HEAVY METALS IN BULK AND PARTICLE SIZE FRACTIONS FROM STREET DUST OF KATHMANDU CITY AS THE POSSIBLE BASIS FOR RISK ASSESSMENT

Neena Karmacharya* and **Pawan Raj Shakya****

*Department of Biology, Padmakanya Multiple Campus, Tribhuvan University, Bagbazar, Kathmandu.

**Department of Chemistry, Padmakanya Multiple Campus, Tribhuvan University, Bagbazar, Kathmandu.

Abstract: Street dust has been sampled from eight major locations of Kathmandu city. The samples were separated into three particle size fractions (<425, 425-600 and >600 μm) and analyzed for Pb, Cu, Zn and Fe using Atomic Absorption Spectrophotometric method. Results revealed that the bulk samples as well as all particle size fractions under investigation were found to have the metal abundance order as Fe > Zn > Cu > Pb. However, the trace metal concentrations increased with the decrease of dust particle size in all samples. About 35-68% of heavy metals were associated with the small particle size fraction (<425 μm) and this particle size accounted for 64-81% of the total mass of street dust from all locations. The smaller particle size fraction has a higher heavy metal content, low density, high mobility in runoff, and thus is a higher risk for the residents of Kathmandu city. From the present study, we conclude that a monitoring plan and a suitable risk assessment are 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.

Keywords: Environment; Heavy metals; Street dust; Kathmandu city.

INTRODUCTION

Street dust, particles deposited on road, originates from the interaction of solid, liquid and gaseous materials produced from different sources.[1] The composition of dust is very variable, as dust originates from different sources depending on climate, human activities, soils and rocks of the surrounding areas, etc.[2] Indeed, their components and quantity are environmental pollution indicators.[3] Metals may be accumulated in dust from atmospheric deposition by sedimentation, impaction and interception.[4] Accumulations of metals including Pb, Zn, Cd and Cu on road surfaces arise from vehicle exhausts, industrial discharges, oil lubricants, automobile parts and corrosion of building materials, asphalts, road paints, concrete, etc.[5]

There is ample evidence that street dust is an important pathway in the exposure of people to toxic elements.[6,7] The intake of dust particles with high concentration of toxic substances, especially potentially toxic metals, poses a potential threat to human health.[8] For instance, in California, 5–10% of the allergenicity for atmospheric total suspended particulate matter was attributed to paved road dust emissions.[9] Therefore, the monitoring of such material has been set as a priority in risk assessment programs in order to evaluate the risk of inhalation and ingestion of dust for humans, especially for children.[10]

As the case with many urban areas, Kathmandu city also has some vulnerable areas plagued with consistently higher concentration of pollutants, particularly heavy metal pollution. For the last decade, the city has been expanding, including the construction of new buildings and commercial areas, and an ever increasing number of vehicles. This fastest growing city with high commercial activities harbors around 3 hundred thousand vehicles and the number is likely to be doubled in next few years (Office of Traffic Police, Kathmandu - personal communication). As a consequence, new sources of potentially toxic metal pollution through dust may be present. Some major locations of the city such as Kalanki, Gongabu, Chabahil, Tinkune, Sahidgate, Ratnapark and Thapathali are considered to be strategically important from environmental point of view as these locations are densely populated and also suffer heavy traffic loads and hence may be used for assessing the environmental status of the Kathmandu city due to street dust. Therefore, the potential presence of metals in street dust of these locations and their distribution according to particle size fractions had to be established.

Many studies on metal concentrations in street dust have been conducted particularly in developed countries with long history of industrialization.[11,12,13] Very few studies have been carried out in developing countries like Nepal. Besides, very little information is available about the distribution of metals in different particle size fractions of the dust. Hence, the objectives of this study were to: (1) assess the contamination of heavy metals such as Pb, Cu, Zn and Fe in street dust (bulk sample) from different sampling locations of Kathmandu city by comparison with reported results from other cities and (2) investigate the metal distribution in particle size fractions (three particle sizes) from street dust of the city.

Author for Correspondence: Pawan Raj Shakya, Department of Chemistry Faculty of Science, Padmakanya Multiple Campus Tribhuvan University, Bagbazar, Kathmandu. E-mail: pawansh2003@yahoo.com.

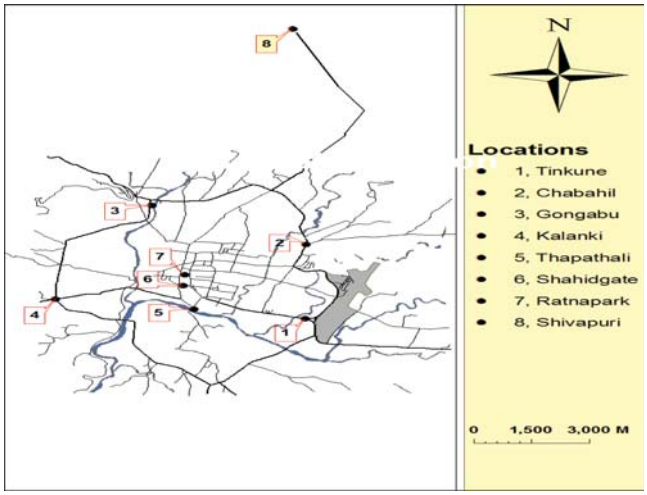

Fig. 1: Sampling map of the study areas of Kathmandu city

MATERIAL AND METHODS

Study area and sampling

The study sites were located at different places around the Kathmandu city (Fig. 1), *viz.*, Tinkune, Chabahil, Gongabu, Kalanki, Thapathali, Sahidgate, Ratnapark and Shivpuri (control). A total of 24 street dust samples (three samples from each place) including control were collected during dry season to avoid rain washing out the heavy metals. The sampling was carried out by sweeping an area of about $1m^2$ from the paved roads using a brush and plastic dustpan. The amount of dust collected from each site was 250–500 g. In order to avoid re-suspension of the finest particles during sampling, the sweeping was made slow and collected directly into the plastic bag. Samples were then taken for analysis. Precautions were taken to avoid contamination during sampling, drying and storage. Table 1 shows the description of all sampling locations of Kathmandu city.

Analytical methods

Bulk samples including those of control were oven-dried at 105 °C for 24 hr to drive out moisture and then passed through a 2 mm metal free sieve to remove unwanted fragments and pebbles. The soil *p*H in bulk samples was analyzed by using a glass electrode in a 1:1 soil/water suspension[14] and electrical conductivity at room temperature in a 1:5 soil/water suspension[15] on a CON 510 bench conductivity meter, using a 2-ring stainless steel ultem-body conductivity electrode (cell constant, K = 1.0) with built-in temperature sensor. For analyzing particle size distribution, 100 g of each of the bulk sample from the different sampling locations were separated into three particle size fractions by using a stack of sieves with the sizes, 600 and 425 µm such that particle size fractions of >600, 600-425 and <425µm were obtained. The particle size fractions in the present study may be categorized as follows: >600 (large size), 600-425 (medium size) and <425µm (small size).

For analyzing heavy metals (Pb, Cu, Zn and Fe) in bulk, control and particle size fractions, 1 g of each of the dried samples was digested using 20 mL nitric/perchloric acid at 210°C during 90 minutes. After cooling, 0.1 N HCl was added to fill a 100 mL volumetric flask[16] and the total amounts of metals were measured by atomic absorption spectrometry (SOLAAR M5 Dual Automizer, 180-900nm, Thermo Elemental, UK). All the standard solutions (1000 ppm) for Pb, Cu, Zn and Fe were certified and obtained from FLUKA AG, Switzerland. These solutions were diluted carefully to the required concentrations with double-distilled water. The instrumental parameters were those recommended by the manufacturer. 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 4 (Table 1) were analyzed by three times. The standard deviation for both samples was calculated to 2.5 and 3.1% respectively and can be considered satisfactory for environmental analysis. All analyses were performed in triplicate.

Metal concentration was calculated using the working formula given below:

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

We used the concentration for undisturbed areas from the current study as local background (control) metal contents. The selected undisturbed areas are lands without evidence of past and current anthropogenic activities and no signals of disturbances were observed during the sampling.

The statistics

All statistical analyses and data processing in this study were performed on an IBM-PC computer using Statistical Package for Social Sciences (SPSS) program. Descriptive statistics (mean, percentage and standard deviation) were performed after multi-element analysis. The inter-element correlation coefficients (r) for street dust samples were calculated by $p<0.05$. The contamination ratio for each site separately for street dust was calculated; Contamination ratio is the average metal concentration of a site over (:) the metal concentration of the reference site (control).

RESULTS AND DISCUSSION

Street dust properties

The *p*H in the different locations under investigation was mostly alkaline (Table 2), which may be explained by the presence of carbonates.[17] The small differences among the locations show the high stability of *p*H in the dust.

Electrical conductivity (EC) was found to be variable, ranging from 0.3 dS m^{-1} in Shivpuri dust (undisturbed area; control) to 2.8 dS m^{-1} in Kalanki (Table 2). This shows that the salt content in dust depends on the location; the highest salt concentrations in the locations such as Kalanki and Gongabu dust are likely due to a spill of material rich in salts.[18]

Fractionation of bulk samples to various particle sizes revealed that <425 ìm (small size fraction) was the dominant fraction (64.3–80.6%) into the dust from all locations (Table 2), the highest being found in Chabahil and the lowest in

Table 1: Description of different sampling locations of Kathmandu city.

Site No.	Sampling locations	Area code	Description of the sampling locations
1	Tinkune	TKN	Traffic load, sub station; densely populated and commercial area; main exit point to Bhaktapur
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 (Undisturbed area; Control)	Ctrl	Low traffic; sparse residential and undisturbed area

	TKN	CBL	GGB	KLK	THP	SGT	RPK	Ctrl
*p*H	7.8 (0.3)	7.8 (0.1)	7.8 (0.2)	7.6 (0.0)	7.6 (0.3)	7.6 (0.2)	7.9 (0.4)	7.9 (0.4)

Shivpuri (undisturbed area; control). The amount of the medium fraction (600-425 µm) ranged from 7.1% (Ratna park) to 18.3% (Sahid gate), while the occurrence of particles >600 µm (large size fraction) in size varied from 9.5% (Sahid gate) to 19.7% (Shivpuri; control). The particles with small sizes are considered a major environmental and health hazard.[19] Therefore, the highest risk for humans and the environment occurs in Chabahil (80.6%) > Ratna park (77.2%) > Kalanki (76.7%) > Gongabu (74.4%) > Sahid gate (72.6%) > Thapathali (70.1%) > Tinkune (69.2%) > Shivpuri (control; 64.3%).

Heavy metals in bulk samples

The mean and standard deviation of metal concentrations and average contamination ratios investigated in the studied samples, as well as values of other cities, are presented in Table 3. As might be evident from the results that the mean concentration of all metals in Kathmandu city is different and can be ranked by abundance as follows: Fe > Zn > Cu > Pb. Similar metal abundance order was obtained in all the locations including control site. The mean concentration of heavy metals in the Kathmandu dust (mean of all locations) was 7.2 mg/g for Fe, 62.2 µg/g for Zn, 29.5 µg/g for Cu and 22.3 µg/g for Pb respectively while those of control were 2.1 mg/g for Fe, 29.9 µg/g for Zn, 15.6 µg/g for Cu and 12.3 µg/g for Pb respectively. Besides, the metal concentration from all the locations ranged from 2.1(control) - 8.2 mg/g(Ratna park & Sahid gate) for Fe, 29.9(control) – 110.4 µg/g(Ratna park) for Zn, 15.6(control) – 41.9 µg/g(Kalanki) for Cu and 12.3(control) – 43.7 µg/g(Ratna park) for Pb respectively. Iron was found to be prevalent in significantly higher level in bulk samples from all locations. Homady *et al.*[20] also noticed significant accumulation of Fe from street dust in Jordan which they identified to be due to vehicle sources, petroleum residue and tyre repair. Additionally, the high abundance of Fe in nature could be another source of contamination along with activities related to mechanical workshops, iron bending and welding of metals. Moreover, the observed differences in the range of metals are most likely caused by variation in the sources of the metals. Acosta *et al.*[21] identified industrial activities and traffic as the main sources of Pb while Cu was associated with inorganic fertilizers in agricultural areas, and Zn was related to recreational, domestic, and commercial sources. Adachi and Tainosho[22] from their studies on the morphology

Table 2: Properties of street dust bulk samples (n = 3, mean, standard deviation) from different sampling locations of Kathmandu city.

* EC(dSm^{-1})	2.1 (0.9)	1.8 (1.6)	2.7 (0.9)	2.8 (1.0)	0.7 (0.1)	1.2 (0.3)	1.2 (0.7)	0.3 (0.1)
Particle size fractions (%)								
>600	19.1 (5.1)	11.1 (4.1)	14.6 (6.01)	14.7 (2.2)	12.5 (6.3)	9.5 (6.0)	15.3 (3.5)	19.7 (7.3)
600-425	11.9 (3.9)	8.3 (3.9)	9.1 (1.9)	8.5 (1.3)	17.0 (8.6)	18.3 (4.5)	7.1 (1.3)	16.1 (1.7)
<425	69.2 (6.6)	80.6 (10.1)	74.4 (8.9)	76.7 (6.6)	70.1 (16.0)	72.6 (11.6)	77.2 (12.1)	64.3 (3.5)

* EC: electrical conductivity

and chemical composition of heavy metals embedded in tyre dust and traffic related materials, concluded that tyre dust is a significant pollutant, especially as a source of Zn in the urban environment.

If the results from this study are compared with those reported in other cities (Table 3), the high variability in metal concentrations in the dust is clear, indicating that the interplay of sources of metals, human habits, populations, etc. of each city determines the metal concentration in dust samples.[23,24] But in the absence of knowledge regarding activities or characteristics of the sampling sites in the various cities or countries, comparison of data recorded and comments on the causes of the differences between metal levels may be unjustified. However, the results from this study revealed that the mean levels of Zn, Cu and Pb were found to be significantly lower than the reported values of various cities (Table 3). The Fe value could not be compared due to unavailability of the reported values of Fe of other cities. In addition, taking into account the concentration of metals in Shivapuri (undisturbed area) and after calculating average contamination ratio (ACR), we can conclude that the street dust from the Kathmandu city is contaminated by Fe (ACR =

Table 3: Heavy metals in street dust (bulk sample), mean (standard deviation; n = 3) "ìg/g" from different cities and guidelines.

	Pb	Cu	Zn	*Fe	References
TKN	13.4(1.6)	18.5(3.1)	36.8(4.8)	6.7(0.8)	This study (n = 3)
CBL	14.4(1.3)	20.4(4.9)	69.3(11.1)	6.7(0.9)	
GGB	18.4(2.1)	16.2(3.5)	44.5(7.7)	6.7(0.6)	
KLK	25.3(3.3)	41.9(11.6)	52.5(15.1)	7.1(0.5)	
THP	24.8(4.3)	30.1(6.1)	65.6(16.4)	7.0(0.7)	
SGT	15.9(2.4)	39.4(7.1)	56.4(13.6)	8.2(1.0)	
RPK	43.7(6.4)	40.1(8.3)	110.4(19.4)	8.2(1.0)	
Kathmandu (mean all uses, n = 21)	22.3	29.5	62.2	7.2	
Undisturbed area (Control)	12.3(1.2)	15.6(1.3)	29.9(2.8)	2.1(0.3)	
Average contamination ratio (ACR)	1.8	1.9	2.1	3.4	
Heavy metals concentration in street dust from cities around the world (µg/g)					
Ontario (USA)	90	87	227	-	26
Madrid (S ain)	1927	188	476	-	27
Dhaka (Bangladesh)	74	46	154	-	28
Oslo (Norwa)	180	123	412	-	27
London (UK)	897	300	1866	-	29
Istanbul (Turke)	185	122	447	-	30
Xi'an (China)	230	95	421	-	3
Hong Kong (China)	181	173	1450	-	4
Taejo (Korea)	52	57	214	-	31

* Fe concentration in mg/g

3.4), Zn (ACR = 2.1), Zn (ACR = 1.9) and Pb (ACR = 1.8). Moreover, a positive correlation between Pb and Cu ($r = 0.783$, $p<0.05$), Pb and Zn (($r = 0.813$, $p<0.05$) and Zn and Cu ($r = 0.879$, $p<0.05$) (Table 4) could indicate a common source of the metals in the street dust of the Kathmandu city.

The contamination ratio in street dust from different sampling locations is also presented in Table 5. It can be concluded from the results that all the locations under study are severely contaminated by Fe. However, the contamination ratios of Zn, Cu and Pb were found to be variable among the locations probably due to interplay of sources of metals as discussed earlier. Furthermore, among the different locations, Ratna park suffered the highest contamination of Fe, Zn and Pb by the ratio of 3.9, 3.7 and 3.6 respectively. Similarly, Sahid gate also suffered from the highest contamination of Fe (3.9) whereas the highest contamination ratio of Cu (2.7) was found in Kalanki dust.

Heavy metals in particle size fractions

Table 6 shows the heavy metal concentrations in three particle size fractions. All the particle size fractions are enriched in metals; however, the effect of particle size is different among the locations and metals concerned. It was found that the concentration of heavy metals embedded into the dust increased with the decrease of particle size. Accordingly, the distribution of Fe, Zn, Cu and Pb in all the sampling locations was found to increase with the decrease of the particle size as follows:

large size (>600 μm) < medium size (600-425 μm) < small size (<425 μm)

In all the three fractions, the mean concentrations of the metals can be ranked by their abundance in the order as Fe > Zn > Cu > Pb. The metal ranking is similar to those of the bulk samples. A careful analysis of the data (Table 6) revealed that particles with size <425 μm contributed alone in a range of about 35-68% to the total concentration for all metals. For particles with sizes 600-425 μm, this was about 18-39% and for >600 μm size, the contribution reached to 7-32%.

For Pb, Ratna park dust showed 27.9, 33.4 and 75.5 μg/g in large, medium and small size fractions respectively, all the values being comparatively higher to those of the other locations. For Cu, 28.0 and 87.6 μg/g were recorded as the highest values respectively for large and small size fractions from Ratna park dust whereas Kalanki recorded 48.1 μg/g as the highest concentration for medium size fraction. As for Zn, it was also from Ratna park dust that recorded the highest values of 170.3 and 101.5 μg/g respectively for small and medium size fractions whereas large size fraction from Kalanki dust measured the highest value (44.7 μg/g). In case of Fe content, Ratna park dust recorded 10.4 mg/g for small size fraction, Sahid gate recorded 8.4 mg/g for medium size fraction and Kalanki recorded 7.0 mg/g for large size fraction; all the values being comparatively higher to other locations. For small size fraction, Ratna park dust reported a comparatively higher concentration of the metals.

The results of the present study are in agreement with the study conducted by Fergusson and Ryan[25] who also found the increasing concentrations of heavy metals such as Cd, Pb, Cu, Zn, Mn and Fe with decrease in size of the street dust particles from cities like London, New York, Halifax, Christchurch, Kingston etc. Duong *et al*[26] while studying the street dust from the Ulsan of Korea, also found that the concentrations of metals such as Cd, Cu, Pb and Ni increased with decrease in the size of dust particles.

Metal partitioning as a function of particle size is very important for soil-bound potentially toxic metals.[27] The preferential partitioning of metals to the small particle size fractions in all locations and for all metals is shown in Table 6. Such a pattern is usually attributed to the increase in the specific surface area and concomitant increase in the proportion of reactive substrates[28] with negative charges associated with these fine particles.[29]

Environmental impact

Most of the studies about risk assessment of metal focus on the concentration of metals in bulk soil/dust samples, and most of them are located in a specific soil use. However, this work shows the distributions of metals from three particle size fractions (>600, 600-425 and <425 μm) from 8 locations including undisturbed area and the results of this work show that street dust particles in all locations showed concentrations of metals higher than those found in undisturbed area. The results indicated a preferential partitioning of metals to small particle size fractions in all cases. The accumulation in the small size fractions was higher when the metals had an anthropogenic origin. Therefore, we recommend that risk assessment programs include monitoring of heavy metal concentrations in dust where each land-use is separately evaluated. The finest particle fractions should be examined explicitly and separately given in order to apply the most efficient measures for reducing the risk for humans and the environment of the Kathmandu city.

CONCLUSION

The street dust from different sampling locations in Kathmandu city has an alkaline *p*H probably due to a high amount of carbonates. Its electrical conductivity is very variable. Fractionation of bulk samples into three particle sizes revealed that the percentages of particles considering a major environmental and health hazard (<425 μm) were: Chabahil (80.6%) > Ratna park (77.2%) > Kalanki (76.7%) > Gongabu (74.4%) > Sahid gate (72.6%) > Thapathali (70.1%) > Tinkune (69.2%) > Shivpuri (control; 64.3%).

Bulk samples as well as all particle size fractions in all locations were found to be enriched for all metals having the metal abundance order as Fe > Zn > Cu > Pb. The average contamination ratio (ACR) in the Kathmandu dust for Fe, Zn, Cu and Pb were 3.4, 2.1, 1.9 and 1.8 respectively. The mean metal concentrations in all the locations were found to be higher than those found in undisturbed area. However, these values were found to be significantly lower than those of the reported values of other cities. Among the metals analyzed, Fe was found in significantly higher level in all locations.

It was found that the trace metal concentrations increased with the decrease of dust particle size fractions. About 35-68% of heavy metals were associated with the small particle size fraction (<425 μm) and this particle size accounted for 64-81% of the total mass of street dusts. This contribution is comparatively higher than any other particle size under investigation. For small size fraction, Ratna park dust reported

Table 4: Interelement correlations for street dust bulk samples from the study area.

Element	Pb	Cu	Zn	Fe
Pb	1.000			
Cu	0.783	1.000		
Zn	0.813	0.879	1.000	
Fe	0.368	0.465	0.532	1.000

High significance by $p<0.05$ are in bold.

Table 5: Contamination ratio in street dust from different sampling locations.

	TKN	CBL	GGB	KLK	THP	SGT	RPK
Pb	1.1	1.2	1.5	2.1	2.1	1.3	3.6
Cu	1.2	1.3	1.0	2.7	1.9	2.5	2.6
Zn	1.2	2.3	1.5	1.8	2.2	1.9	3.7
Fe	3.2	3.2	3.2	3.4	3.3	3.9	3.9

Table 6: Heavy metal concentrations (ig g^{-1}) in particle size fractions from street dust of different sampling locations of Kathmandu city; mean (standard deviation; n = 3).

Sampling locations	Particle size (µm)	Pb	Cu	Zn	*Fe
	>600	3.9(0.3)	9.8(2.6)	11.3(1.8)	3.8(0.2)
TKN	600-425	7.0(1.4)	10.4(2.0)	23.8(3.8)	5.7(0.3)
	<425	23.0(8.3)	36.7(5.3)	66.2(11.7)	9.9(1.4)
CBL	>600	6.7(1.1)	7.5(1.4)	17.2(2.1)	5.8(0.5)
	600-425	10.4(2.3)	15.4(2.5)	65.4(10.8)	5.9(0.5)
	<425	32.2(7.8)	44.7(8.5)	121.2(12.1)	9.0(0.7)
GGB	>600	3.8(0.9)	11.0(2.2)	12.1(2.2)	4.9(0.5)
	600-425	19.6(2.7)	14.2(3.6)	32.3(4.9)	5.0(0.4)
	<425	28.8(4.3)	25.8(6.5)	79.8(12.4)	9.6(1.2)
	>600	18.7(2.1)	22.1(2.7)	44.7(3.2)	7.0(0.5)
KLK	600-425	26.9(3.1)	48.1(3.2)	58.3(7.8)	7.1(0.4)
	<425	36.2(5.1)	52.5(6.2)	66.0(12.2)	7.6(0.6)
THP	>600	5.9(0.7)	7.1(1.2)	23.1(2.7)	5.8(0.4)
	600-425	23.6(1.8)	28.8(3.6)	67.7(10.8)	6.0(0.6)
	<425	36.1(7.8)	51.5(11.2)	118.1(18.9)	8.8(0.7)
SGT	>600	6.3(1.4)	19.6(2.5)	20.5(1.2)	6.8(0.5)
	600-425	11.8(1.7)	37.6(7.2)	51.1(7.7)	8.4(0.6)
	<425	28.7(3.7)	71.0(11.4)	85.6(12.3)	9.5(0.7)
RPK	>600	27.9(5.0)	28.0(1.7)	40.6(6.8)	6.7(0.5)
	600-425	33.4(6.5)	31.8(2.5)	101.5(10.5)	8.3(0.7)
	<425	75.5(8.2)	87.6(12.4)	170.3(31.3)	10.4(2.0)
	>600	3.5(0.8)	6.5(1.5)	9.8(2.9)	0.9(0.3)
Ctrl	600-425	6.8(0.7)	9.0(2.4)	19.6(3.5)	1.3(0.2)
	<425	22.0(2.8)	23.5(3.6)	56.8(6.7)	4.2(0.8)

* Fe concentration in mg/g

a comparatively higher concentration of the metals. Results from other locations were found to be variable.

From the present study, 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 of the Kathmandu city. In addition, the concentration of all metals in the dust is markedly affected by the land use, associated with the metal sources. Therefore we think that a suitable risk assessment should evaluate specifically each use and avoid mixing samples from different uses.

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