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Integrated assessment of heavy metals pollution along motorway M-2

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Abstract

The study was carried out to assess the soil contamination induced by traffic in the vicinity of a Motorway (M-2) through an intensive field study. The soil samples collected from 397 quadrats of 50 study sites were analyzed for total lead, cadmium, nickel, chromium and zinc. The results showed that the heavy metals (Zn, Pb, Ni, Cd and Cr) concentration with the exception of iron, decreased with the increase in distance from the road, i.e. from the border zone to the verge zone. All the elements that measured were found to be at high levels in samples. The mean values of Pb, Zn, Ni, Cd, Cr were 0.5, 81.40, 14.19, 0.46 and 14.61 µg g $^{-1}$, respectively. The above data analysis provides a benchmark of heavy metal pollution levels in road verges.

Keywords: Heavy metals, Motorway (M-2), Soil pollution

Introduction

Automobile emission causes remarkable metal contamination of the neighboring roadside ecosystem. Not only lead but also cadmium, copper and zinc are associated with the mobile sources; since they are included in petrol, engines, tires, lubricant oils and galvanized parts of the vehicles (Falahi-Ardakani, 1984). The influence of the traffic load on heavy metal accumulation in topsoils and vegetation and variability with distance is well documented (Ward *et al.,* 1977; Rodriguez and Rodriguez, 1982; Scalon, 1991).

Like other countries, a major part of roads in Pakistan passes through countryside and the surrounding habitats also exert their influence on the roadside soils. In the rural areas, roads usually pass through heavily fertilized crop fields. There is a possibility of transport of materials (including nutrients) from the neighboring fields to the road verges. Cale and Hobbs (1991), while studying the effect of soil nutrient status on degradation of roadside vegetation in Western Australia, found that vegetation on the road verges in that area was severely affected by nutrient input from adjacent agricultural lands. Latif *et al*. (2008) studied the heavy metal contamination of different water sources, soil and vegetables in Rawalpindi area.

Soil adjacent to the road surface typically contains the highest concentration of heavy metals.Among heavy metals, lead and cadmium are not essential elements for plants and are generally of low availability in soils (Fredeen *et al*., 2002). Kibria *et al*. (2007) investigated the cadmium and lead uptake grown in three different textured soils and found Cd and Pb concentration in plant parts were highly correlated with Cd and Pb application, respectively. Similarly, the essentiality of chromium for plants has not been demonstrated (Guthrie, 1982), whereas the importance of nickel has been documented by a few scientists (Dixon *et al*., 1975; Brown *et al.*, 1987). Zinc and iron are essential nutrients for plants (Fredeen *et al*., 2002). The heavy metals of most concern are cadmium and zinc, as these show great mobility in the soil environment (Wilson and Bell, 1996).

The aims of the present work were to assess the effect of distance and the location (related to traffic flow) and influence of the geographical patterns on the metal contents in road soils, and to corroborate the source of pollution using factor analysis.

Materials and Methods

The present study investigated the emission of metals (Pb, Fe, Zn, Cr, Ni and Cd) from the highway and the border. The whole study area was divided into three major divisions based on geographical patterns and results are presented region-wise to find out whether the geographical patterns influence or cause fluctuations in the edaphic factors studied (Table 1).

In terms of underlying geology, it can be said that the M-2 passes through the following three major geological regions (Akhtar *et al*., 2000).

The Islamabad-Kallar Kahar region: It is typical arid landscape with denuded and broken terrain characterized by undulations and irregularities. This consists almost entirely of alluvial deposits and rocks. Kalar Kahar has a landscape fascinated with striking contrasts. This landscape is controlled largely by rock formations exposed in the area. The "loess" forms spacious flat interfluves, whereas the

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loess is closely dissected by denritic growth of nullahs, therefore, the area becomes badland in appearance.

The Kalar Kahar-Lilla region: This consists mainly of rocksThe ramparts of the salt range stretching from east to west in the south separate Potohar from the Punjab plains. The real importance of salt range lies in the large deposits of pure salt and large seems of coal.

The Lilla-Lahore region: This consists almost entirely of alluvial deposits. It is a fertile land of river Indus and its five eastern territories-Jhelum, Chenab, Ravi, Sutlaj and Bias.

A site normally comprised of two zones:

Zone 1: Border Zone

The road shoulder adjacent to the edge of road sealing and about 1-3 m away.

Zone 2: Verge Zone

The fence zone which was demarcated from the adjacent private or state owned land by fence about 6 m away.

Collection of soil samples

From each 1 x 2 m quadrat, a soil sample was taken with a stainless steel trowel. The soil was generally taken from 0-15 cm of the topsoil because much of the nutrient uptake by plants is from this depth (Allen, 1989) and brought to laboratory for analysis. The soil samples collected from 397 quadrats of 50 study sites were analyzed for pH, organic matter, total nitrogen, calcium, potassium, phosphorus, magnesium, total lead, cadmium, nickel, chromium and zinc. Soil sample were air-dried and passed through 2 mm sieve.

Soil analysis

Soil organic matter was determined gravimetrically by using the loss on ignition method (Allen, 1989).

Heavy metals

Aqua- regia extraction method (Cottenie *et al.,* 1982) was used for digestion and determination of iron, zinc, lead, nickel, cadmium and chromium in the soil samples. The heavy metals were estimated by atomic absorption spectrophotometer (Shimadzu AA-667).

Table 1: Median and mean values with standard errors for the edaphic variables calculated for three regions of the study area

(No. of soil samples in Region I =120, Region II=80 and in Region III= 197)

Edaphic Factor	Region I		Region II		Region III	
	Median	Mean ± S.E	Median	Mean ± S.E	Median	Mean ± S.E
pH	7.60	7.53±0.01	7.55	7.58±0.02	7.60	7.58±0.01
Organic matter (%)	0.60	0.64±0.02	0.50	0.54±0.02	0.60	0.63±0.01
Total nitrogen (%)	0.07	0.08±0.002	0.05	0.05±0.002	0.07	0.08±0.002
Phosphorus ($\mu g\ g^{-1}$)	18.00	25.21±1.94	28.00	31.59±1.37	22.00	26.88±1.13
Potassium ($\mu g\ g^{-1}$)	132	129±4.73	121.50	128±8.82	135	138±4.99
Sodium ($\mu g\ g^{-1}$)	13.20	16.78±1.50	29.95	32.40±2.55	17.75	22.33±1.38
Calcium ($\mu g\ g^{-1}$)	861	104±3.98	61	64.8±2.16	69	71.2±3.31
Magnesium ($\mu g\ g^{-1}$)	140	155±8.76	75.50	108±8.66	69.00	68.90±0.99
Iron ($\mu g\ g^{-1}$)	749	731±5.82	688	695±8.48	721	718±4.81
Zinc ($\mu g\ g^{-1}$)	98.00	99.33±4.54	87.00	93.64±5.80	65.00	66.48±1.99
Lead ($\mu g\ g^{-1}$)	52.75	52.75±1.96	57.60	56.36±3.36	44.35	49.22±1.68
Nickel ($\mu g\ g^{-1}$)	13.00	12.43±0.43	14.00	16.49±1.02	15.00	14.94±0.41
Cadmium ($\mu g\ g^{-1}$)	0.09	0.48±0.04	0.09	0.51±0.06	0.09	0.42±0.03
Chromium ($\mu g\ g^{-1}$)	15.00	15.17±0.28	17.00	17.25±1.01	14.00	13.60±0.32

Results and Discussion

The nature of soil is characterized by several basic physical, chemical and biological properties. The interrelationship between these properties determines the capabilities and limitations of the soil for plant growth. Thus the soil acts as a reservoir for plant nutrients. Not all the nutrients are present in plant available form. Some are components of rock minerals or organic compounds that must be simplified before they can be utilized by the plant. If all the nutrients are present in adequate amounts, the plant should exhibit good growth and vigor (Craul, 1992). However roadside soils are affected by the geology of substrate, trampling by off road vehicles and addition of pollutants from automobiles.

In the present study of M-2 soils, it was found that most roadsides have neutral to basic pH with low amount of organic matter and total nitrogen. Soil reaction or pH is a simple and direct measure of the overall chemical condition of soils (Brady, 1996). It has been found that soil pH is correlated with the solubility of nutrient compounds and hence their availability to the plant. Similarly it commonly recognized that at pH 6.5, nutrient availability to plants is at highest and toxicity at the lowest (Harris *et al.*, 1996). The pH of soil in the study area ranges from 7-8.1 with mean value of 7.4. This pH value also favors the widest range of soil organisms and their activities (Alexander, 1980).

Organic matter is needed for the chemical well being of the plant and soil fertility status because it is the source of nearly all the nitrogen and most of the phosphorus in some soils (Craul, 1992). In the present study organic matter showed a mean value of 0.61 µg g^{-1}. Hussain (2001) described that most of Pakistani soils contain low organic matter, but addition of organic matter can markedly increase soil productivity by providing essential plant nutrients and by improving the physical properties of the soil. This moderate amount of organic matter in present study is supported by the fact that pH will be higher where organic matter is well decomposed and incorporated into the surface mineral horizon (Craul, 1992). The amount of organic matter maintained in any soil is largely dependent on the amount of nitrogen present. The ratio between the nitrogen and organic matter is, thus, also rather constant. Brady (1996) states that organic matter contents in soil cannot be increased without simultaneously increasing its nitrogen contents and vice versa.

The other macronutrients essential for plant growth, potassium, calcium and magnesium were present in adequate amount. Among them, potassium was present in slightly higher amount i.e. median value of 135 µg g^{-1} (Table 2), as most of Pakistani soils are rich in available potassium (Bajwa and Rehman, 2001). In present study, the alkaline to neutral nature of soil pH supports the moderate range. Phosphorus has been described by many botanists as a major limiting factor in the growth of plant communities (Bowen, 1981); the increased level may influence the vegetation growing in the M-2. Many roadside verges are particularly susceptible to elevations in soil nutrients because of their close proximity to agricultural areas (Muir, 1979). Same situation was also seen at few places, whereas area across the fence was being used for agriculture.

Heavy metals are chemical elements common to all types of soils, and their abundance ranks between percentage (iron only) and parts per million. The very low general level of their content in soil and plants, as well as the biological role of most of these chemical element, has led them being grouped under the generic name of 'micro elements'. When the soil has very high content of such chemical elements, the term 'heavy metal pollution' is used. Hence heavy metals are synonyms to pollution and toxicity (Hodson, 2004). The determination of heavy metals in soils was carried out for the measurement of the total element content and to assess the base line knowledge of soil components with respect to which changes in soil composition produced by vehicular pollution and agricultural inputs in the surrounding fields.

Soil contamination by heavy metals is increasing nowadays (Lin and Lin, 2005). In the present study, the heavy metals (Zn, Pb, Ni, Cd and Cr) concentration with the exception of iron, decreased with the increase in distance from the road, i.e. from the border zone to the verge zone.

Various studies have shown heavy contamination of roadside soils and vegetation with lead concentration declining steeply with distance from the road (Little, 1995) as was seen in the present study. The rate of lead deposition to the ground is very much dependent upon the presence and nature of vegetation. The rate of deposition of lead on grass is about four times greater than on bare soil (Little and Wiffen, 1978). The distribution of lead in the soil is very characteristic, with a steep decline in lead concentration with increasing distance from the road. As long as lead remains in petrol, levels of lead in soils will continue to increase and zone of heavy metal contamination will gradually widen away from the roads. Ward *et al.* (1977) calculated a sharp increase in lead concentration in the roadside soils with heavy metals. In the present study the lead concentration recorded was quite high than national environmental quality standard range i.e. 0.5 µg g^{-1} (NEQS, 1997).

Zinc is essential element for plant growth, as it serves an important role in plant structure and function (Kabata-Pendia and Pendias, 1984). It is a natural constituent of soils in terrestrial ecosystem. It usually occurs in low concentrations and does not pose a toxicity problem for plants (Paschke *et al*., 2000), but increased concentrations of zinc in soil can lead to toxic effects in plants (Chaney, 1993). Potentially toxic quantities of zinc in soil result largely from anthropogenic (soil located near roads) sources (Chaney, 1993). In Table 3, the mean value of zinc in study area was 81.40 µg g^{-1} fluctuating between 13 µg g^{-1} to 221 µg g^{-1} (lowest and highest). These values of zinc were quite high as compared to national environmental quality standard range i.e. 5 µg g^{-1} (NEQS, 1997). In recent years, zinc concentrations in some soils particularly on roadsides have gradually increased. Total zinc levels of several hundred and thousand of kilograms of zinc in soil have been reported in Federal Republic of Germany (Kiekens, 1990). However, it binds to soil organic matter and becomes available to plants, but higher availability is usually associated with low pH (Tucker *et al*., 2003).

Nickel plays an essential role in metabolic processes of higher plants (Brown *et al*., 1987). The mean value of nickel in study area was 14.19 µg g^{-1} fluctuating between 1.0 µg g^{-1} to 51.50 µg g^{-1} (lowest and highest). These values of nickel were quite high as compared to national environmental quality standard range i.e. 1 µg g^{-1} (NEQS, 1997).

Cadmium is yet not known to have any biological; function on the contrary, is said to be highly toxic to plants and animals (Alloway, 1990). Compared with the other metals cadmium is more mobile in soil, in relation to both leaching and availability to plants (Tiller *et al*., 1984). The mean value of 0.46 µg g^{-1} in the study area states a moderate input into the road verges. These values indicate quite coherence with national environmental quality standard range i.e. 0.09 µg g^{-1} (NEQS, 1997). Blake and Goulding (2002) estimated 0.45 µg g^{-1} of cadmium in soil under Broad Balk Wilderness, UK. Bell *et al.* (2003) reported that there was decrease in both shoot and root of *Pinus sylestris* in all cadmium levels tested. It has also been found that cadmium pollution without co-contamination by zinc is rare (Chaney and Oliver, 1996). Similarly Berthelsen *et al.* (1995) found that spatial pattern of cadmium level in vegetation was analogous to that of zinc.

Although the essentiality of chromium for plants has not been documented however, few studies have shown the importance of nickel in soil for plants, but nickel is more likely to be toxic than the relatively large concentration of chromium (Brooks, 1987). Mean value of chromium (14.50 µg g^{-1}) in the present study indicates a fairly high level in the study area. Among the heavy metals, chromium is commonly identified soil contaminant. It is ubiquitous environmental pollutant and is phototoxic at very low concentrations. It is preferentially retained in the roots (Sen *et al*., 1987; Gupta *et al*., 1994; Rai *et al*., 1995) that would be lethal to most plant species. Significant growth reductions were observed at chromium concentrations exceeding 2 mg L^{-1} (Zurayk *et al*., 2001). In the study area, chromium value fluctuates from 4 µg g^{-1} to 38 µg g^{-1} with mean value of 14.61 µg g^{-1}, but still this value can cause toxicity to the soil and plants because the toxic range set by national environmental quality standard was 1 µg g^{-1} (NEQS, 1997).

Table 2: Lowest, highest, median and mean values with standard error for edaphic variables calculated for all quadrats (n=397)

Edaphic Factors	Lowest	Highest	Median	Mean ± S.E	P≤0.05
pH	7.00	8.10	7.57	7.43±0.07	0.07
Organic matter (%)	0.10	1.40	0.60	0.61±0.01	0.23
Total nitrogen (%)	0.01	0.17	0.07	0.07±0.002	0.00
Phosphorus (µg g^{-1})	5.00	80.00	22.50	26.92±1.24	0.003
Potassium (µg g^{-1})	30.00	400.00	135.00	132±4.89	0.002
Sodium (µg g^{-1})	3.40	89.05	15.00	22.02±1.44	0.001
Calcium (µg g^{-1})	30.50	231.65	72.50	75.8±2.37	0.725
Magnesium (µg g^{-1})	20.50	425.00	74.50	101±5.25	0.415
Iron (µg g^{-1})	545.00	874.00	723.00	705±8.58	0.507
Zinc (µg g^{-1})	13.00	221.50	77.25	81.40±3.12	0.00
Lead (µg g^{-1})	5.35	115.15	50.87	51.09±1.79	0.00
Nickel (µg g^{-1})	1.00	51.50	14.00	14.19±0.48	0.007
Cadmium (µg g^{-1})	0.04	1.70	0.09	0.46±0.03	0.003
Chromium (µg g^{-1})	4.00	38.00	14.50	14.61±0.42	0.016

Individual edaphic factors

The results of the analysis of roadside soils for edaphic factors are presented in Table 3 with lowest, highest and mean with standard error and median value for each variable in the study area. To measure the significance of difference between different zones for each variable, an analysis of variance (ANOVA) was carried out.

Table 3: Zone wise lowest, highest and mean values for edaphic variables calculated for different regions of study area

Region	Zone		Edaphic Factors	pH	O.M.	Total N	P	K	Na	Ca	Mg	Fe	Z	Pb	Ni	Cd	Cr
					%		µg g $^{-1}$										
Region I	Zone	Border	Lowest	7.00	0.20	0.03	5.00	40.00	3.50	54.50	27.00	610.0	24.00	28.60	4.00	0.50	10.00
			Highest	7.80	1.30	0.17	67.00	265.0	69.60	231.0	365.0	812.0	222.0	114.2	21.00	1.40	25.00
			Mean	7.48	0.62	0.72	17.50	127.0	15.30	103.0	142.0	724.0	105.0	65.39	12.10	0.49	15.18
		Verge	Lowest	7.00	0.20	0.01	5.00	46.00	3.50	54.50	29.00	625.0	21.00	8.80	5.00	0.50	10.00
			Highest	7.81	1.40	0.17	80.00	278.0	69.00	231.0	425.0	854.0	188.0	69.80	22.00	1.39	26.00
			Mean	7.57	0.67	0.88	28.73	131.0	18.27	105.0	169.0	737.0	93.00	39.34	12.76	0.48	15.16
Region II	Zone	Border	Lowest	7.30	0.20	0.03	16.00	30.00	3.60	57.00	32.00	545.0	64.00	20.20	11.00	0.07	7.00
			Highest	7.90	0.90	0.10	42.00	220.0	65.20	110.0	330.0	810.0	211.0	114.5	38.00	1.70	34.00
			Mean	7.58	0.51	0.72	27.80	114.0	26.74	63.30	103.0	688.0	123.0	74.39	19.90	0.82	19.07
		Verge	Lowest	7.00	0.30	0.04	16.00	42.00	3.50	30.0	33.00	545.0	21.00	5.20	1.00	0.04	39.00
			Highest	7.90	0.10	0.14	76.00	400.0	88.70	99.0	325.0	806.0	164.0	72.60	28.00	1.10	13.50
			Mean	7.58	0.57	0.88	35.38	142.0	38.05	66.30	112.0	702.0	64.03	38.33	13.08	0.19	15.43
Region III	Zone	Border	Lowest	7.00	0.10	0.03	5.00	17.00	3.30	16.0	20.00	555.0	24.00	20.10	3.00	0.06	6.00
			Highest	8.00	1.10	0.10	51.00	250.0	71.20	103.0	115.0	809.0	168.0	115.0	53.00	1.20	25.00
			Mean	7.58	0.60	0.62	22.46	113.0	14.41	68.90	69.00	712.0	80.75	64.50	15.76	0.51	14.51
		Verge	Lowest	7.00	0.30	0.01	6.00	33.00	4.40	49.0	44.00	545.0	12.00	5.60	4.00	0.04	6.00
			Highest	8.10	1.20	0.17	78.00	360.0	89.10	104.0	125.0	875.0	104.0	79.10	25.00	1.50	26.00
			Mean	7.58	0.66	0.96	31.30	164.0	30.26	71.30	69.98	724.0	52.21	33.75	14.12	0.34	12.75

Pakistan is predominantly an agricultural country with a sub tropical semi arid continental climate. The soils of the country are alkaline and major nutrient deficiencies occur with N, P, Zn, and Fe (Rashid and Rafique, 1989). Present study illustrates more or less same patterns in road verges of newly developed Lahore-Islamabad motorway with few exceptions. The contamination of soil by heavy metals is one of the environmental problems that scientific community is facing today. Different studies have revealed that lead reduces the uptake and transport of some mineral nutrients in plants such as Ca, Mg and P (Walker *et a*l., 1977; Godbold and Kettner, 1991) and thus cause deficiencies in nutrients. Although new roads lead to development, but they result in loss of key habitats, natural flows and increased soil and water pollution.

Conclusion

The highway induces a contamination on the nearer environment by a pollutant transfer via the atmospheric fallouts. The deposition of metals, the levels of metals in surface soil decreased with increasing distances from the highway. The Cd, Cu, Pb and Zn metal contents in road soils confirmed the effect of the traffic as source of pollution. The use of factor analysis showed that motor vehicles seem to be the responsible source of pollution for Cd, Cu, Pb and Zn in road soils.

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