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Heavy Metal concentrations in Street and Leaf Deposited Dust in Anand City, India

Bhattacharya Tanushree [1], Chakraborty S.[2], Fadadu Bhumika [1] and Bhattacharya Piyal [3]
[1]Dept. of Environmental Science and Technology, Institute of Science and Technology for advanced Studies and Research,
[2]Dept. of Biosciences and Environmental Sciences, N.V.Patel College of Pure and Applied Sciences,
Vallabh Vidyanagar, Anand – 388120, Gujarat, INDIA
[3]Dept. of Environmental Sciences, University of Kalyani, Kalyani, Nadia, West Bengal, INDIA

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Abstract

Heavy metal concentrations in roadside dusts are increasingly becoming of health concern. Street dust samples and leaf deposited dust samples were collected from all the sites and analysed for Cu, Ni, Pb and Zn from five major roadways in Anand city, also known as milk capital of India .Metal concentrations in such dusts from five major roadways indicated that roadside dust contained elevated levels of heavy metals. Cu concentration ranged from 52-130 mg/kg; Ni from 57-71 mg/kg, Pb from 66- 105 mg/kg and Zn from 44- 93 mg/kg in street dust samples. Dust deposited on the leaves of four roadside plants common to the region viz. Alstonia scholaris, Ficus bengalensis, Morus alba, and Polyalthia longifolia, also had elevated levels of the same metals indicating a common anthropogenic source. The most likely source for the contamination of theses dusts was vehicle emissions supplemented by local industrial activities. PCA and correlation coefficient analysis also supported this fact

Keywords: Street dust, heavy metals, leaf deposited dust, Anand city, PCA.

Introduction

Heavy metals at trace levels are ubiquitous in natural water, air, dust, soil and sediment[1]. Many of these heavy metals 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[2]. Consequently, in recent years, public and scientific attention has increasingly focused on heavy metal contamination and its effect on humans and other living creatures[3]. In the urban environment, such pollutants are commonly found in street dust which can be potentially harmful to roadside vegetation, wildlife, and neighboring human settlements[4]. Street dust is typically derived from anthropogenic sources via the interaction of natural solid, liquid or gaseous materials with pollutant sources[5] such as water transported material from surrounding soils and slopes, dry and wet atmospheric deposition, biological inputs, road surface wear, road paint degradation, vehicle wear (tyres, body, brake lining, etc.) and vehicular fluid and particulate emissions and emissions and discharge from metal processing industries[6].

Metals accumulate in street dust and in the leaves of roadside plants through atmospheric deposition involving sedimentation, impaction and interception. Although there have been a considerable number of studies of heavy metals concentrations in roadside soil and plants, the vast majority of theses have been carried out in developed countries with long histories of industrialization and extensive use of leaded gasoline and very few studies have been carried out in developing countries such as India where data on the concentration and distribution of metals in street dust is scarce. Therefore, this study examines heavy metal levels in street dust and dust deposited on plants along a major traffic highway in Anand city, Gujarat, India.

Material and Methods

The study area was located in Anand city, popularly known as the milk capital of India, situated in the state of Gujarat which is well known for developing industrial and commercial sectors, educational hubs. Commensurate with an increase in industrial activity and population Gujarat has also seen a dramatic increase in vehicular activity. Anand is located in the eastern part of Gujarat; 22°35 N-72°55 E with an urban population exceeding 130685 inhabitants (Census 2001). While the predominant wind direction is from the northwest, the wind velocities are usually low. In winter wind speed is 1.9-9.2 km hr^{-1} in a northwest direction and in summer 3.5-10.7 km hr^{-1} in south west direction.

The region has a semi arid to arid climate which fosters the transfer of huge amount of suspended particulate matter into the lower levels of the atmosphere in the dry seasons. The vehicular pollution is also growing at an alarming rate with the associated manifestation of increases efflux of toxic heavy metals like Pb, Ni, Zn and Cu into the environment. The city's industrial belt (Gujarat Industrial Development Corporation) consisting of chemical, dyes, paints, and engineering equipment manufacturing industries also contributes to heavy metal pollution.

Sampling: Five major roadways in Anand city were selected for dust collection (figure 1). Roadways were selected on the basis of traffic load, population density and anthropogenic activities. A detailed description of the selected sites is given in table 1. Description of the traffic load and site related information was collected from the road transport office, Anand and urban planning department Anand. Dust samples were collected from twenty individual sampling points from both sides of each roadway under calm weather conditions in November 2008. Samples were simply collected from pavement edges using plastic dust pans and brushes and between each sampling, brushes were cleaned thoroughly. Sites with obvious pollution sources such as industries, gasoline stations and parking lots or recently soiled or oil stained samples, were avoided. Any irrelevant material like cigarette ends, fallen dry leaf, pebbles or other debris were not collected as a part of the sample. Samples were sealed in plastic bags and carried to the laboratory after collection. Special care was taken to avoid loss of fine dust particles due to disturbances while carrying the samples[7]. The twenty samples from each roadway were analysed separately and the average values of each site were represented in the text. Background soil samples were collected from sites away from heavily trafficked areas and analysed for the metals.

Table-1
Description of sampling sites

Site No.	Name of site	No. of vehicle/hr	Site description
S1	Anand-Vidyanagar Road (n=20)	4276	Heavy traffic, Commercial, residential area, high population with some educational institutes
S2	Station Road (n=20)	3101	High traffic, and commercial area
S3	Anand-Lambhvel Road) (n=20)	2425	Medium traffic, semi urban area with religious places, recreational areas, agricultural fields and residential areas
S4	Anand-Karamsad road (n=20)	1931	Industrial area (chemical, dyes, paints, chemical and engineering equipment manufacturing industries)
S5	Anand-Vadtal Road (n=20)	1907	Rural area, mainly agricultural fields, farm houses, few educational institutes and few colonies

Leaves of four different plant species growing along the roads viz. *Alstonia scholaris, Ficus bengalensis, Morus alba* and *Polyalthia longifolia* were picked at a height of 2 m. These four species were selected because they were commonly found throughout Anand city. The leaves were brushed separately for the collection of particulate deposits, using the methods adopted by Shams and Beg[8]. The surface area of the leaves collected from each site was calculated by graph paper method. Samples were collected in triplicate.

Sample Analysis: Soil pH was measured in 1:5 dust: distilled water (w/v) suspension.. Electrical conductivity (EC) was measured in a 1:2 dust: distilled water (w/v) suspension of street dust. Organic carbon content was determined by the Walkley Black method modified by Jackson[9]. 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. Dust samples were 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^oC in Teflon bombs[10]. 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 AAS (Perkin Elmeyer model) for Ni, Cu, Zn, Pb using an air-acetylene gas mixture using hollow cathode lamp. Statistical analysis viz. correlation and principal component analysis was done is SPSS software version 11.

Results and discussion

Street Dust: The pH of the street dust samples were relatively similar in all five sites, ranging from 7.96 (S_5) to 8.1(S_4) (table 2). The electrical conductivity was relatively high in all the sites and the percentage of organic carbon ranged from 2.0% (S_2) to 3.4% (S_5). The elevated level of organic carbon at S_5 reflects the greater distribution of vegetation and grasses at S_5 which was taken along the Anand –Vadtal road which passes by rural areas containing significant vegetation showed while the station road sample (S_2) had the least vegetation and consequently the smallest amount of organic carbon. The mean metal concentration in street dust sample varied with sampling location. While the relative distributions of individual metals concentrations varied with sampling location, overall the mean concentration of metals followed the order $S_1>S_2>S_3>S_4>S_5$, which was expected from the numbers of vehicles. The background concentration of metals in soil collected from sites away from the heavily trafficked sites are 35.61 mg/kg for Cu, 51 mg/kg for Pb, 42.13 mg/kg for Ni and 31.07 mg/kg for Zn.

Table-2
The arithmetic mean, standard deviation of metal concentrations in street dust samples (n=20) (all values are expressed as microgram metal per gram street dust)

Variables	S_1	S_2	S_3	S_4	S_5
pH	8.1±0.1	8.10 ± 0.1	8.0 ± 0.2	8.1 ± 0.2	8.0± 0.3
EC (mScm^{-1})	0.20±0.07	0.30±0.04	0.16 ± 0.02	0.21±0.05	0.21 ± 0.06
OC (%)	2.6±0.4	2.0 ± 0.3	3.1 ± 0.4	2.3 ± 0.8	3.4 ± 0.3
Cu (mg/kg)	130± 4	92 ±11	88 ±16	56 ± 12	52 ±13
Pb (mg/kg)	105±3	97 ±15	91 ±21	79 ± 15	66 ±15
Ni (mg/kg)	71±9	69 ±12	68 ±16	63 ± 9	57 ± 7
Zn (mg/kg)	93±12	72 ± 5	69 ±10	55 ± 10	44 ±7

EC = electrical conductivity, OC = organic carbon

Irrespective of the sampling site, Pb and Cu concentration in dust samples were consistently high. The high Pb concentration was interpreted as resulting from the continued use of leaded gasoline on the outskirts of the city were some petrol stations still sell unleaded petrol. In addition, Pb is also used in manufacture of pesticides, fertilizers, paints, dyes and batteries[11]. Therefore industrial sources can also contribute to Pb levels from vehicle emission. The residence time of Pb in the atmosphere is also very high being 150 years[8]. So that even after phasing out of leaded gasoline from year 2000 it is likely to persist in the environment for a considerable period years/months. Pb concentrations in the street dust of Anand city ranged from 65.9-105.4 mg kg^{-1} were to a large extent significantly lower than other reported studies (table 3). The maximum acceptable limit of Pb normal soil is 100 mg kg-1[12, 13] which was only exceeded at S_1.

Copper concentrations in street dust samples in the present study ranged from 51.60 to 129.98mg kg^{-1} which was similar to other levels reported (table 3). As with Pb, only S_1 exceeded the maximum acceptable limits[13], of 100 mg kg^{-1} for Cu and this site also had the highest traffic density. The main source of copper in street dust may arise from the corrosion of metallic vehicles parts, wear and tear of the car engine, bearing metals and also spillage of lubricants.

Table-3
Comparison of heavy metals in street dust with Anand city data, Ranges or the mean* level of the heavy metal concentrations (mg kg^{-1}) in street dust samples in various sites of countries and cities in chronological order

City/Country	Pb	Cu	Zn	Ni
Anand city (Gujarat,India)	65.91-105.39	51.66-129.98	43.64-92.79	56.90-75.81
Islamabad (Pakistan)[20]	104*	52*	116*	23*
Madurai (India)[21]	140-250	-	-	-
Amman (Jordan)[7]	236*	177*	358*	88*
Surat (Gujarat,India)[22]	-	137.5	139	79
Kayseri (Turkey)[23]	28–312	12–144	33–733	16–217
Dhaka (Bangladesh)[11]	205*	304*	169*	54*
Delhi (India)[24]	130-200	50-1350	120-380	100-989
Calcutta (India)[25]	536	44	159	42

The concentration of nickel (Ni) in the street dusts of Anand city ranged from 56.9-75.81 mg kg^{-1} in agreement with worldwide reported studies (table 3). In all samples the Ni concentration exceeded the maximum acceptable limit of 50 mg kg^{-1} Ni for a normal soil. The main source of nickel in street dust is the combustion of diesel fuel[14]. Unexpectedly, nickel content was relatively higher, compared to other metals, in the rural area (S_5) suggesting that the extensive use of diesel in three wheelers, tractors and water pumps used for irrigation in rural areas was contributing the elevated level in dust.

Zinc concentrations ranged from 43.6 to 92.8 mg kg^{-1} in street dust which was much lower compared to previous reports (table 3). The maximum acceptable limit for Zn in normal soil is 300 mg kg^{-1} Since no smelting industry existed within the study area, which is a major industrial sources of street dust pollution, zinc used as a vulcanization agent in tyres, was the most likely source, resulting from attrition of motor vehicle tire rubber exacerbated by poor road surfaces. Specially, in a semi-arid environment the abrasion of car tyres increases. Lubricating oils also contain zinc as additives such as zinc dithiophosphaates[16].

Metal Deposition on Plant Samples: Metal concentration in the particulate matter deposited on the leaves of different plant species growing along the roadside of the study area are presented in table 4. Metal concentrations in the leaf deposited dust followed the same trend as road dust with metal concentration being highest on leaf deposited dust at S_1 and lowest at S_5. The observance of the same trend indicated that dust and leaf deposited dust were most likely from the exact same source of metal contamination. Particulate deposits per unit area of leaf where found to be greatest on the leaves of *Ficus bengalensis* followed by *Morus alba, Polyalthia longifolia* and *Alstonia scholaris. Ficus Bengalensis* bears almost horizontally oriented leaves, while the leaves of the other species studied are somewhat more vertically oriented. The leaf size of *F.bengalenis* is also much larger so, it captures the largest amount of dust. Moreover, *F.bengalenis* and *Morus alba* have sunken stomata and hairy leaf surfaces which assists in trapping condensation of water vapors during transpiration which maintains moisture on leaf surface and increases the capturing of the dust by these plants. *Polyalthia longifolia* leaf also has high stomatal frequency but it does not have a hairy surface, so capturing capacity is relatively less[17]. *Alstonia scholaris* leaves also have the least leaf surface area and the upper side is glossy so it has least dust deposited per unit area. The metal concentrations reported here are in accord with other globally reported studies [18, 19].

Table-4
Concentration of metals (mg kg^{-1}DW) on leaf deposited dusts

Sites	Vegetation type	Metal deposits on leaf surface			
		Cu	Pb	Ni	Zn
S1	*Morus alba*	103±3	89±1	67± 2	83± 2
S2	*Polyalthia longifolia*	81 ± 2	87±1	51± 3	59± 2
S3	*Ficus bengalensis*	71 ± 2	76±3	45± 2	49± 1
S4	*Alstonia scholaris*	42 ± 2	62±1	56±2.	42 ±2
S5	*Ficus bengalensis*	38 ± 4	44±2	50± 1	34± 1

Statistical Analysis of Data Correlation Coefficient Analysis: Pearson's correlation coefficients for metals in street dust in Anand city is shown in Table 5. Inter-element relationship showed significant correlations between the five studied elements indicating that road-side dust contamination by metals originated from a common anthropogenic source. As the study area has an industrial belt, we may assume that the heavy metal analyzed in street dust was derived almost exclusively from automobiles and local industries.

Table-5
Correlation matrix between metals in the street dust samples, each cell shows the Pearson correlation coefficient

	Cu	Pb	Ni	Zn
Cu	1			
Pb	0.943*	1		
Ni	0.968**	0.989**	1	
Zn	0.991**	0.972**	0.993**	1

*signifies 0.05 level, ** signifies 0.01 level

The metal content in leaf deposits and the street dust showed a good correlation, except for nickel (figure 2) Indicating that Cu, Cd, Pb and Zn in leaf deposits originated from the same source as in the street dust. Positive correlations also indicated that as the street dust metal concentration increased the meal concentration in leaf deposits also increased except for Ni.

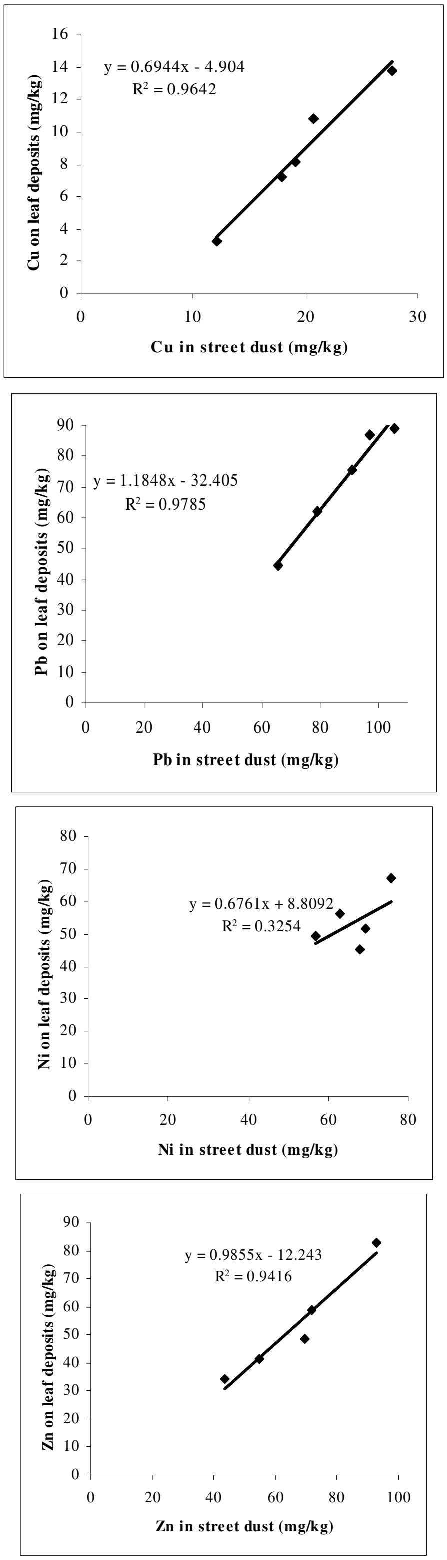

Figure-2
Relationships between the concentrations of heavy metals in soil and concentration of metals in the dust deposited on leaves

Principle Component Analysis (PCA): PCA was conducted to examine the effect of various factors on the concentration of metals in street dust and thereby determine the potential sources of pollution. The rotation of principle component was done using the Varymax method with Kaiser Normalization. The factor loading obtained following PCA is shown in the component plot (figure 3).

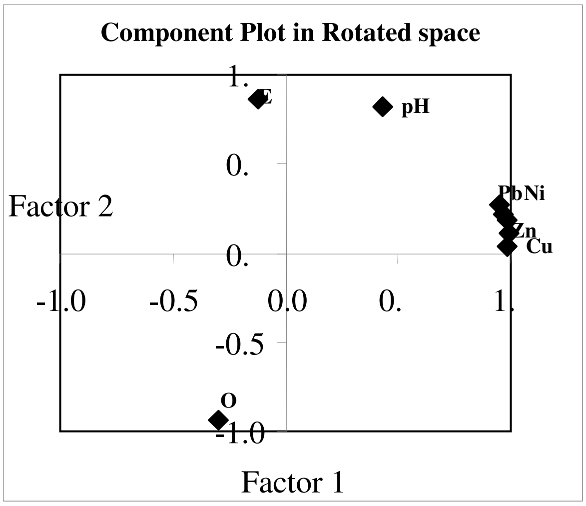

Figure-3
Rotated component matrix for data of Anand street dusts (PCA loadings>0.80 were considered)

Two principle components where abstracted from the variable dataset, that explained approximately 94% of the total variance of the data. Factor-1 comprised 74% of the variance and factor-2 only 24%. All the metals were clumped together in the factor with high loadings (>0.9) suggesting the common source for them which is vehicular emission and industrial emission. Factor 1 showed that the dust pH may influence metal content and its mobility, but organic carbon and conductivity are not related to metal concentrations. However factor-2 showed that pH and conductivity were more related to organic carbon content than metal concentration.

Statistical analysis of the data shows that the metal pollutants in street dust of Anand originate mostly from the same source which may be vehicular and industrial emissions.

Conclusion

While street dust and dust deposited on leaf surface in Anand city contained elevated levels of heavy metals, metal contamination was much lower compared to other studies of metal in dusts from around the world. Among the five different sites studied, the extent of metal pollution in street dust was influenced more by heavy traffic than by industrial activities, since the lowest level of metals in street dusts occurred at sites with low vehicular traffic and population density (S_4 and S_5).

Among all the metals considered, Cu and Pb concentrations were most elevated. The results of the statistical analysis also suggested that vehicular traffic and industrial emission represents the most important metal contamination source in the Anand city. Plants capture dust to a considerable extent as suggested by the particulate deposits per unit area of leaf. *Ficus bengalensis* exhibited maximum dust collection efficiency among all the tree species because of its leaf morphology.

The present study indicates that further investigation is needed to assess the spatial distribution of metals in street dust and background soils.

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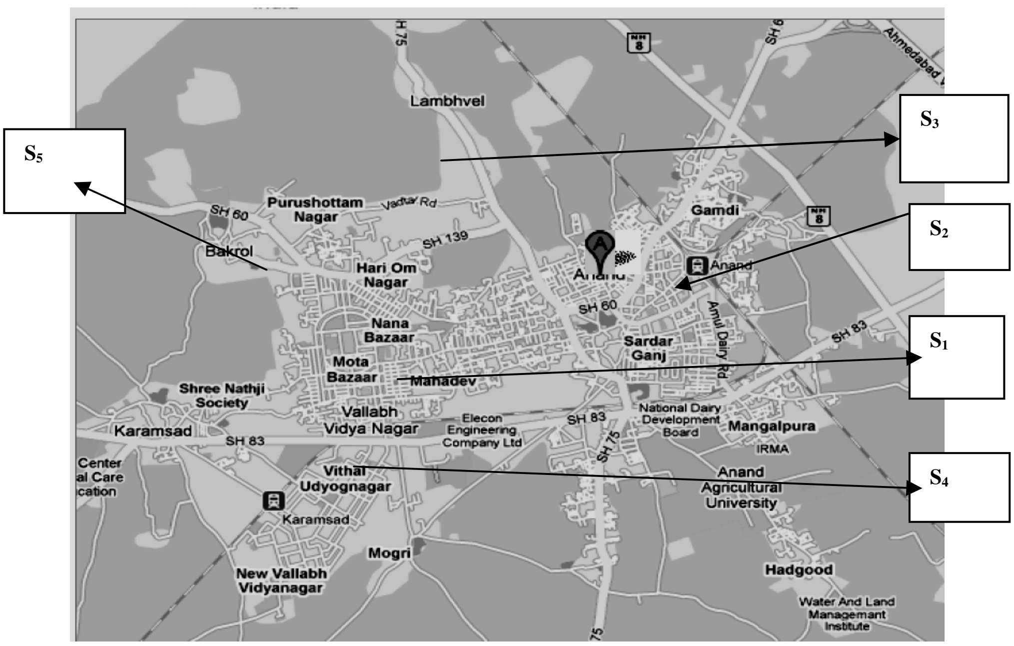

Figure-1
Locations of sampling sites within Anand city