focused on heavy metal contamination and its effect on humans and other living creatures [11]. In the urban environment, such pollutants are commonly found in dust which can be potentially harmful to roadside vegetation, wildlife, and neighboring human settlements [12].

Considerable attention has been paid to the study of metal pollution in city air, roadside dusts and soils. However, there is a lack of concern of the presence of trace metals in household dust in the populous city of Kathmandu, where it has traditionally been assumed that such pollutants are rapidly dispersed by roadside dusts. This research, therefore aims at quantifying the concentrations of heavy metals in household dust within the home environment in Kathmandu metropolitan area. The results of this study seem to suggest anthropogenic activities as source of metal contamination in household dust.

Materials and Methods

Study area and sample collection

A total of 40 household dust samples (five replicates from each site) including those from undisturbed (control) area were sampled from seven major roadways of Kathmandu metropolitan area (Fig. 1) during a dry season (October to December). Sampling locations were selected keeping in view of traffic load, population density and anthropogenic activities. Office and private residences, commercial buildings, shopping complexes, schools and hospitals were among the sources of sample collection. For the present study, sources of dust from such physical infrastructure except street dust were categorized as household dust unless and otherwise mentioned. A detailed description of the selected locations is given in (Table 1).

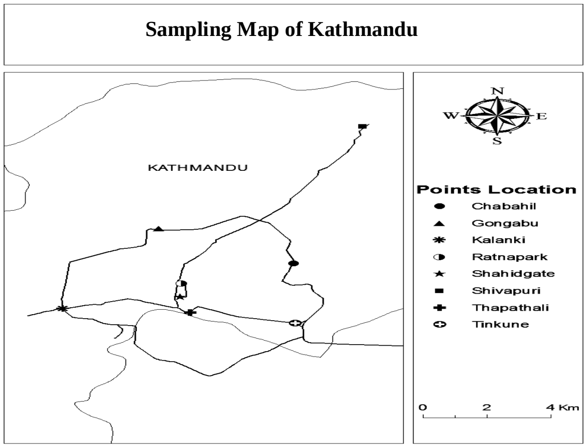

Figure 1. **Sampling map of the study areas of Kathmandu metropolitan area.**

Table 1. **Description of different sampling locations of Kathmandu metropolitan area**

Site No.	Sampling locations	Area code	Description of the nearby locations of sampling households
1	Tinkune	TKN	Traffic load, densely populated and commercial area
2	Chabahil	CBL	Traffic load, densely populated and commercial area
3	Gongabu	GGB	Heavy traffic load; main bus station; densely populated and commercial area
4	Kalanki	KLK	Heavy traffic; sub station; densely populated and commercial area; main entry point to Kathmandu city
5	Thapathali	THP	Traffic load; densely populated and commercial area
6	Sahid gate	SGT	Heavy traffic; central sub station and commercial area
7	Ratna park	RPK	Heavy traffic, central sub station; densely populated and commercial area
8	Shivpuri (Control; undisturbed area)	CTR	Low traffic; sparse residential and undisturbed area

Household dusts were collected repeatedly in adequate quantities by gentle sweeping of the floor area of about 1 m^2 by means of a soft plastic brush into a plastic dustpan and transferred into a polyethylene bag. The samples were brought to the laboratory and then sieved to exclude particles larger than 30 mesh. A portion of each of the five replicate samples was dried at 105°C for 24 hr and weighed for analytical purpose. Control samples collected from undisturbed area were also treated in a similar manner. We used the concentration for undisturbed area from the current study as local background (control) metal contents. The selected undisturbed areas are those without evidence of past and current anthropogenic activities and no signals of disturbances were observed during the sampling.

Sample analysis

The *p*H in bulk household dust samples was analyzed by using a glass electrode in a 1:5 soil/water suspension and electrical conductivity at room temperature in a 1:5 soil/water suspension [13] on a CON 510 bench conductivity meter using a conductivity electrode (cell constant, K = 1.0). Organic carbon content was determined by the Walkley Black method modified by Jackson [14]. Briefly, dust samples were oxidized with 1N $K_2Cr_2O_7$ and H_2SO_4 and the residual $K_2Cr_2O_7$ titrated against 0.05N ferrous ammonium sulfate using a pinch of NaF, H_3PO_4 and diphenylamine indicator. Blank (with no dust sample) was run for standardization.

Sample digestion, reagents and instrument

For each sample, 1.0 g of sieved dust was digested using tri-acid mixture (9 mL of 70% HNO_3, 1 mL of 60% $HClO_4$ and 6 mL of 48% HF) at 140 ^{o}C in Teflon bombs [15]. After digestion, boric acid was added to the solution and kept for about one week to allow complete formation of the gelatinous precipitate of borosilicate. Samples were then filtered through 0.45 µm millipore filter paper to obtain a clear solution. The filtrate was collected and stored in polypropylene bottles prior to total metal analysis by atomic absorption spectrophotometer (Hitachi model 180-270) for Cd, Cr, Ni, Pb and Zn using an air-acetylene gas mixture using hollow cathode lamp.

Determination of metal ions

Initially, the Atomic Absorption Spectrophotometer (AAS) was sufficiently warmed up for about 30 minutes. Hollow cathode lamps were used along with a deuterium background corrector at respective wavelengths using an air-acetylene flame. Background correction measurements were made by means of non-absorbing lines, and blanks were determined by completion of the full analytical procedure without samples. After each analytical run, the calibration curve was displayed on the screen and a visual check was made for linearity and replication. Prior to each analysis, the instruments were calibrated according to manufacturer's recommendations. All the standard solutions (1000 ppm) for Cd, Cr, Ni, Pb and Zn were certified and obtained from FLUKA AG, Switzerland. These solutions were diluted carefully to the required concentrations with doubly deionized water. The sample solutions were passed through the column by a flow rate of 2mL min^{-1}. Quality assurance of analytical results was controlled using the reference materials “NIST SRM 1648” for dust. The recovery percentage of metal concentrations from the reference materials was between 96.3 and 98.1%. In order to determine the precision of the analytical process, samples from the sites 1 and 5 (Table 1) were analyzed by three times. The standard deviation for both samples was calculated to 2.3 and 2.1% respectively and can be considered satisfactory for environmental analysis.

Metal concentration was calculated using the working formula given below:

$$\text{Concentrationofmetal}, \mu g/g = \frac{\text{Observed conc.}(\mu g/mL)^{*}\,\text{Vol. of sample prepared}(mL)}{\text{Wt. of dust sample}(g)}$$

Enrichment factor

The amount of anthropogenically introduced metal in household dust of different study locations was estimated using an enrichment factor (EF_x). EF_x was calculated with respect to the natural concentration by using the following expression [16,17]:

$$EF_x = X/X_{ref}$$

where X is the concentration of the metal in each fraction (mg/kg) and X_{ref} is the background concentration of metal in each fraction (mg/kg) from the undisturbed area.

Statistical analysis

In the present study, all statistical analyses and data processing were done using Statistical Package for Social Sciences (SPSS) program on an IBM-PC computer. Descriptive statistics such as mean, range and standard deviation were used after multi-element analysis. Correlation coefficients between various metals were calculated by $p<0.001$ using Pearson's (r) values.

Results and Discussion

Household dust properties

The pH of dust samples were relatively similar in all the locations, ranging from 7.5 (TKN) to 8.1 (RPK) (Table 2). The alkaline nature of the dust samples may be explained by the presence of carbonate [18] and high stability of pH due to small difference among the sites. The electrical conductivity was relatively high and variable in all the sites ranging from 0.09 mS/cm (THP) to 0.28 mS/cm (GGB) (Table 2). This indicates that the salt content in household dust depends on the location; the highest salt concentration in the household dust of GGB location are likely due to a spill of material rich in salts in the surrounding areas [19]. The percentage of organic carbon (OC) ranged from 1.0% (CTR) to 3.5% (TKN). If the organic carbon content in the household dust from the undisturbed area is compared with the percentage of OC in dusts from other sampling locations of the present study, we can conclude that the amount of OC in the dust samples for all locations is generally high (Table 2). Therefore, the elevated level of organic carbon in the household dust reflects that dust is an important sink of organic material in Kathmandu metropolitan area, which is subsequently transported by wind or runoff water and accumulated on buildings and/or streets. In addition, hydrocarbons, which come from vehicle oil or gasoline, and organic material from anthropogenic waste, may contribute to the organic carbon content in dust [20,21].

Heavy metals in household dust

The mean and standard deviation of heavy metal concentrations investigated in the studied samples are presented in (Table 3). Results reveal that the mean concentration of all metals in the dust samples was found to be in order of their abundance as Zn > Pb > Cr > Ni > Cd. Interestingly, the metal abundance order was found to be almost similar in all the locations including undisturbed area under investigation. The metal levels in the household dust (mean of all locations) of Kathmandu metropolitan area were 76.2 mg/kg for Zn, 40.6 mg/kg for Pb, 29.9 mg/kg for Cr, 23.9 mg/kg for Ni and 8.2 mg/kg for Cd. The values were significantly higher than those of the control location which recorded the mean concentration 35.9 mg/kg for Zn, 21.2 mg/kg for Pb, 14.6 mg/kg for Cr, 12.3 mg/kg for Ni and 2.8 mg/kg for Cd. Besides, the metal levels in the dust samples from the studied locations ranged from 47.6 (TKN) – 149.4 mg/kg (RPK) for Zn, 22.8 (GGB) – 58.7 mg/kg (RPK) for Pb, 15.9 (CBL) – 47.7 mg/kg (RPK) for Cr, 16.6 (TKN) – 38.1 mg/kg (RPK) for Ni and 3.6 (KLK) – 10.7 mg/kg (RPK) for Cd. Among the metals, Zn was found to be in significantly higher level in the dust samples from all locations. Similarly, among the studied samples, the household dust from RPK location recorded the highest concentrations of almost all the metals under investigation. The undisturbed area (CTR) however recorded comparatively the lowest levels of all metals under the similar experimental condition.

Adachi and Tainosho [22] reported that tyre dust is a significant pollutant, especially as a source of Zn in the urban environment. Zinc used as a vulcanization agent in tyres, was the most likely source in the dust samples in Kathmandu metropolitan area, resulting from attrition of motor vehicle tyre rubber exacerbated by poor road surfaces. Lubricating oils also contain zinc as additives such as zinc dithiophosphates [23]. Similarly, Acosta *et al.* [24] identified industrial activities and traffic as the main sources of Pb and Zn was related to recreational, domestic, and commercial sources.

Table 2. **Properties of household dust samples, mean (standard deviation, n = 5) from different sampling locations of Kathmandu metropolitan area**

Parameters	**TKN**	**CBL**	**GGB**	**KLK**	**THP**	**SGT**	**RPK**	**CTR**
*p*H	7.5 (0.1)	7.8 (0.2)	7.8 (0.1)	7.6 (0.2)	7.6 (0.3)	7.8 (0.2)	8.1 (0.4)	7.9 (0.2)
* EC(mS/cm)	0.20 (0.08)	0.25 (0.06)	0.28 (0.02)	0.24 (0.09)	0.09 (0.04)	0.15 (0.03)	0.13 (0.07)	0.04 (0.02)
**OC (%)	3.5 (0.7)	1.7 (0.5)	2.1 (1.1)	3.2 (0.7)	3.4 (1.8)	1.9 (1.0)	2.6 (0.6)	1.0 (0.4)

* Electrical conductivity; **Organic carbon

Table 3. **Heavy metals in household dust, mean (standard deviation; n = 5) ‘‘mg/kg’’, from different locations of Kathmandu metropolitan area**

Sampling sites	**Cd**	**Cr**	**Ni**	**Pb**	**Zn**
TKN	8.9(1.4)	18.7(3.5)	16.6(1.4)	27.8(3.8)	47.6(5.4)
CBL	6.2(0.9)	15.9(2.6)	21.9(5.1)	30.4(3.9)	73.9(10.2)
GGB	10.3(1.0))	19.5(3.2)	17.8(2.9)	22.8(2.9)	54.4(6.9)
KLK	3.6(0.2)	42.6(6.8)	29.4(3.9)	55.9(14.3)	61.5(11.5)
THP	5.2(0.3)	28.2(5.6)	19.8(5.3)	41.1(7.1)	78.9(15.9)
SGT	12.8(2.4)	37.1(4.2)	23.9(3.4)	47.4(7.9)	67.4(12.6)
RPK	10.7(3.2)	47.7(9.4)	38.1(7.8)	58.7(9.4)	149.4(23.4)
Kathmandu (mean all uses, n = 35)	8.2	29.9	23.9	40.6	76.2
CTR (Undisturbed area)	2.8(0.3)	14.6(3.2)	12.3(3.8)	21.2(3.7)	35.9(4.6)

Lead is the element of most concern in environmental metal pollution. The lead source may be directly associated with emissions from vehicle exhausts using leaded gasoline. The residence time of Pb in the atmosphere is also very high being 150 years [25]. So that even after phasing out the use of leaded gasoline in Kathmandu, it is likely to persist in the environment for a considerable period of years/months. Despite the sharp increase of unleaded fuel utilization, followed by a rapid decline of Pb levels in the atmosphere, the content of Pb in urban dust still remains high with a consequent associated risk for children via the soil hand mouth pathway [26].

The main source of nickel in dust is the combustion of diesel fuel [27]. This suggests that the extensive use of diesel in heavy vehicles, three wheelers, tractors and water pumps was contributing the elevated level in dust [2]. Similarly, the common anthropogenic sources of cadmium in dust are from metal plating, tyre enforced with metals, burning of tyres and bad roads [28]. The uses of cadmium-plated and galvanized equipment in food processing, cadmium-containing enamel and pottery glazes, and cadmium base pigments or stabilizer in plastics may also be significance sources of contaminations [29]. Similarly, chromium in street dust is associated with the chrome plating of some motor vehicle parts [30].

Enrichment in household dust

Taking into account the concentration of metals in undisturbed area (CTR) and after calculating enrichment factors from the mean concentrations of all uses (Table 3), we can conclude that household dust from Kathmandu metropolitan area is severely enriched by Cd (EF = 2.9), Cr (EF = 2.1), Ni (EF = 1.9), Pb (EF = 1.9) and Zn (EF = 2.1).

Also, it is observed that the degree of enrichment for each metal is variable in household dust of the studied locations (Fig. 2). Results show that dust samples from TKN, CBL, GGB and SGT were enriched most by Cd while those from KLK and RPK were found to be affected by Cr and Zn respectively. Among the studied locations, dust from RPK was most severely enriched by Cr (EF =

3.3), Ni (EF = 3.1), Pb (EF = 2.8) and Zn (EF = 4.2) except Cd which was most severely enriched (EF = 4.6) in dust of SGT location. Results clearly show variability in enrichment factor in the household dust indicating the interplay of sources of metals, human habits, populations, etc. of each location determines the metal concentration in dust samples [31,32]. Additionally, the dust metals may travel from the roads, through the windows and balconies, into the houses as those homes that have their windows opened often had a higher level of contaminants in their house dust. Body *et al.* [33] reported that those occupants who sweep their floors or dust on their furniture on daily bases, or use vacuum cleaners, had a lower level of metals inside their houses. Another finding of interest is that the color of the wall paint used in the house was another factor influencing the contamination levels.

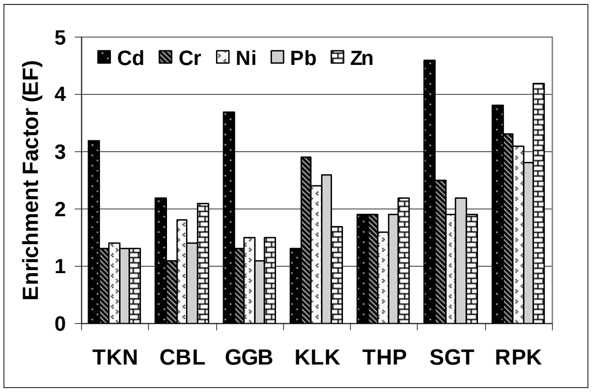

Figure 2. **Enrichment factors in different studied locations.**

Pearson's correlation coefficients for metals in household dust in Kathmandu metropolitan area is shown in (Table 4). Inter-element relationship showed significant correlations between Ni and Cr (r = 0.461, $p<0.001$), Pb and Cd (r = 0.933, $p<0.001$), Zn and Cd (r = 0.939, $p<0.001$), Zn and Cr (r = 0.487, $p<0.001$) and Pb and Zn (r = 0.874, $p<0.001$) indicating that household dust contamination by metals originated from a common anthropogenic source. As the study area has no industrial belt, we may assume that the heavy metals analyzed in household dust samples were derived almost exclusively from local traffic as well as other household activities.

Table 4. **Inter-element correlations for household dust samples from the study area**

Element	Cd	Cr	Ni	Pb	Zn
Cd	1.000				
Cr	0.281	1.000			
Ni	0.085	0.461*	1.000		
Pb	0.933*	0.290	0.044	1.000	
Zn	0.939*	0.487*	0.254	0.874*	1.000

Conclusion

The household dust from different major roadways (seven studied locations) in Kathmandu metropolitan area has an alkaline pH which may probably be due to a high amount of carbonates (calcite and dolomite) that can react with metals to form metal-carbonate complex/minerals. Its electrical conductivity is variable and the elevated level of organic carbon in household dust reflects that dust is an important sink of organic material in Kathmandu metropolitan area.

The mean metal concentrations in all the studied locations were found to be in significantly higher levels than those obtained for undisturbed area. Dust samples from all those locations were found to be associated with the metals following their order of abundance as Zn > Pb > Cr > Ni > Cd. Among the studied locations, the household dust from RPK recorded the highest concentrations of almost all the metals under investigation. Although variability in enrichment factor (EF_x) was found in all the sites, the household dust in Kathmandu metropolitan area was found most severely affected by Cd. Therefore, we conclude that a monitoring plan is necessary to evaluate the evolution of metal concentration in dust in order to develop the proper measures for reducing the risk of inhalation and ingestion of dust for humans and environment. Besides, further work would be required to establish whether the major source of metals in the house is from indoor or outdoor origins as atmospheric transport of metallic particulates.

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