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Foliar Transfer of Dust and Heavy Metals on Roadside Plants in a Subtropical Environment

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ABSTRACT

In this study, the contents of dust and associated heavy metals on roadside plants were investigated to assess their foliar transfer. The study was conducted at six different locations (four roadside and two industrial) near an industrial area in Bilaspur (Chhattisgarh), India. Six metals (Fe, Mn, Pb, Cu, Cr, and Cd) were examined in this study. The concentrations of heavy metals in foliar dust were found to be in the order of Fe>Mn>Pb>Cu>Cr>Cd. However, this relative order changed in the case of leaf concentrations to Fe>Mn>Cd>Cu>Pb>Cr. The metal concentrations in the dust and leaves can be attributed mainly to industrial and vehicular emissions. In contrast to other metals, Cd showed significant accumulation in the leaves compared to the respective dust samples. This study showed different patterns in the distributions of heavy metals between the dust deposited on the leaves and the metal accumulated in the leaves. These results suggest that the dust retention and heavy metal accumulation in native plant species should be explored in an attempt to manage these hazardous metallic elements.

Key words: Toxic heavy metals, Accumulation, Urban roadsides, Phytomonitoring, Air Quality

1. INTRODUCTION

Hazardous air pollutants (HAPs) are released from a variety of manmade sources including industry, the combustion of fossil fuels, vehicular traffic (transport), and energy production. A large fraction of HAPs are "heavy metals" (Sawidis *et al.*, 2011), including toxic trace elements such as Cu, Zn, Pd, Cd, and Cr. Vehicular transportation is responsible for re-suspending and mixing fine particles in street dust (Zhang *et al.*, 2012). Heavy metals in dust can exert direct effects on public health because they can easily enter the human body via breathing, dermal contact, and dust ingestion, ultimately damaging the tissue of lungs (Zhang *et al.*, 2012; Hu *et al.*, 2011; Shi *et al.*, 2011; Zheng *et al.*, 2010; Ferreira *et al.*, 2005; Drekert *et al.*, 1991).

It has been reported that plants may be used as biological filters by taking advantage of their foliar accumulation of particulate matter (PM) (Escobedo *et al.*, 2008; Nowak *et al.*, 2006). Plants can also be used as effective biomonitors to detect the presence of metals, even at trace levels, in the soil and in the atmosphere (Sawidis *et al.*, 2011). In recent years, a number of studies have reported the use of different plant parts as potential biomonitors of airborne heavy metals including (1) the leaves/needles of spruce (Brunner *et al.*, 2008; Shparyk and Parpan, 2004), (2) birch (Kozlov, 2005), (3) pine (Przbysz *et al.*, 2014; Serbula *et al.*, 2013; Sawidis *et al.*, 2011), (4) oak (Madejon *et al.*, 2006), (5) olive (Madejon *et al.*, 2006), (6) the bark of oak (Aboal *et al.*, 2004), (7) pine (Patrick *et al.*, 2007; Saarela *et al.*, 2005), and (8) ash trees (Catinon *et al.*, 2009). Hence, both leaves and bark can be used to monitor heavy metals (dust-bound) due to their high affinity for accumulation (Sawidis *et al.*, 2011). Tomasevic *et al.* (2005) described that the amount of PM deposited on leaves depends on the species and is related to the different characteristics of the epidermis. Because most of these studies have been confined to developed regions around the world, there is a paucity of information from other regions, especially from India.

In this study, airborne heavy metals in dust particles that have been deposited on leaves were investigated to attain knowledge about the roadside contamination of hazardous air pollutants (HAPs) in Bilaspur. The present study seeks to quantify toxic heavy metals (including Pb, Cu, Cd, Mn, Fe, and Cr) in dust-deposited plant leaves and determine the extent of their uptake/accumulation in the leaves. Moreover, the dust-holding capacities of different plant species were also calculated to explore their possible role in dust nuisance management.

2. MATERIALS AND METHODS

2. 1 Study Area

Bilaspur city is located in central India in the state of Chhattisgarh. Its estimated population is 331030 with an area of 145.76 km^2. This region is a semi-arid, subtropical zone. A map of the study area showing the study sites is presented in Fig. 1. Dust/plant samples were collected from six different locations (S1 to S6) along the roadside (Bilaspur to Sipat). Six plant species (i.e., *Mangifera indica*, *Pongamia pinnata*, *Calotropis procera*, *Kigelia pinnata*, *Butea monosperma*, and *Alstonia scholaris*) were used for biomonitoring of dust-bound heavy metals. The first two sampling sites (S1 and S2) were located inside the premises of the National Thermal Power Corporation (NTPC), which is a coal-based thermal power plant. The coal for the power plant is transported from the mines of South Eastern Coal Field Limited (SECL). Site 3 (S3) is located near the gate of the fly ash plant of the NTPC. The other three sites (S4 to S6) were roadside locations with high traffic density (more than 3500 cars/heavy vehicles per hour). A detailed description of the selected sites is given in Table 1.

2. 2 Sampling and Sample Preparation

Plant leaf samples were collected from all of the study sites at a height of approximately 1.5 m (ambient height) in the month of January within a period of one day (January 28, 2014) to minimize temporal changes. These plants were selected because they are commonly found throughout the city of Bilaspur. Samples were collected in Ziploc plastic bags and carried to the laboratory. Special care was taken to avoid loss of fine dust particles while separating dust from the sampled leaves. Dust was removed from the plants leaves and weighed. Leaf samples were washed, and their surface areas were calculated by a graph paper method. The leaves were oven dried for 24 h at 30°C and crushed into a fine powder. The weight of each sample (both dust and leaf powder samples) was approximately 2 g. Both dust and leaf powder samples were digested and prepared according to US EPA method 3050 B in order to analyze the heavy metals via atomic absorption spectroscopy (US EPA 1996).

2. 3 Analysis of Metals

After sample preparation, the heavy metal concentrations of the samples were analyzed using flame atomic absorption spectroscopy (AA 7000, Shimadzu, Japan). The elements were measured against a 1000 $\mu g\ mL^{-1}$ multi-element AA calibration standard solution ($999 \pm 10\ \mu g\ mL^{-1}$). A calibration curve was used to determine the concentrations of the elements. Blank corrections were also made from samples containing no dust. All concentrations are reported in $\mu g\ g^{-1}$. The detection limits (DLs) of the six target metals were 0.04 $\mu g\ g^{-1}$ (Fe), 0.01 $\mu g\ g^{-1}$ (Mn), 0.08 $\mu g\ g^{-1}$ (Cr), 0.08 $\mu g\ g^{-1}$ (Pb), 0.006 $\mu g\ g^{-1}$ (Cd), and 0.009 $\mu g\ g^{-1}$ (Cu). The precision, when expressed as a relative standard deviation (RSD %), was below 5% for all of the metals.

2. 4 Dust-holding Capacity

After cleaning, the collected leaves were put on graph paper and outlined with a pencil. The leaf areas were calculated based on the graph squares. The dust-hold-

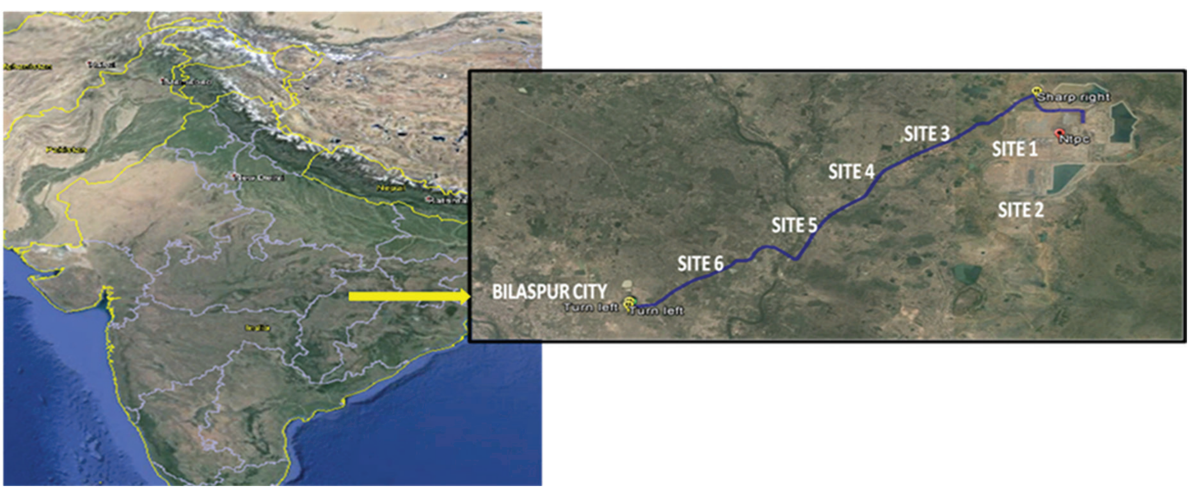

Fig. 1. Geographical map showing the sampling locations and study areas in Bilaspur (C.G.), India.

Table 1. Description of the sampling sites.

Site No.	Name of plants	GPS location	Site description	Site pictures
S1	*Mangifera indica*	N 22°07′19.2″ E 82°17′17.5″	NTPC near the coal dump area. Coal particles are deposited everywhere.	
S2	*Pongamia pinnata*	N 22°07′09.4″ E 82°17′27.9″	NTPC near the coal crushed house-II plant. Fine coal particles settled on plant parts.	
S3	*Calotropis procera*	N 22°08′11.4″ E 82°17′05″	Near ash plant gate, heavy fly ash depositions on plants.	
S4	*Kigelia pinnata*	N 22°07′44.5″ E 82°15′55.5″	Near a mandir, heavy traffic and industrial area.	
S5	*Butea monosperma*	N 22°07′13.9″ E 82°14′31.8″	Near roadside, traffic area.	
S6	*Alstonia scholaris*	N 22°06′20.5″ E 82°14′31.8″	Roadside, near rice mill, medium traffic.	

ing capacities of the sampled leaves (from different sites) were calculated by the formula W/A ($W = W_2 - W_1$)

where
W = total dust content (g)
W_2 = final weight of the paper with dust
W_1 = initial weight of the paper
A = total area of leaf (cm^2)

3. RESULTS AND DISCUSSION

3.1 Dust-holding Capacity of Different Plant Species

As shown in Table 2, the highest dust-holding capacity ($g\ cm^{-2}$) was recorded for *Calotropis procera* (0.0250). This was followed by *Alstonia scholaris* (0.0042), *Pongamia pinnata* (0.0040), *Mangifera indica* (0.0038), *Kigelia pinnata* (0.0030), and *Butea monosperma* (0.0025). Dust deposition and accumulation in different plant species can depend on a variety of factors such as the leaf shape and size, orientation, texture, presence/absence of hairs, and the length of the petioles. Higher dust deposition may be due to hairy, waxy coatings on the leaves with folded margins and rough surfaces. Lower depositions can be ascribed to the vertical position of the leaves. There was an inverse correlation ($r = -0.90$, $P > 0.01$, one-tailed) between leaf area and the dust-holding capacity. This goes against the general expectation that a higher leaf area will hold more dust. In this work, it was found that instead of the leaf area (or leaf size), the plant type (species) is more important.

3.2 Concentrations of Metals in Dust and Leaves

The concentrations of heavy metals in the deposited dust and accumulated in the leaves are given in Table 3. The distribution behaviors of the individual metals that we measured are discussed below:

Fe

Fe was found to be the dominant metal. In this study, the amount of Fe in the dust samples ranged from 1968 (at site 1) to 2103 μg g^{-1} (at site 3). Site 3 was near a fly ash dump area of the NTPC and had the highest density of heavy traffic (to transport the fly ash produced by the NTPC). The lowest Fe concentration was found at site 1; this is likely due to the fact that it had the lowest level of traffic. However, in the case of the leaf samples, site 5 (*Butea monosperma*) showed the highest accumulation of Fe (1669 μg g^{-1}). Site 5 was situated near the roadside and had a high traffic load. At site 2, *Pongamia pinnata* had the lowest accumulation of Fe (447 μg g^{-1}).

Mn

The amount of Mn in the dust samples ranged from 166 (at site 1) to 547 μg g^{-1} (at site 3). Due to the heavy traffic at site 3, *Calotropis procera* showed a high concentration of Mn. There is a considerable difference in the Mn content between the different sampling sites. However, in the case of accumulation on the leaves, *Butea monosperma* recorded the highest concentration (159 μg g^{-1}) of Mn; this may be due to its larger surface. The lowest concentration of Mn was observed at site 6 (*Alstonia scholaris*).

Cr

The Cr concentration in the dust ranged from 6.60 (at site 1) to 30.6 μg g^{-1} (at site 3). At site 3, a large amount of fly ash dust was deposited on plant leaves near the fly ash plant of the NTPC. Moreover, this site is also affected by a heavy traffic load. The amount of Cr in the dust can be affected by the chrome plating of some motor vehicle parts (Alshayep and Seaward, 2001). The lowest level of Cr was found at site 1, where very little traffic activity was observed. Among the leaves, the highest concentration of Cr (27.9 μg g^{-1})

Table 2. Dust-holding capacity (DHC) calculated for different plant species at different sites (Dust weight for all of the samples was 2 g).

Site	Plant species	Leaf area (cm^2)	DHC (g cm^{-2})
S1	*Mangifera indica*	520	0.0038
S2	*Pongamia pinnata*	502	0.0040
S3	*Calotropis procera*	80	0.0250
S4	*Kigelia pinnata*	660	0.0030
S5	*Butea monosperma*	794	0.0025
S6	*Alstonia scholaris*	476	0.0042

Table 3.

(a) Concentrations of metals deposited on leaf surfaces in the dust (μg g^{-1}).

S. No.	Metal	S1 *Mangifera indicia*	S2 *Pongamia pinnata*	S3 *Calotropis procera*	S4 *Kigelia pinnata*	S5 *Butea monosperma*	S6 *Alstonia scholaris*
1	Fe	1968	2014	2103	2100	2086	2099
2	Mn	166	183	547	473	455	529
3	Cr	6.60	7.80	30.6	16.5	14.4	15.0
4	Pb	9.18	27.9	24.8	16.5	25.7	23.6
5	Cd	0.06	0.63	0.09	1.31	0.38	0.54
6	Cu	12.5	8.11	17.1	27.7	22.9	21.1

(b) Concentrations of metals accumulated in the leaves (μg g^{-1}).

S. No.	Metal	S1 *Mangifera indica*	S2 *Pongamia pinnata*	S3 *Calotropis procera*	S4 *Kigelia pinnata*	S5 *Butea monosperma*	S6 *Alstonia scholaris*
1	Fe	447	301	1080	1294	1669	716
2	Mn	158	130	143	64.9	159	45.8
3	Cr	27.9	2.10	7.20	3.60	3.30	1.80
4	Pb	1.22	11.9	11.6	12.6	11.3	11.9
5	Cd	13.6	14.5	13.7	13.0	12.3	11.8
6	Cu	27.5	8.89	5.63	9.33	11.2	3.50

was observed at site 1 (*Mangifera indica*). This was situated in a coal dump area. The lowest Cr concentration was found at site 6 (*Alstonia scholaris*).

Pb

The Pb concentration in the dust ranged from 9.18 (at site 1) to 27.9 μg g^{-1} (at site 2). Concentrations of Pb in the deposited dust samples were reported to be mainly caused by the traffic activity due to the utilization of leaded gasoline (Day *et al*., 1975; Yongming *et al*., 2006). The other sampling sites showed a range of concentrations, indicating the variable levels of vehicular activities.

In the leaves, the highest Pb value (12.6 μg g^{-1}) was found at site 4 (*Kigelia pinnata*). This site was near a road junction with heavy traffic. Hence, the large amount of leaded petrol emissions on the leaves of *Kigelia pinnata* at this location likely contributed to the highest accumulation of Pb. Site 1 (*Mangifera indica*) had the lowest Pb accumulation (1.22 μg g^{-1}) because it was located at a coal dump area with negligible traffic.

Cd

In the case of the dust samples, the concentration of Cd ranged from 0.09 (at site 3) to 1.31 μg g^{-1} (at site 4). Interestingly, it was below the detection limit (0.006 μg g^{-1}) at site 1. The concentration of Cd in the leaves showed the highest value at site 2 in *Pongamia pinnata* (14.5 μg g^{-1}). If we compare the concentration values of Cd in the dust against those in the leaves, its ratio ranged from 10 (in leaves of *Kigelia pinnata* at site 4) to more than 100 (in leaves of *Calotropis procera* at site 3). Hence, it appears that Cd was the most accumulated toxic metal in plant leaves (from dust and/or other sources, mostly airborne) at all of the sites. *Calotropis procera* showed the highest accumulation potential for foliar uptake of Cd.

Cu

The concentration of copper in the dust ranged between 8.11 (at site 2) to 27.7 μg g^{-1} (at site 4). The source of copper in street dust can be attributed to the abrasion of metallic parts of vehicles caused by engine wear, brushing, and bearing metals (Al-khashman and Shawabkeh, 2006; Al-Khashman, 2004). Interestingly, at site 4, there was a speed bump; copper can be released from brake linings as vehicles stop and start. At site 1, *Mangifera indica* showed the highest concentration of Cu (27.5 μg g^{-1}) among the leaves. The minimum value of Cu in the leaves was 3.50 μg g^{-1} at site 6 (*Alstonia scholaris*). The relatively high concentration of Cu in these leaves showed the high accumulation potential of *Mangifera indica*.

3.3 Overall Distribution Pattern of Target Heavy Metals

In order to obtain an overall picture of the distributions and relative contributions of the different metals, the mean concentration values of each metal were computed from the different sites (Table 4). As shown in Table 4, Fe constituted the major fraction among all of the target metals, showing a concentration of 2062 ± 56.8 μg g^{-1}. This was followed by Mn (392 ± 172 μg g^{-1}), Pb (21.3 ± 7.06 μg g^{-1}), Cu (18.2 ± 7.16 μg g^{-1}), Cr (15.2 ± 8.58 μg g^{-1}), and Cd (0.48 ± 0.50 μg g^{-1}). However, in the leaves, the order changed to Fe > Mn > Cd > Cu > Pb > Cr. Moreover, all of the metals showed significantly positive correlations between the dust concentrations and the leaf concentrations, suggesting that a certain fraction of the metals are transferred from the dust to the leaves (Table 5). Hence, if we assume that all of these toxic metals are due to the airborne dust that is released from vehicular and industrial sources, the accumulation of toxic metals should depend on the location relative to the emission sources. Additionally, the leaf concentrations varied across different plants at different sites in the order of *Butea monosperma* > *Calotropis procera* > *Kigelia pinnata* > *Alstonia scholaris* > *Mangifera indica* > *Pongamia pinnata*. This may reflect variations in both plant characteristics and source-related activities.

3.4 Factors Affecting the Distribution Behavior of Heavy Metals

A correlation analysis was performed between the

Table 4. Statistical parameters for the distribution of target heavy metals in the dust deposited on the leaves and in the leaves from the selected study areas.

Metal		Fe	Mn	Cr	Pb	Cd	Cu
All site (Leaf dust)	Mean ± SD	2062 ± 56.8	392 ± 172	15.2 ± 8.58	21.3 ± 7.06	0.48 ± 0.50	18.2 ± 7.16
	Min-Max	1968-2103	166-547	6.60-30.6	9.18-27.86	0-1.31	8.11-27.7
	(Median)	(2093)	(464)	(14.7)	(24.2)	(0.46)	(19.1)
All site (Leaves)	Mean ± SD	918 ± 524	117 ± 49.1	7.65 ± 10.1	10.1 ± 4.37	13.2 ± 0.99	11.0 ± 8.54
	Min-Max	301-1669	45.8-159	1.80-27.9	1.22-12.6	11.8-14.5	3.50-27.5
	(Median)	(898)	(137)	(3.45)	(11.8)	(13.3)	(9.11)

different metals (Table 6). According to the correlation analysis, there were significant positive correlations between pairs of Mn/Fe ($r=0.97$, $P<0.01$), Cr/Mn ($r=0.80$, $P<0.05$), Cu/Fe ($r=0.76$, $P<0.05$), Cu/Mn ($r=0.76$, $P<0.05$), and Fe/Cr ($r=0.74$, $P<0.05$). This observation indicates that dust contamination by metals may originate from common anthropogenic sources.

Table 5. Correlation of metals between leaves and dust across different sites (plants).

Plants	Correlation (r)	Metals
Mangifera indica	0.96**	Fe, Mn, Cr, Pb, Cd, Cu
Pongamia pinnata	0.95**	Fe, Mn, Cr, Pb, Cd, Cu
Calotropis procera	0.99**	Fe, Mn, Cr, Pb, Cd, Cu
Kigelia pinnata	0.98**	Fe, Mn, Cr, Pb, Cd, Cu
Butea monosperma	0.99**	Fe, Mn, Cr, Pb, Cd, Cu
Alstonia scholaris	0.98**	Fe, Mn, Cr, Pb, Cd, Cu

**Correlation is significant at 0.01 level (one-tailed)

Table 6. Results of correlation analysis: Factors affecting the distribution of heavy metals.

(a) Dust on leaves

	Fe	Mn	Cr	Pb	Cd	Cu
Fe	1					
Mn	0.97**	1				
Cr	0.74*	0.80*	1			
Pb	0.49	0.35	0.33	1		
Cd	0.45	0.26	−0.04	0.15	1	
Cu	0.76*	0.76*	0.37	−0.07	0.56	1

(b) Leaves

	Fe	Mn	Cr	Pb	Cd	Cu
Fe	1					
Mn	0.02	1				
Cr	−0.37	0.48	1			
Pb	0.42	−0.48	−0.98**	1		
Cd	−0.53	0.49	0.27	−0.21	1	
Cu	−0.28	0.54	0.92**	−0.94**	0.28	1

*Correlation is significant at 0.05 level (one-tailed)
**Correlation is significant at 0.01 level (one-tailed)

Mn and Fe are the most dominant metals in the deposited dust. It was noted that, other than the NTPC, there is no heavy (or major) industrial development near the sampling sites; thus, the target heavy metals in the deposited dust appear to be derived mainly from automobiles.

In the leaves, Pb/Cr ($r=-0.98$, $P<0.01$) and Pb/Cu ($r=-0.94$, $P<0.01$) consistently showed inverse correlations. Such a strong inverse correlation between Pb and Cr suggests their competing potential for uptake/accumulation. In addition, Cr/Cu showed a strong positive correlation ($r=0.92$, $P<0.01$).

Statistical analysis revealed that some metals are strongly accumulated by specific plants. For instance, in the case of Fe, *Mangifera indica*, *Calotropis procera*, and *Kigelia pinnata* showed a strong correlation between the dust and leaf concentrations. Hence, *Mangifera indica*, *Calotropis procera*, and *Kigelia pinnata* are shown to be efficient accumulators of Fe. Similarly, in the case of Mn, *Mangifera indica*, *Pongamia pinnata*, *Kigelia pinnata*, and *Alstonia scholaris* showed significant accumulation. For Cr, *Pongamia pinnata*, *Calotropis procera*, *Kigelia pinnata*, and *Butea monosperma* were found to be good accumulators. For Pb, *Mangifera indica*, *Pongamia pinnata*, *Calotropis procera*, and *Butea monosperma* were good accumulators. For Cd, *Mangifera indica*, *Calotropis procera*, and *Kigelia pinnata* showed good performance in terms of metal accumulation. For Cu, *Mangifera indica*, *Kigelia pinnata*, and *Butea monosperma* showed a superior correlation coefficient. Moreover, it is important to note that Mn, Cr, and Pb showed good correlations ($P<0.01$ level), suggesting that these metals are heavily accumulated in these plants (Table 7).

3. 5 Comparison between Different Studies

The concentrations of heavy metals reported in previous studies (deposited dust samples and/or leaf accumulation) are compared with this study in Table 8. The coal-based thermal plant and roadside traffic activities should be the main sources of heavy metal pollution at the study site. In Calcutta, India, the concentrations of

Table 7. Correlation of metals between leaves and dust in selected plants of all the sites.

Metal	Correlation (r)	Plants considered (showed the best correlation results)
Fe	0.96	*Mangifera indica*, *Calotropis procera*, *Kigelia pinnata*
Mn	0.98**	*Mangifera indica*, *Pongamia pinnata*, *Kigelia pinnata*, *Alstonia scholaris*
Cr	0.995**	*Pongamia pinnata*, *Calotropis procera*, *Kigelia pinnata*, *Butea monosperma*
Pb	0.99**	*Mangifera indica*, *Pongamia pinnata*, *Calotropis procera*, *Butea monosperma*
Cd	0.97	*Mangifera indica*, *Calotropis procera*, *Kigelia pinnata*
Cu	0.98	*Mangifera indica*, *Kigelia pinnata*, *Butea monosperma*

*Correlation is significant at 0.05 level (one-tailed)
**Correlation is significant at 0.01 level (one-tailed)

Table 8. Comparison with previous studies or standards (all concentrations are in μg g^{-1}).

(a) Dust deposited on leaves

City	Fe	Mn	Cr	Pb	Cd	Cu	Reference
Calcutta	2.18 (%) 21800	820	97	1030	1.78	269	Chatterjee and Banerjee (1999)
Hangzhou	45.6	526.7	73.3	150.9	2.62	63.7	Lu *et al.* (2008)
Huizhou	–	–	364.7	410.4	8.6	603.3	Qiu *et al.* (2009)
Bilaspur	2061	392	15.2	21.3	0.48	18.2	Present Study

(b) Metal accumulated in leaves

City	Fe	Mn	Cr	Pb	Cd	Cu	Reference
Calcutta	0.38 (%) 3800	141	16.6	214	0.47	40	Chatterjee and Banerjee (1999)
West bank	349	71.8	2.63	1.40	0.14	14.5	Swaileh *et al.* (2004)
Huelva city	233.1	35.45	0.43	2.85	–	24.15	Oliva and Mingorance (2006)
Bilaspur	918	117	7.65	10.1	13.2	11	Present Study

metals (Fe, Mn, and Pb) were the highest in both deposited dust and leaf samples, where the main sources were heavy traffic activities, industrial emissions (such as a Pb factory), and the use of agricultural chemicals. In the deposited dust, the mean Fe concentration of the present study (2061 μg g^{-1}) was considerably lower than that of Calcutta (21800 μg g^{-1}); the Fe concentrations in this study were roughly one order of magnitude lower than those in Calcutta. Alternatively, the mean concentration of Mn (329 μg g^{-1}) in the deposited dust was nearly 2.5 times lower than that of Calcutta (820 μg g^{-1}) and two times lower than that of Hangzhou (526.7 μg g^{-1}). In the case of Hangzhou, the major sources of heavy metals were suggested to be coal combustion, traffic emissions, and industrial activity.

The mean levels of Cr (15.2 μg g^{-1}) in the deposited dust of Bilaspur were much lower than those of other cities; these values were six times lower than Calcutta (97 μg g^{-1}), five times lower than Hangzhou (73.3 μg g^{-1}), and 24 times lower than Huizhou (364 μg g^{-1}). The highest concentrations of Cd and Pb were reported at Huizhaou; these were caused by the combined effects of many strong sources such as industrial, commercial, and traffic activities. The lowest value of Fe was reported in Calcutta (2.18 μg g^{-1}) which was nearly three orders of magnitude lower than the concentration reported in our study. Alternatively, the mean concentration of Mn (329 μg g^{-1}) in our deposited dust was nearly 2.5 times lower than Calcutta (820 μg g^{-1}) and two times lower than Hangzhou (526.7 μg g^{-1}). The mean level of Cr (15.2 μg g^{-1}) in the deposited dust of Bilaspur was almost six times lower than Calcutta (97 μg g^{-1}), five times lower than Hangzhou (73.3 μg g^{-1}), and 24 times lower than Huizhou (364 μg g^{-1}). Similarly, the Pb (21.3 μg g^{-1}), Cd (0.48 μg g^{-1}), and Cu (18.2 μg g^{-1}) concentrations in our study were present at lower levels than were reported in the literature.

In the leaf samples, the concentration of Fe in our study was 918 μg g^{-1}, which was 41 times lower than Calcutta (3800 μg g^{-1}). However, it was 2.5 and four times higher than the West Bank (349 μg g^{-1}) and the city of Huelva (233.1 μg g^{-1}), respectively. The accumulation of Mn (117 μg g^{-1}) in Bilaspur (the present study) is nearly 1.5 times higher than that of the West Bank (71.8 μg g^{-1}), which has high traffic activity. In contrast, it was 3.4 times higher than that of Huelva (35.45 μg g^{-1}), which is subject to industrial emissions. Finally, it was 1.2 times lower than that of Calcutta (141 μg g^{-1}), which is affected mostly by traffic and industrial sources.

In the leaves, the concentration of Fe in this study was 918 μg g^{-1}, which was more than three orders of magnitude higher than Calcutta (0.38 μg g^{-1}), 2.5 times higher than the West Bank (349 μg g^{-1}), and four times higher than the city of Huelva (233.1 μg g^{-1}). The accumulation of Mn (117 μg g^{-1}) in Bilaspur (the present study) was nearly 1.5 times higher than the West Bank (71.8 μg g^{-1}), 3.4 times higher than Huelva (35.45 μg g^{-1}), and approximately 1.2 times lower than Calcutta (141 μg g^{-1}). Similar results were found for Cr (7.65 μg g^{-1}) and Pb (10.1 μg g^{-1}). However, the levels of Cu (11 μg g^{-1}) in this study were generally lower than previously reported results (Table 8). Cd concentrations in the leaf samples in this study were more than two orders of magnitude higher than both Calcutta (0.47 μg g^{-1}) and the West Bank (0.14 μg g^{-1}). Hence, the transfer of heavy metals from deposited dust to plant leaves appears to be governed by the combined effects of the type of plant and the type of metal.

4. CONCLUSION

In this study, six heavy metals (Fe, Mn, Cr, Pb, Cd, and Cu) were investigated in dust samples with respect to their possible transfer and uptake in plant leaves. If we compare specific metal concentrations, Fe is dominant compared to all of the other metals in both the dust and leaf samples. Cd showed the highest accumulation potential in plant leaves from the dust compared to the other metals. *Calotropis procera* showed the highest accumulation potential for Cd. The significant inverse correlation found between the leaf area and the dust-holding capacity revealed that, instead of the leaf area (or leaf size), the plant type (species) is the most important factor. Hence, the plants growing in affected areas should be investigated for their metal accumulation potential in order to use them for possible monitoring of toxic species in air.

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