Dispersion Gradient of Free Fall Dust and Heavy Metal Elements Concentration in Dust along a Main Road

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Summary: Gradient of mass flux of free fall-fall dust was measured at distances 50, 100 and 200 m away from grand trunk road at four different locations. Metal elements concentrations of free fall dust and other soil samples were also determined. Average monthly free-fall dust values were found to be decreased as the distance increased. Monthly free-fall dust ranged between 24 – 96 tons/km^2/month at 50 m, 15 – 90 tons/km^2/ month at 100 m and 9 – 27 tons/km^2/ month at 200 m distance, which implied that maximum reduction in the range of 62 – 71 % had occurred at 200 m distance. Free-fall dust values were found to be alarmingly higher than permissible limit (5 tons/km^2/ month). Dispersion gradient of metal elements, measured at three distances (50, 100 and 200 m), showed decrease as distance increased. Higher values of mass flux of free fall particles and metal elements loadings near road indicated that vehicle exhaust emissions could be the major source of particles and heavy metals. Samples of soil upto 3 inches depth from different locations were analyzed to see accumulation of heavy metals. It was found that accumulation of these metals decrease with depth.

Introduction

There is an increasing recognition that adverse health effects due to the exposure to airborne particulate matter (PM) could be more significant than due to the exposure to many other airborne pollutants. Throughout the last thirty years, there have been a number of scientific studies indicating that particulate air pollution can have an acute effect on human health. Several recent studies suggest an association between automobiles exhaust and increased respiratory systems and/ or diminished pulmonary function. Numerous epidemiologic studies have shown statistically significant associations of ambient PM levels with a variety of human health such as mortality, hospital admissions, respiratory illness and physiologic changes in pulmonary function. It has been reported that the combustion particles that have a high content of soluble metals, can cause lung injury and even death in affected animals [1]. Subsequent studies of ultrafine particles have shown that the chemical constituents of ultrafines substantially modulate their toxicity. Lester found that diesel exhaust particulate matter (DPM) exacerbates the allergic response to inhaled antigens [1].

Trace elements in the atmosphere are mostly associated with particulates, although there may be some in the gaseous phase. There are diverse sources of particulate matter, natural and anthropogenic. Anthropogenic sources include mining operations, smelting and other industrial activities, combustion of wood, oil and coal, waste incineration, agricultural operations, tyre and engine wear and cremation. Enhanced inputs may occur near sources, but these are diluted by wind action which disperses trace elements long distances, thereby adding to background concentrations.

For exposure assessment, it is necessary to quantify particle emission levels, and also to determine particle behavior after emissions, as they are transported away from the emission source. Exposure to air pollution from traffic was assessed in different ways: distance of home and school from motorway, traffic density of motorway and indoor air pollution in schools. The validity of distance from the motorway as a measure of exposure to air pollution from traffic was investigated by conducting outdoor measurements of PM_{10}, $PM_{2.5}$, black smoke, benzene and NO_2 at different distances from the motorway [2]. There have been some studies conducted on the behavior of gaseous emissions at an increasing distance from the road, as well as on behavior of mass concentration of particles in terms of PM_{10} or $PM_{2.5}$, but very limited studies on particle number concentration. A study focused on the nitrogen oxides and ozone close to the motorway was conducted by Kuhler *et al.*, [3]. They modeled the

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dispersion of NO, NO_2, CO and O_3 concentrations. Concentration gradient of the same gases was measured at three distances (50, 100 and 600 m) from a motorway. They observed an increase in the concentration of these gases with maximum at a distance of 50 m, and then gradual decrease from 50 to 600 m. Roorda-Knape *et al.*, also measured the gradient of PM_{10}, $PM_{2.5}$, black smoke and benzene at distances 50, 100, 150 and 300m from a major motorway at two different locations [2]. They found that black smoke concentrations decreased as distance increased from the road, whereas there was no significant decrease in the content of PM_{10}, $PM_{2.5}$ and benzene. Janssen *et al.*, compared the mass concentration and elemental composition of particles sampled near major roads and at background locations [4]. They reported that PM_{10}, $PM_{2.5}$ and black smoke concentrations were on average 1.3 and 2.6 times higher near the road as compared with the background levels respectively. Another study by Clairborn et al., evaluated the PM_{10} emission rates from paved and unpaved roads out to distances of 80 m using the tracer gas SF_6 [5]. They observed an evident decreasing trend of SF_6 level with increasing distance. Horizontal and vertical distribution profiles of fine particulate matter were investigated by Morawska *et al.*, [6]. They selected two sites within the city area, one at a distance of 210 m from a freeway, and the other at a distance of 73 m located at the junction of several major transport routes. There was no significant decrease in particle number concentration with distance from the road for the first site, but there was a decrease in concentration at the second site. This difference was thought to be due to the variation in the topography of two sites. Nakai *et al.*, measured indoors and outdoors concentrations of NO_2 in three zones at different distances from two busy roads [7]. Mean outdoor concentrations of NO_2 were always appeared higher in the zone closest to the road. Nitta et al., in a study measured suspended particulate matter at three distances at one of the locations [8]. Concentrations at the roadsides were higher than away from the roadside. Janssen *et al.*, carried out outdoor measurements of PM_{10}, $PM_{2.5}$, benzene and black smoke at four different distances from the roadside in two of six city districts near motorway in the West of Netherlands [4]. They found that the outdoor concentrations of black smoke and NO_2 declined with distance from the roadside. In Switzerland, Monn *et al.*, measured vertical and horizontal PM_{10} concentrations profiles orthogonal to a road in the city of Zurich and showed that mean ground level concentrations of PM_{10} directly at the roadside were 30μg/ m^3 [9].

Hitchins *et al.*, investigated the distribution of PM with distance from a road [10]. Measurements were made at distances of 15, 55, 95, 135, 215, 295 and 375m from the road at site one and at distances of 15, 40, 80, 120, 160, 200, 240 and 280m from the road at site two respectively. Their findings showed that there was a clear decrease in fine and ultrafine particle number concentration as distance from the road increased, which indicated that the particles were related to vehicle exhaust emissions. Tripathi et al., studied the atmospheric deposition of trace metals like Pb, Cd, Cu and Zn at Deonar, Bombay [11]. They found that the levels of particulate matter were minimum at Deonar in Bombay. The deposition rate of sub micron particles from turbulent gas streams was investigated by Hahn *et al.*, [12]. They found that the highest concentrations of air borne particles were usually close to the source. Hussain *et al.*, measured suspended particulate matter (SPM) in Lahore, Pakistan [13]. They collected SPM samples from various urban and suburban sites in the city by taking the dust deposited on the filters of air conditioners. Soil samples were also collected from areas close to the SPM sampling sites. They employed only X-ray diffraction technique to characterize the samples. X-ray diffraction results showed that quartz, calcite and albite were the main minerals of the atmospheric dust. Results revealed higher contents of quartz in samples from city center than the suburban sites.

Trace elements in the atmosphere are associated with dust particles, which are comprised mainly of soil, and fly ash particles and a few trace elements may be in the gaseous phase. Although dust particles are commonly more than 5μm in diameter, there is always the possibility that some dust will consist of windblown clay particles that are by definition less that 2 μm in diameter. There are several field studies in which soils were analyzed for various trace elements. For example, Bradford *et al.*, analyzed soil and plant samples taken from several locations around a 1500MW power station in Nevada and found decrease in concentration for Ca, Mg, Sr, Ba and B in saturation extracts of surface soils and similar effects for Ca, Sr and B in plant samples [14].

Pinto stated that automobile contributions arose from exhaust emissions enriched in Pb; from rust as Fe; tire wear particles enriched in Zn; brake linings enriched in Cr, Ba, and Mn; and cement particles derived from roadways by abrasion. The principal components of emissions from diesel and gasoline fueled vehicles are organic carbon (OC) and elemental carbon (EC). It is reported that most of the PM emitted by motor vehicles is in the $PM_{2.5}$ size range [15].

Results and Discussion

Traffic Density

Table-1 represents the 8 hours average (day time) traffic density at different stations. Traffic included trucks, buses, wagons, cars and motorbikes. Traffic appeared to be highest at Shahdra followed by Muredkey and Kala Shah Kaku. Since Shahdra is main exit to the metropolitan Lahore, a greater traffic density was observed at the site.

Table-1: Summary of traffic density at different stations on GT-Road.

Vehicles	8 Hours (Day Time) Density		
	Shahdra	Kala Shah Kaku	Muredkey
Trucks	14880	14400	17280
Buses	14400	7200	5280
Wagons	12960	13440	13440
Cars	22560	17760	21120
Motor bikes	80116	840	17760
Total	144916	53640	74880

Monthly Dust-Fall

Gradient of monthly dust-fall at distances 50, 100 and 200 m from GT-road at four different locations is given in Table-2. The graphical presentation of the data is shown in Fig. 1.

Table-2: Rate of monthly dust-fall horizontally away from GT-road.

Distance	50 m	100m	200m
	Rate of dust-fall (tons/km^2/month)		
Muredkey	96	90	27
Kala Shah Kaku	33	21	22
Ferozwala	24	15	9
Shahdra	51	45	18

Monthly dust-fall was to be almost 19 times at Murdkey (96 tons/km^2/month), 7 times at Kala Shah Kaku (33 tons/km^2/month), 5 times at Ferozwala (24 tons/km^2/month) and 10 times at Shahdra (51 tons/km^2/month) than the permissible level (5tons/km^2/month). At Muredkey, greater rate of free fall dust was observed close to the road i.e. within 50 m distance horizontally away from road. This rate of deposition decreased as the distance from the road increases i.e. within 100 m and 200 m distances away from the road. The rate of free fall dust declined 6 % at 100 m distance and a highly significant decrease *i.e.*, 71 % was apparent at 200 m distance. The same decreasing trend of rate of deposition of free fall dust particles with increasing distance from the road was observed at Ferozwala and Shahdra. The rate of decrease of free fall dust at Ferozwala was 37 % at 100m and 62 % at 200 m distance relative to 50m distance from the road. At Shahdra, 12 % decrease in the rate of free fall dust was observed at 100m distance and 65 % at 200 m distance with respect to 50 m distance from the road. The results observed at

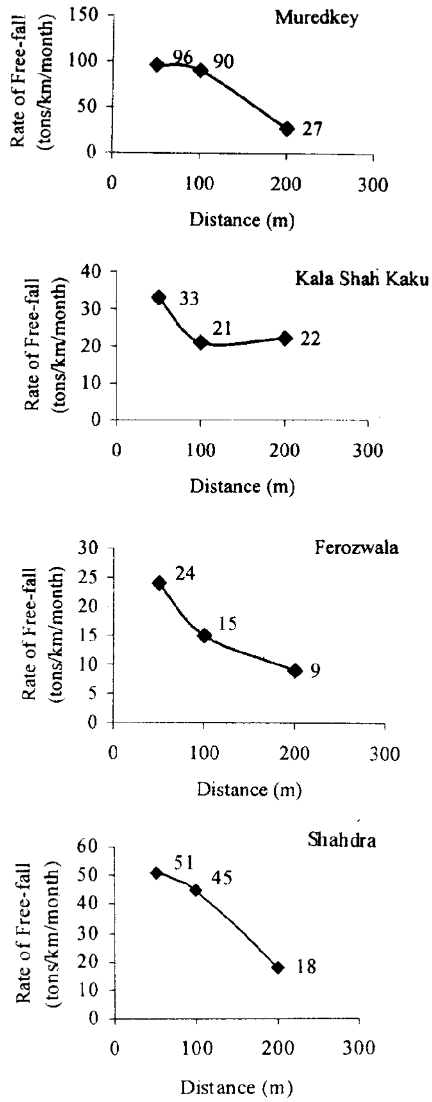

Fig. 1: Monthly dust fall at different locations.

Muredkey, Ferozwala and Shahdra were in good agreement with those of Hitchins *et al.*, [10] and Janssen *et al.*, [4].

At Kala Shah Kaku, the rate of deposition of free-fall dust was higher close to the road i.e. within 50 m distance. However, the deposition rate at 100 and 200 m distance is not significant.

The results clearly showed that the rate of deposition of free fall dust was higher close to the road, which indicated that these particles are related to vehicle exhaust emissions.

Heavy Metals Concentrations in Free Fall Dust

Free fall dust was analyzed for determining the contents of heavy metal elements such as Cd, Cu, Ni, Pb and Zn. Analysis results are given in Table-3 and the graphical presentation of the data is shown in Fig. 2.

A decrease in heavy metal concentrations with increasing distance from the road was significantly apparent at Muredkey, Ferozwala and Shahdra, whereas at Kala Shah Kaku heavy metals concentrations were not significant with increasing distance from the road. Relatively higher concentrations of Cd, Cu, Pb and Zn were observed at Shahdra close to the road, which may be attributed to traffic density at the respective site.

Table-3: Heavy metals concentrations (mg/ kg) in free fall dust samples horizontally away from GT-Road.

Distance		50m	100m	200m
		Concentration (mg/kg)		
Murdkey	Cd	0.6	0.5	0.3
	Cu	8.0	5.0	1.0
	Ni	4.0	2.0	0.6
	Pb	14	10	8.0
	Zn	24	22	20
Kala Shah Kaku	Cd	0.6	0.6	-
	Cu	2.0	2.0	-
	Ni	ND	ND	-
	Pb	7.0	6.0	-
	Zn	12	10	-
Ferozwala	Cd	0.6	-	0.5
	Cu	2.0	-	1.0
	Ni	1.0	-	ND
	Pb	14	-	7.0
	Zn	18	-	10
Shahdra	Cd	0.8	0.6	-
	Cu	10	4.0	-
	Ni	1.0	ND	-
	Pb	16	10	-
	Zn	24	16	-

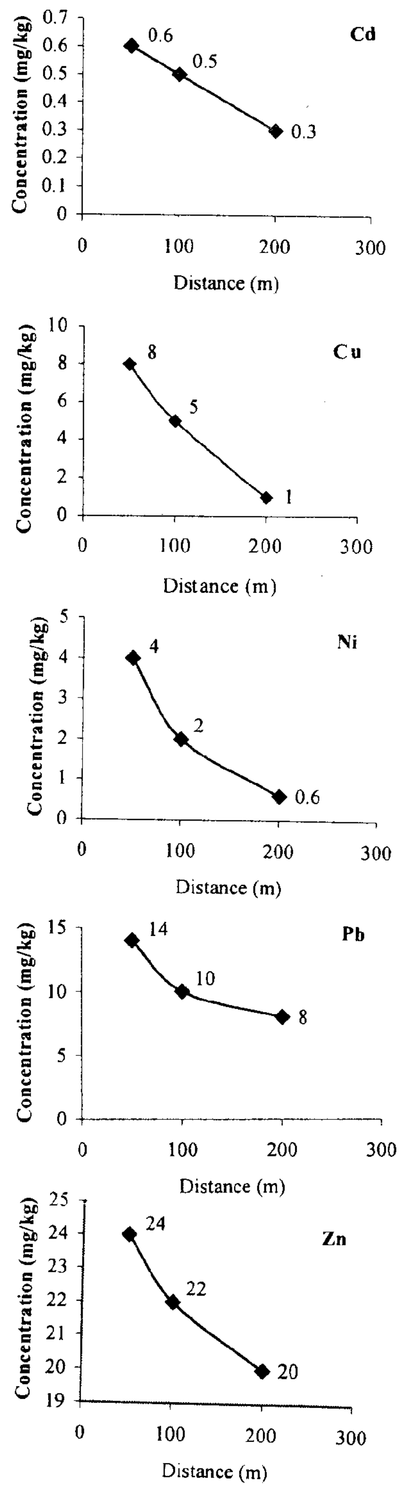

Fig. 2 Concentrations of different heavy metals in the free fall dust at Muredkey.

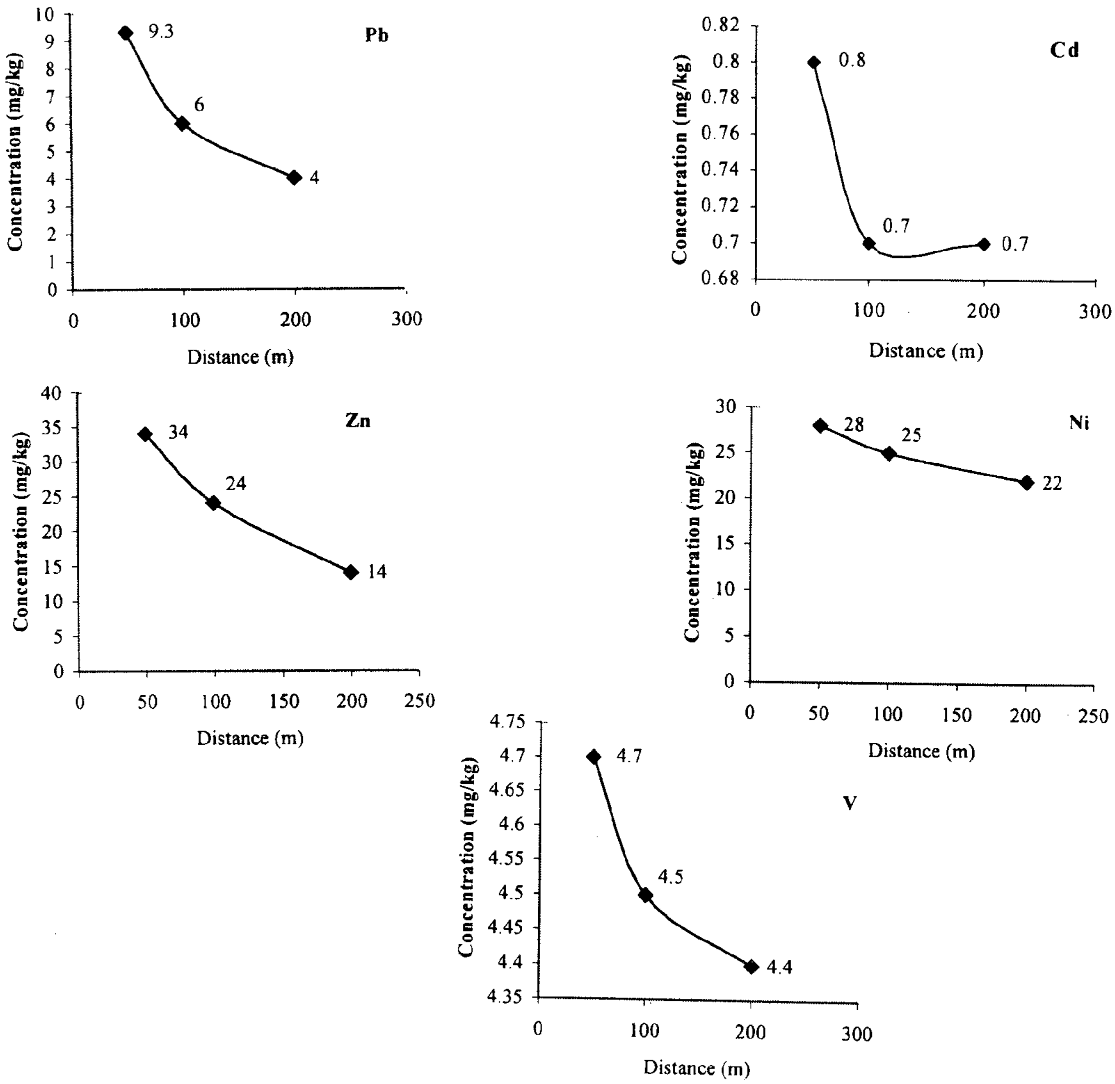

Fig-3(a) Heavy metal element contents in roadside dust at Muredkey.

Heavy Metals Concentration in Roadside Dust

Table-4 represents heavy metals concentration in roadside dust at distances 50 m, 100 m and 200 m across the GT-Road. Graphical presentation for different heavy metal concentrations at different locations is shown in Fig. 3.

At Murdkey, concentrations of Pb, Zn and Ni decreased with increasing distance away from GT-road. Whereas Cd and V show almost same concentrations at all distances. At Kala Shah Kaku, Pb, Cd, Ni and Zn concentrations followed the decreasing trend with increasing distance away from the road, while the concentration of V was same at all distances. Concentrations of all the metals in the road side dust of Ferozwala decreased with increase in distance away from GT-road. At Shahdra, concentrations of Zn, Ni and Pb followed the same decreasing trend while Cd and V concentrations did not follow the above trend.

Maximum concentration of Pb in roadside dust was found at Shahdra (14.0mg/ kg) near to the road. This may be due to greater traffic density at the respective sites. Relatively greater concentration of Cd in roadside dust was found at Ferozwala (0.96mg/ kg) and Kala Shah Kaku (0.95mg/ kg). This may be

Table-4: Concentration of Heavy Metals (mg/ kg) in roadside dust samples.

Distance		50m	100m	200m
		Concentration (mg/kg)		
Muredkey	Pb	9.3	6.0	4.0
	Cd	0.8	0.7	0.7
	Zn	34	24	14
	Ni	28	25	22
	V	4.7	4.5	4.4
Kala Shah Kaku	Pb	10	ND	6.0
	Cd	0.9	0.9	0.7
	Zn	15	14	11
	Ni	41	ND	35
	V	5.1	5.0	4.9
Ferozwala	Pb	8.0	ND	6.0
	Cd	1.0	0.8	0.7
	Zn	16	15	12
	Ni	37	27	22
	V	5.4	5.2	4.8
Shahdra	Pb	14	ND	4.0
	Cd	0.7	0.7	0.7
	Zn	30	13	12
	Ni	35	31	28
	V	5.4	5.5	5.0

due to the presence of zinc – cadmium smelting industries in the Kala Shah Kaku industrial estates. Concentration of Zn in roadside dust was found to be greater at Muredkey (33.6mg/ kg). Relatively greater concentration of Ni in roadside dust was observed at Kala Shah Kaku (40.7mg/ kg) close to the road. This again may be due to the presence of industrial estate there. Most of these industries used oil and coal for combustion purpose, which are the primary sources of emission of Ni.

Heavy Metals Concentration in Soil Samples

Heavy metal elements concentrations were observed in 1-, 2- and 3–inches deep soil of different sampling locations close to the road (200 m away). Table-5 represents the data on heavy metal concentrations in deep soil samples at different locations.

Same concentration of Cd were observed in all the three layers of soil i.e, 1-, 2- and 3- inches deep at Muredkey, whereas both at Kala Shah Kaku and Shahdra, greater concentration of Cd was found in the upper 1–inch soil followed by 2- inch and 3–inch soil layers. This showed that some seepage of Cd has occurred deep in the soil. At Kala Shah Kaku, greater concentration of Ni was observed in the upper 1-inch soil layer followed by 2- inch and 3- inch soil layer, while both at Muredkey and Shahdra, Ni concentration was found only in the upper 1–inch layer of soil. Similarly, concentration of Pb was observed only in the upper 1-inch soil layer at

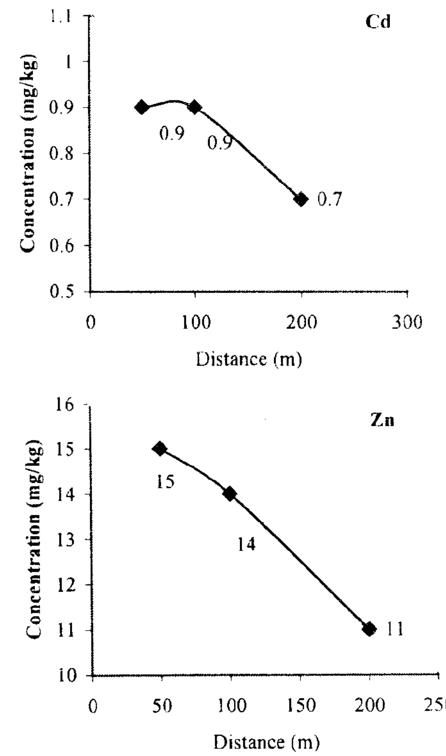

Fig-3(b) Heavy metal element contents in roadside dust at Kala Shah Kaku.

Table-5: Heavy metals concentrations (mg/kg) in (1 – 3 inches) deep soil samples.

Soil depth		1-inch	2-inch	3-inch
		Concentration (mg/kg)		
Muredkey	Cd	0.92	0.92	0.92
	Ni	44.8	ND	ND
	Pb	4.00	ND	ND
	V	4.40	4.10	4.10
	Zn	7.10	6.84	3.94
Kala Shah Kaku	Cd	0.94	0.76	0.72
	Ni	20.5	18.4	16.2
	Pb	6.00	4.00	ND
	V	5.12	4.66	4.64
	Zn	11.3	5.52	4.72
Shahdra	Cd	0.88	0.68	ND
	Ni	21.1	ND	ND
	Pb	10.0	ND	ND
	V	5.80	6.00	5.76
	Zn	16.5	10.2	13.1

Murdkey and Shahdra, whereas at Kala Shah Kaku greater concentration of Pb was observed in 1-inch layer followed by 2-inch layer of soil. Almost same concentration of V was found in all 1-, 2- and 3-inch deep soil samples at Shahdra, whereas at Murdkey and Kala Shah Kaku greater concentration of V was observed in the upper 1-inch soil layer followed by 2-

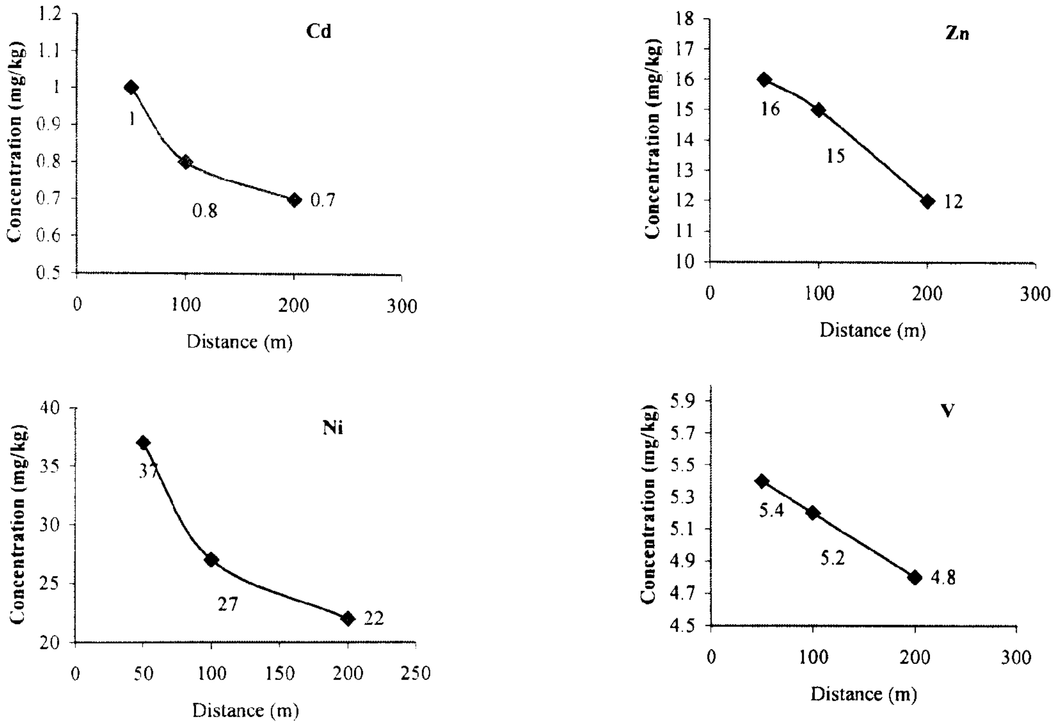

Fig-3(c) Heavy metal element contents in roadside dust at Ferozwala.

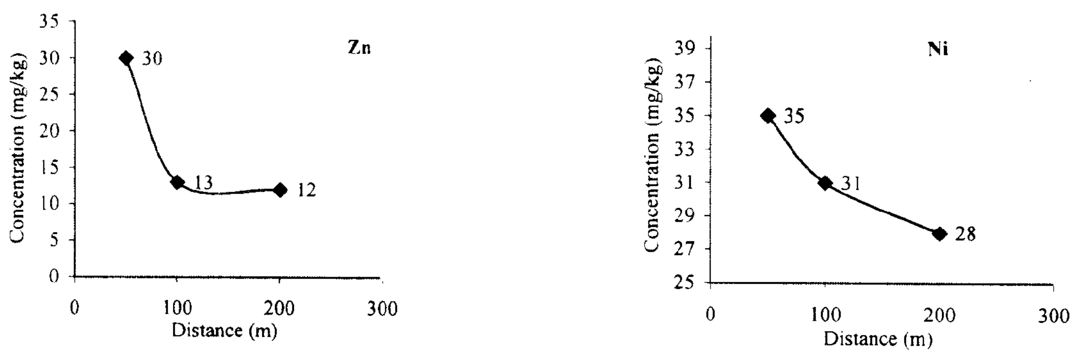

Fig-3(d) Heavy metal element contents in roadside dust at Shahdra.

inch soil layer. Greater concentration of Zn was found in the upper 1-inch soil layer at all the sites followed by 2-inch and 3-inch soil layers. The results indicated that the upper 1-inch layer of soil is much more contaminated with metals.

Experimental

There are several methods for measuring deposition, that is, the amount of an element reaching the earth's surface. The traditional deposit gauge was a funnel sitting in a bottle, thereby measuring the total wet and dry deposition. Impactors are used especially to collect several sizes of particles. Another approach uses a sticky surface, which retains particles falling on it. An inverted Frisbee has been suggested as a collector of atmospheric particulates [16]. The concentration of trace elements in air can be carried out by filtering larger volumes of air using a high volume sampling technique, which gives a result as a weight of element in a given volume of air. Although this is related to the deposition in some way it cannot be used to calculate the amount of deposition [17].

This study was carried out along a grand trunk road (GT-road) that extends from Lahore to Rawalpindi. A portion of the GT-road stretching from Shahdra to Muredkey, covering a distance of about 21 km, was selected to determine monthly dust fall and metal contents in the dust at four different locations i.e., Muredkey, Kala Shah Kaku, Ferozwala and Shahdra. Free-fall dust particles deposition was determined at distance 50 m, 100 m, and 200 m away from the road. Roadside dust samples were taken from 10 different sites approximately each at 2 km interval on the GT-road. Soil samples upto 3 inches depth from three sites were taken to see the vertical distribution of heavy metals. The experimental set up used for the measurement of dry deposition of free fall dust particles was consisted of a plastic bucket. Bucket base was wetted with the de-ionized water to facilitate the particles capture. These free fall samples were collected for the period of 2 weeks. Roadside dust was wiped into polythene bags, labeled and stored. Deep soil samples were collected with a simple device consisting of a hollow pipe with a sharp edge.

The plastic buckets containing free fall dust were washed with de-ionized water and filtered through Whattman 42 filters. These filters were dried at 120 °C and weighed before and after filtration. The weight of the residue gave the free fall deposition of dust particles per unit area. Roadside dust samples were dried at 120 °C for 24 hours to remove the moisture. Accurately weighed samples were taken in platinum crucibles and digested with concentrated sulphuric acid. These were then placed in muffle furnance at 1000°C for 90 minutes. Finally, the samples were treated with aqua regia and 10 % hydrochloric acid, filtered and made solutions in 1 % nitric acid.

Conclusions

Following conclusions were drawn from the study:

- Rate of monthly dust-fall decreased with increasing distance across the GT-Road.
- Heavy metals concentrations in free fall dust and roadside dust were found to be significantly higher close to the road. Higher concentrations of heavy metals particularly Pb and Zn could be attributed to exhaust emissions of vehicles.
- Analysis results of soil showed higher contents of metal elements in the upper one inch soil layer.

From the findings of the study it is clear that human exposure to atmospheric particles is significantly greater closer to the road (i.e within 100m distance). On this basis it is reasonable to assume that the personnel living and working in close proximity to a busy road will likely be exposed to higher levels of atmospheric particles. It is inferred that primary source of these airborne particles is the motor vehicle emissions. Therefore, it is likely that a more viable social and economic solution may be found through the improvement of tailpipe emissions.

Regarding the effect on human health of exposure to airborne particles, future research examining the relative health risks of higher levels of exposure to air borne particles would be well targeted. Construction of building, homes and schools should be well away from the road.

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