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Heavy Metal Content of Roadside Soils along Ring Road in Riyadh (Saudi Arabia)

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The metal content (Pb, Zn, Cu, Cr and Ni) of roadside surface and subsurface soils was determined along the Ring Road in Riyadh city. Their levels were investigated in relation to traffic loads and distance from the road edge. Results showed that enhanced levels of Pb, Zn and Cu correlated well with traffic density. The concentration of Pb and Zn decreased exponentially with distance from the road edge and dropped to a background level at about 40 and 30 m respectively. Cr correlated well with Pb indicating the same source. No evidence of Ni contamination of roadside soils was obtained. Concentrations of Pb, Zn and Cu showed enrichment in the upper surface soils, which is attributed to the low rainfall in the study area. An important source of lead is the combustion of leaded gasoline used for transportation in Saudi Arabia.

INTRODUCTION

The extensive use of automobiles is one of the most important sources of lead contamination, particularly in the roadside environment. Lead levels and distribution in roadside environments are shown by many studies to be functions of several factors such as traffic density, driving mode, distance from roadside and the direction of prevailing wind.

In Hong Kong, Ho and Ti[1] showed that both soil and grass contained elevated levels of lead which were strongly related to traffic volume. Ward[2] investigated contamination in surface soil of two sections of the London orbital (M25) motorway before and after its opening in 1986 and found lead contamination of surface soil to be increasing with the increase of traffic volume.

Wheeler and Rolfe[3] showed the distribution of lead in roadside soil to follow a double exponential function. The first exponent is associated with the large particles that deposited rapidly within about 5 m of the road, and the second with small particles that deposited more slowly within about 100 m of the road. Yassoglou *et al.*[4] evaluated lead contamination of roadside soils in Athens, Greece and found it to decrease exponentially with distance from the road edge, dropping to a background level at about 50 m.

The contamination of the roadside environments by lead has been shown by many researchers, including Ndiokwere[5] and Garcia *et al.*[6]. Chow[7] found the lead

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concentration in surface soil collected from the east side of roads was higher than that collected from the west side. This was caused by the direction of the prevailing winds. In France, Piron-Frenet *et al.*[8] studied the relationship between lead accumulation in surface roadside soil and both traffic density and meteorological parameters. These results show that wind is an important factor in dispersing lead particles if the weather is dry and if the land is flat with little vegetation. Lead pollution in roadside environment comes from combustion of gasoline that contains tetraethyl lead as an anti-knock agent. About 75% of the lead added to petrol is emitted through the exhaust and dispersed as an aerosol in the atmosphere[9]. With a lead content of 0.60 g L^{-1} of gasoline, Saudi Arabia is among the countries using the maximum content of lead in motor gasoline. Naturally, this will have a major impact on the lead level in the environment of the country, especially in urban areas.

It is also recognised that in addition to lead, other metallic pollutants such as Cu, Zn, Ni and Cr are present in elevated quantities adjacent to roads. Roadside soils have been shown by many studies to be contaminated by heavy metals. Nickel was found by Lagerwerff and Specht[10] to range from 2.4 to 7.4 $\mu g\ g^{-1}$ and Zn from 114 to 162 $\mu g\ g^{-1}$ in surface soils. They attributed Ni in soil to result from the use of nickeled gasoline and the abrasion of Ni-containing parts of vehicles. Elevated Zn levels at the roadside were attributed to lubricating oil, motor vehicle tyres and galvanisation of tanks. Ward *et al.*[11] determined Cr, Cu, Ni and Zn in soils alongside a major motorway in New Zealand. All metals were found to have enhanced levels and correlated well with traffic density, and their levels in soil profiles decreased with depth showing that aerial deposition from motor vehicles was their major source. Yassoglou *et al.*[4] evaluated airborne contamination of roadside soils with Zn and Ni in Athens. They were found to be enriched with airborne Zn which fell rapidly and exponentially with distance from the road. No evidence of Ni contamination of roadside soils was obtained. Wearing of Cr-containing asbestos brake linings in vehicles and aerosols produced from Cr catalysts used in emission-reduction systems for treating exhaust fumes may have a major impact on roadside soils[12]. Panek and Zawodny[13] determined the total content of Cr, Cu, Ni and Zn in roadside soils of the Sierra Nevada Mountains in Spain. Zinc concentration showed a decrease with increasing distance from the road, whereas other metals did not show such variation.

In Riyadh city, metal pollutants in roadside soils have never been investigated. Therefore, it is the aim of this work to find out to what extent roadside soils along the ring road were contaminated with Pb and other metals including Cu, Zn, Ni, Cr. The metal content of soils was measured as a function of both distance along and from the roads. Complementary work on the use of date palm (*Phoenix dactyligera* L.) as a biomonitor of lead and other elements in arid environments, has been published elsewhere[14].

EXPERIMENTAL

Sample collection and treatment: The Ring Road consists of southern, eastern and northern sections, which are under use, whereas the western section has yet to be constructed. Therefore, for the purpose of comparison and to highlight the effects of traffic density on the metal content of roadside soils, 24 surface (0–3 cm) and subsurface (5–10 cm) soil samples were collected from the southwest section of the proposed western Ring Road under construction, as well as 44, 56 and 38 surface and subsurface samples from Ring Road (South, East and north respectively). Samples were collected at *ca.* 500 m intervals along the roads.

How roadside soil heavy metal levels vary as a function of both increasing distance away from the road and prevailing wind direction was also studied. Thus, surface (0–3 cm) and subsurface (5–10 cm) soil samples were collected at regular intervals on the north and south sides of the Ring Road (South), and on the east and west sides of the Ring Road (East). Samples were collected at distances of 0, 0.5, 5, 1, 3, 10, 20, 25, 30, 50, 100, 200 m from the road edge.

Sample preparation: All samples collected from the field were thinly spread on polyethylene sheets and allowed to dry in air at ambient temperatures. They were then desegregated and passed through a two millimetre aperture nylon sieve. A subsample of 25 g was taken from each sample by coning and quartering, and packed in clean self-sealing plastic bags with their field numbers. All soil samples were then dried at 105°C to a constant weight and stored in clean plastic containers with distinctive laboratory numbers. The organic content of the soil samples was determined gravimetrically by the loss in weight of the sample after ignition at 430°C.

Sample digestion: Due to its reliability, simplicity, flexibility and wide use by many researchers, aqua regia was used in this work to digest soil samples.

Subsamples (1 g) were weighed into Pyrex test tubes, to each of which 10 mL of aqua regia (3 HCl : 1 HNO_3) was added. The tubes were then placed in a controlled heating block and the samples digested for 1 h at 60°C, 2 h at 80°C, 2 h at 105°C and 3 h at 120°C, successively. After cooling, samples were then centrifuged and made up to volume. Metal contents were then determined by flame atomic absorption spectrometry (Perkin-Elmer model 1100).

Analytical precision and accuracy

In order to obtain acceptable results during the analysis of soil samples, the following procedures were employed for precision and accuracy.

The analytical work was divided into batches of 50 samples. To assess the precision, 20% of the samples in each batch were randomly chosen and duplicated. The precision is expressed as the % coefficient of variation (CV). Generally, the CV for all the metals determined was < 10%.

The accuracy was evaluated by analysing certified reference materials and quoting the percentage recovery. Accuracy in this work was checked by including samples of Buffalo River Sediment (SRM 2704) and BCR Reference Soil (No. 141, calcareous loam) with each soil batch.

RESULTS AND DISCUSSION

Table-1 and Fig. 1 show the levels of the pollutant metals in surface and subsurface soils of the sections of the Ring Road.

TABLE-1

METALS (μg g^{-1} ± S.E.) IN SURFACE AND SUBSURFACE SOILS ALONG RING ROAD SECTIONS (n = 164).

Samples location	Car/h	Soil samples	OM%	Lead	Zinc	Copper	Chromium	Niekel
Ring Road (East)	7188	Surface (n = 28)	2.61 ± 0.17	2650.67 ± 264.84	180.64 ± 12.33	81.53 ± 31.86	28.63 ± 1.72	23.84 ± 0.55
		Subsurface (n = 28)	4.22 ± 0.39	31.61 ± 4.04	25.05 ± 1.13	8.76 ± 0.35	18.45 ± 1.12	29.09 ± 1.31
Ring Road (South)	3920	Surface (n = 22)	3.23 ± 0.24	752.34 ± 76.61	48.63 ± 5.52	26.95 ± 1.61	24.19 ± 1.31	23.79 ± 0.57
		Subsurface (n = 22)	3.87 ± 0.41	133.34 ± 20.53	18.12 ± 1.44	10.16 ± 0.39	16.17 ± 0.60	27.89 ± 1.24
Ring Road (North)	2548	Surface (n = 20)	1.76 ± 0.19	399.97 ± 55.23	50.30 ± 7.81	9.40 ± 0.56	14.52 ± 0.77	17.00 ± 1.00
		Subsurface (n = 20)	5.80 ± 3.16	42.05 ± 9.59	19.93 ± 1.59	9.65 ± 1.72	13.37 ± 0.86	24.61 ± 1.65
Ring Road (West)	Not in use	Surface (n = 12)	4.13 ± 0.50	39.93 ± 10.06	37.13 ± 3.39	11.21 ± 0.98	20.16 ± 2.36	21.06 ± 2.90
		Subsurface (n = 12)	5.77 ± 0.85	7.21 ± 0.96	27.56 ± 3.92	10.97 ± 1.40	17.95 ± 4.04	23.08 ± 4.36

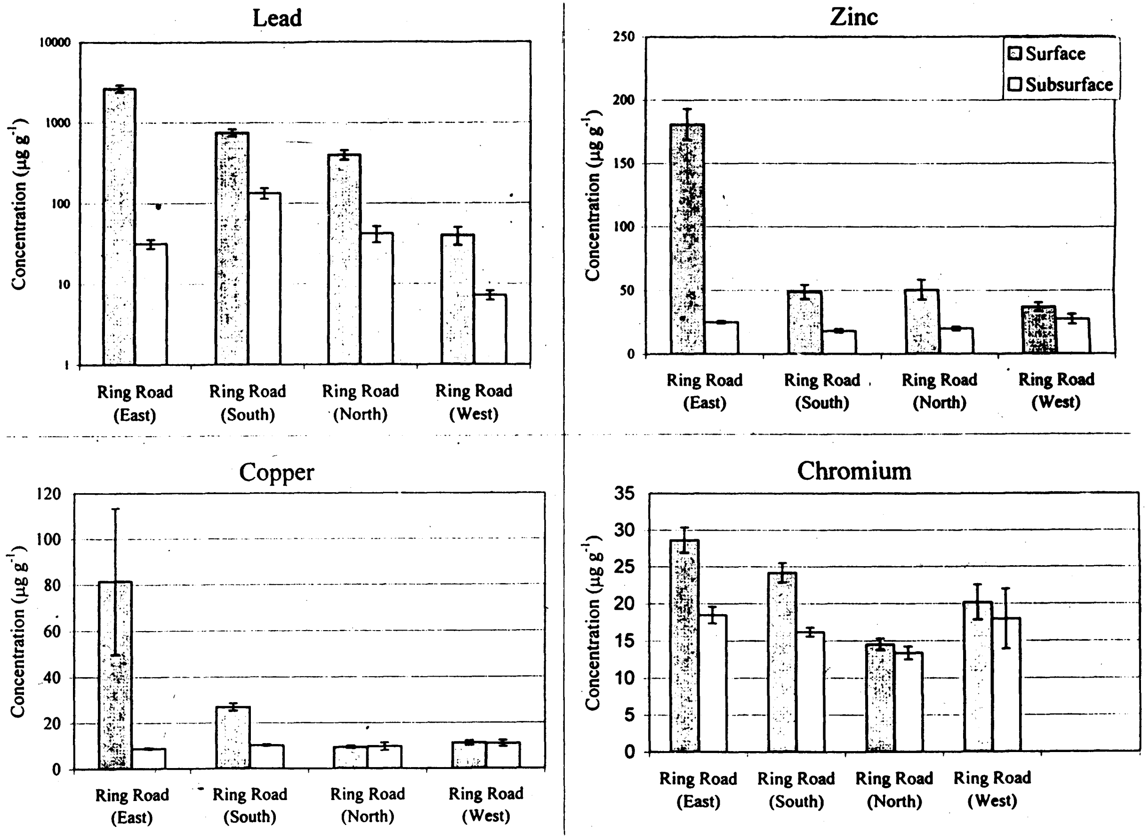

Fig. 1. Metal levels in surface and subsurface soils from roadside along the Ring Road in Riyadh (Mean and SE error bars).

Metals in roadside soils

Lead: Fig. 2 shows lead variation in surface soils along the Riyadh Ring Road. The south-western part of the Ring Road (West) is still under construction and was included for the sake of comparison. The mean lead content in surface soil samples along the south-western part of the Ring Road was 72.28 μg g^{-1}, the lowest level of 6.59 μg g^{-1} and the highest of 460.54 μg g^{-1} being recorded at the end of this part and the beginning of the Ring Road (South). This high concentration is attributed to the traffic in Ring Road (South). The mean lead content in subsurface soils was 19.73 μg g^{-1}, with a minimum level of 4.0 μg g^{-1} and a maximum of 170 μg g^{-1}. The latter was obtained at the end of this part of the Ring Road towards the South.

The lead content in surface soils of the Ring Road (South) was 752.34 μg g^{-1}, which is about nine times higher than the south-western section. The highest concentration, 1461.54 μg g^{-1} recorded at the last third part of this section of the Ring Road, can be attributed to the increase in driving speed due to the absence of any intersections. The lowest concentration was 96.9 μg g^{-1}. Lead levels in subsurface soil samples varied from 28.17 to 403.24 μg g^{-1}, with an average value of 133.34 μg g^{-1}.

The lead concentration in surface soil samples along the Ring Road (East) proved to be the highest among the roads studied with a mean value of 2650 μg g^{-1}, which is more than thirtyfive times higher than the unopened south-western part of the Ring Road. This high lead concentration can be attributed to the high traffic volume in this part of the Ring Road which at times reaches 7200 vehicles per hour and to the low rainfall in the study area (80 mm per annum). The minimum lead level was 232.77 μg g^{-1} and the maximum was 6121 μg g^{-1}. Figure 2 shows that the highest lead levels recorded along the Ring Road are associated with exits and intersections.

In contrast with the surface soils, lead levels in subsurface soil samples along the Ring Road (East) gave relatively low concentrations with an average value of 31.61 μg g^{-1}, with a minimum level of 7.99 μg g^{-1} and a maximum level of 103.70 μg g^{-1}. The large differences between lead levels in surface and subsurface soils emphasise that atmospheric deposition of automobile emissions is the main source of these high levels.

The lead content in surface soil samples along the Ring Road (North) varied from 92.0 μg g^{-1} recorded almost at its western end to 883.12 μg g^{-1} obtained at exit 6 where Abo Bakr Al Seddq Road intersects with the Ring Road. The mean lead content in the surface soil samples was 399.97 μg g^{-1}, which is about four times higher than the unopened south-western section of the Ring Road. This lower lead concentration compared with the Ring Road (East) is attributed to the low traffic volume. In subsurface soils along the Ring Road (North) the lead content varied from 5.99 to 176.42 μg g^{-1}, with an average value of 42.05 μg g^{-1}.

Zinc: Zinc variation in surface soils along Riyadh's Ring Road is shown in

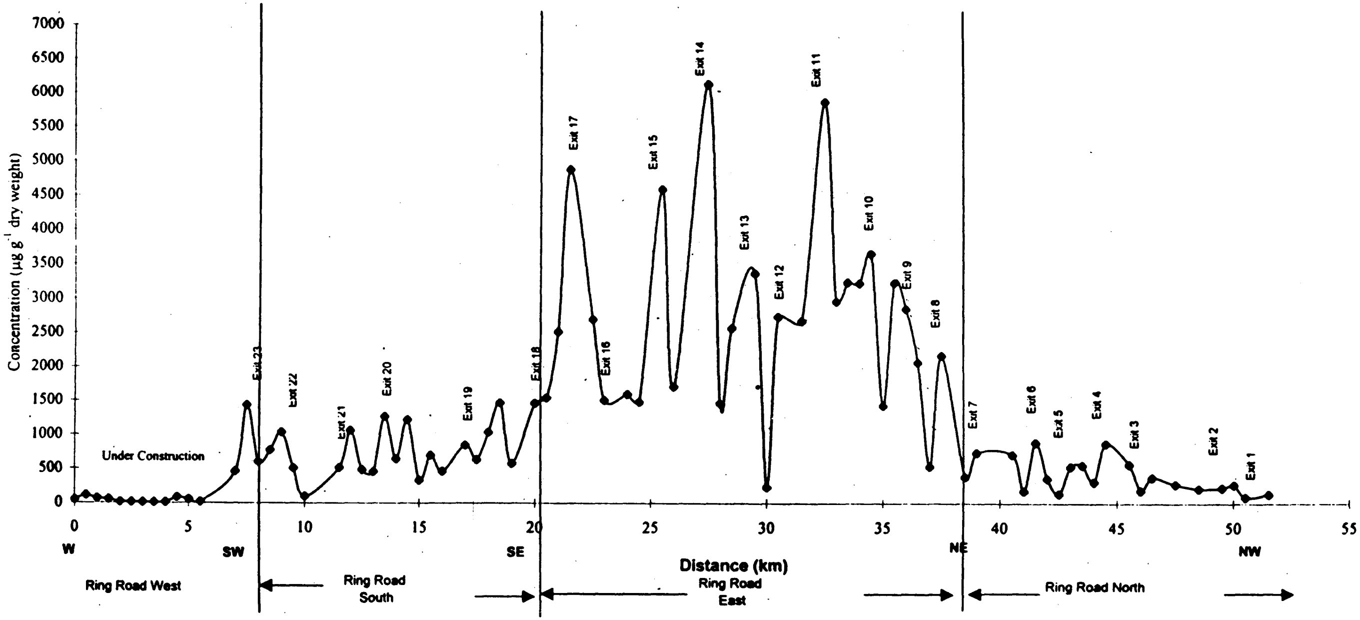

Fig. 2. Lead variation in surface soils along the Ring Road in Riyadh expressed anticlockwise over its 52 km length (incomplete in western area).

Fig. 3. Zinc content in the surface soils of the Ring Road (West) which is still under construction was 37.0 μg g^{-1}. In subsurface soils, the zinc level was 27.56 μg g^{-1}.

Along the Ring Road (South), the zinc concentration in surface soils was 48.63 μg g^{-1}, which is about 31% higher than in the unopened south-western part of the Ring Road. In the last third of this road, zinc concentration has increased from 48.95 to 171.83 μg g^{-1} in a similar behaviour to lead. This was attributed to the increase in driving speed since automobile oil and tyre wear are known to be sources of zinc in roadside environments. In subsurface soils, the mean zinc content was 18.12 μg g^{-1}.

Zinc concentration in surface soil samples along the Ring Road (East) varied from 75.92 to 320.68 μg g^{-1}, with a mean value of 180.64 μg g^{-1}, which is about four times higher than in the unopened south-western part of the Ring Road. The zinc concentration in subsurface soils was 25.05 μg g^{-1}. The large difference between zinc levels in surface and subsurface soils emphasises that atmospheric deposition is the main source of high zinc levels in surface soils along roadsides. In contrast with lead along the Ring Road, the high zinc levels in surface soils were recorded between the exits, attributable to automobile oil and tyres wear.

The zinc content in surface soil samples along the Ring Road (North) was 50.30 μg g^{-1}, which is about 35% higher than in surface soils along the south-western part of the Ring Road. In the last third of this road towards the west, zinc levels decrease to their lowest value along the Ring Road, which is 11.0 μg g^{-1}. This can be attributed to the lower number of vehicles using this section of the road.

Copper: Copper variation in surface soil samples along the Ring Road is shown in Fig. 4. The copper content in surface soils in the unopened south-western part of the Ring Road was 11.21 μg g^{-1}, and in subsurface soils was 10.97 μg g^{-1}.

The copper level in surface soil samples along the Ring Road (South) was 26.95 μg g^{-1}, which is about 140% higher than that of the south-western part of the Ring Road which is still under construction. The copper content of subsurface soils was 10.16 μg g^{-1}.

Along the Ring Road (East), copper levels in surface soils varied from 11.99 to 803.20 μg g^{-1}, with a mean value of 81.53 μg g^{-1} which is about seven times higher than that of the south-western section of the Ring Road. The mean copper content in subsurface soils was 8.76 μg g^{-1}. The large difference in copper content in surface and subsurface soil indicates an atmospheric origin of this metal in surface soils. The copper content in surface soils along the Ring Road (North) was 4.40 μg g^{-1}, which is about the same as in subsurface soils.

Chromium: Chromium is extensively used for roadside lines; its concentration in surface soil samples varied from 10.39 μg g^{-1} in Ring Road (North) to 51.75 μg g^{-1} in Ring Road (East), with an average value of 23.20 μg g^{-1}. In subsurface soils, chromium ranged from 6.79 μg g^{-1} in Ring Road (East) to 35.59

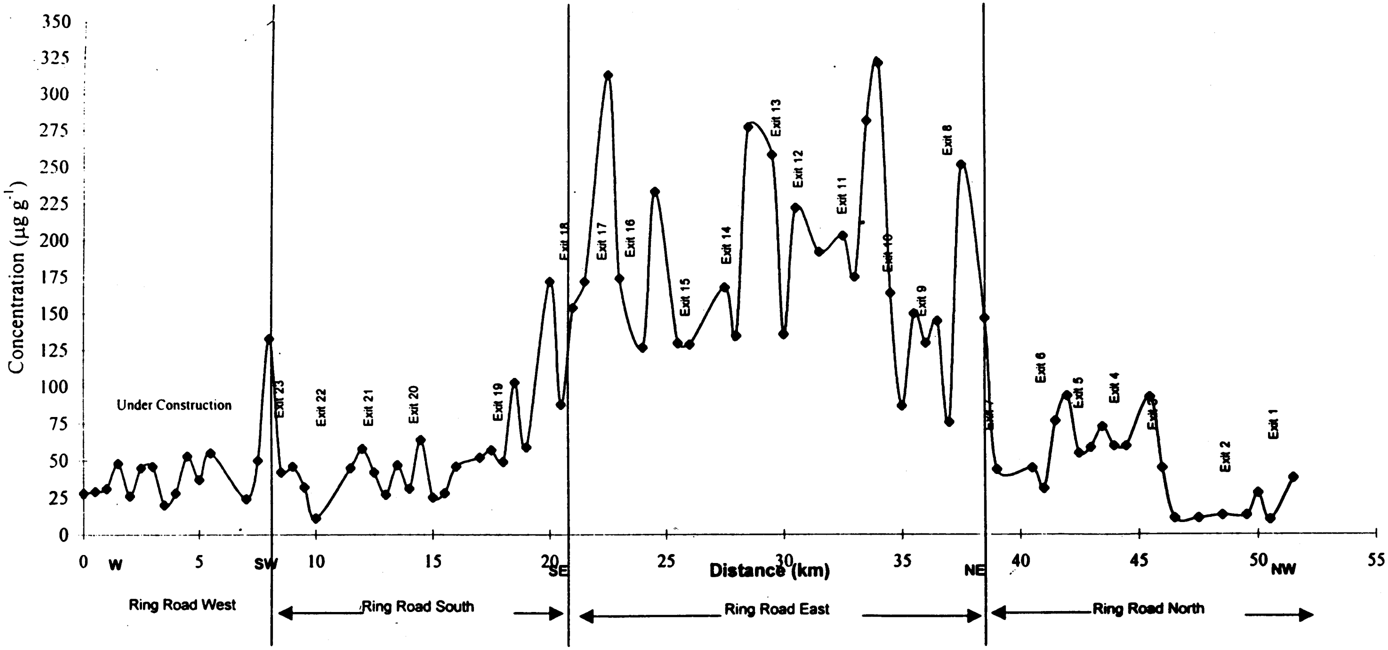

Fig. 3. Zinc variation in surface soils along the Ring Road in Riyadh city expressed anticlockwise over its 52 km length (incomplete in western area).

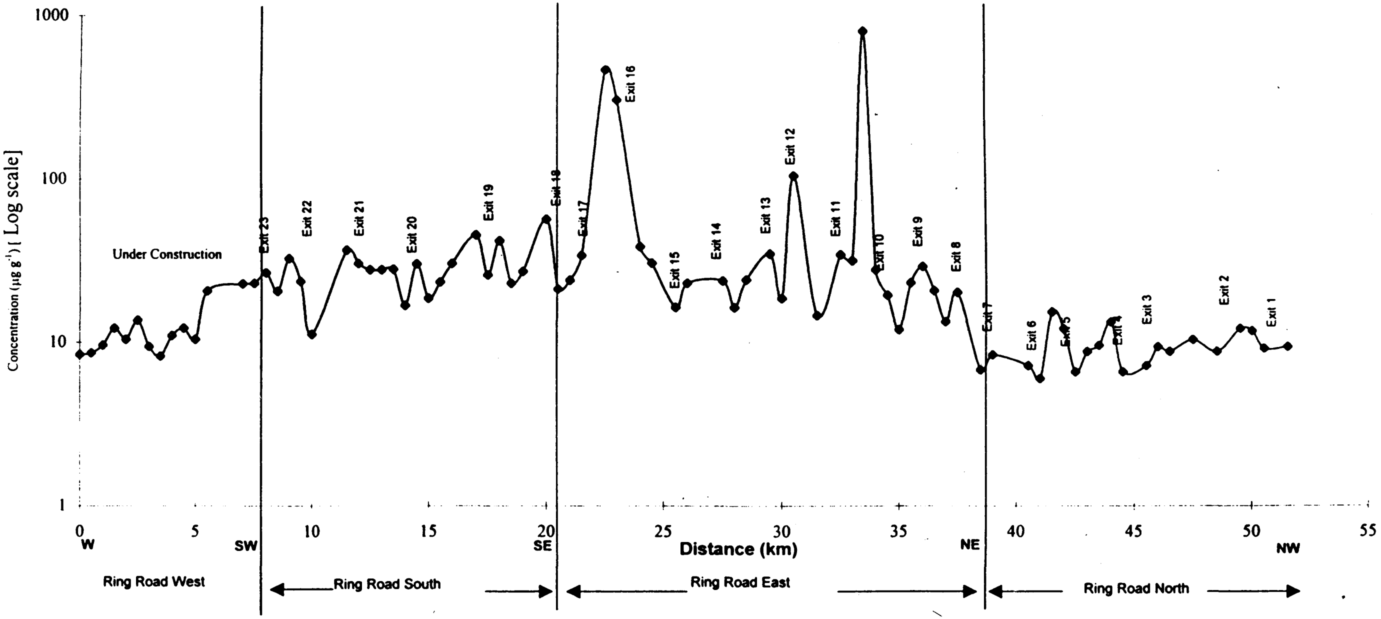

Fig. 4. Copper variation in surface soils along the Ring Road in Riyadh expressed anticlockwise over its 52 km length (incomplete in western area).

μg g^{-1} in the same road, with a mean value of 18.72 μg g^{-1}. Fig. 1 shows that chromium levels in surface and subsurface soils ranked according to lead levels. Chromium levels in surface soils showed a similar variation to that shown by lead, but on a smaller scale, which may indicate a common source for both metals. Fig. 5 show chromium variation in surface soils along the Riyadh Ring Road, which also has a similar behaviour to lead, the high levels of chromium associated with exits along the Ring Road and mainly attributable to attrition of yellow paintwork from road surface.

Heavy metal dispersal in roadside soils: Motor vehicles form the main source of metals in road environments, from the combustion of fuel and by the corrosion and wear of vehicle components such as brake linings and tyres. Metal distribution in roadside soils is affected by prevailing wind directions[15, 16]. The effect of prevailing winds in metal dispersal in Ring Road (South) soils was investigated by analysing surface and subsurface soil samples collected at different distances from the road on both sides (north and south) at two locations. The first was chosen to investigate the effect of combined sources formed by motor vehicles, a second-hand market involving considerable human activity, the city refuse incinerator and a sewage treatment station. The second was chosen to investigate the emission of motor vehicles as a single source of pollution.

To investigate the effect of roadside plantation to reduce the dispersal of metal pollutants arising from motor vehicles, the same method was undertaken at two locations along the Ring Road (East). The first was selected to be within a planted sides section (north) of the road, and the second section of the road (south) lacked roadside planting.

Lead: The lead content in surface soils on both sides of the road clearly showed an exponential decrease with distance from the road edge at the two locations along Ring Road (South) and (East). The influence of the prevailing wind direction on dispersion of the airborne lead particulates is reflected in the elevated lead levels on the south side of the Ring Road (South) at the two locations (Fig. 6a). This constitutes evidence supporting an aerial route for the dispersion of lead throughout the roadside ecosystem. The lead concentration decreased as distances of *ca.* 40 m were reached. This distribution of lead confirms automobile traffic as the source of pollution, but there is a large difference between levels in surface and subsurface soils, emphasising that atmospheric deposition is the main source of high levels in surface soils.

The effect of planted trees along roadsides in filtering heavy metal pollutants emitted from automobiles is shown in Fig. 7. Although the planting in Ring Road (East) is at an early stage, planted trees in the northern section of this road are already having an effect in reducing lead dispersal.

Zinc: Zinc is an important component of some lubricating oils and is present in motor vehicle tyres[10]. Therefore, zinc enrichment of the roadside surface soils showed similar trends to those of lead emitted from automobile exhausts. The data in Fig. 6b show an exponential decrease of zinc in soils with increasing distance from the road edge. The elevated zinc levels on the south side of the Ring Road (South) show the influence of the prevailing wind on dispersion of zinc particulates.

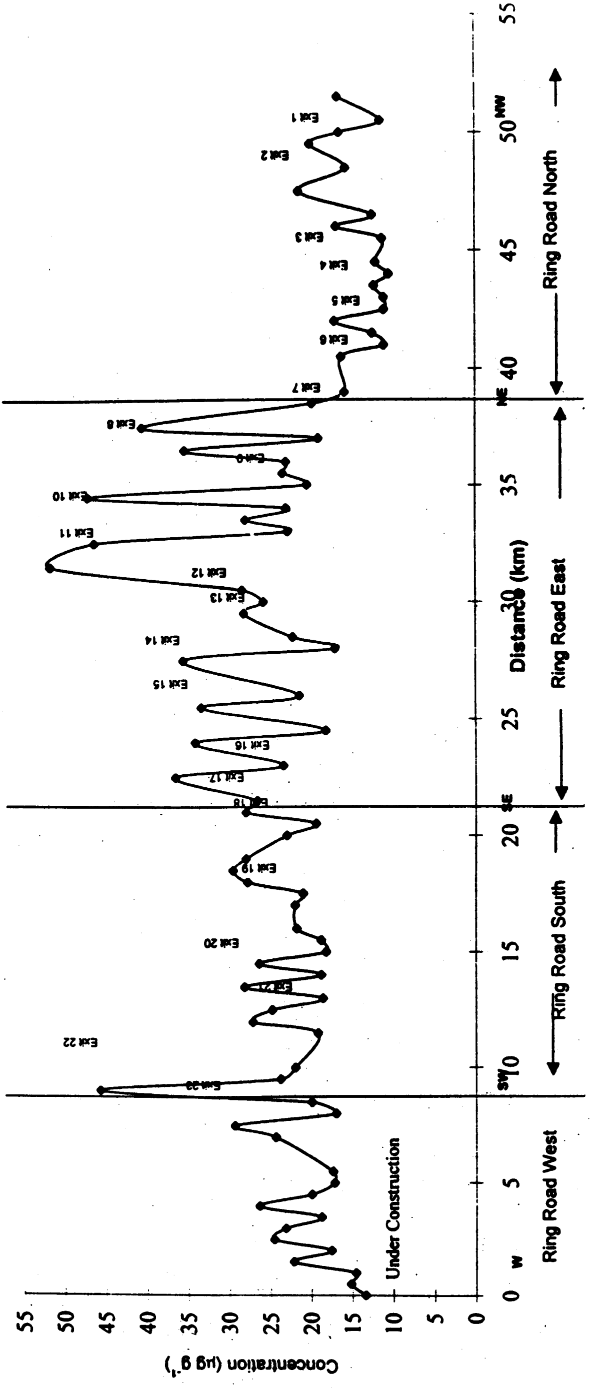

Fig. 5. Chromium variation in surface soils along the Ring Road in Riyadh city expressed anticlockwise over its 52 km length (incomplete in western area).

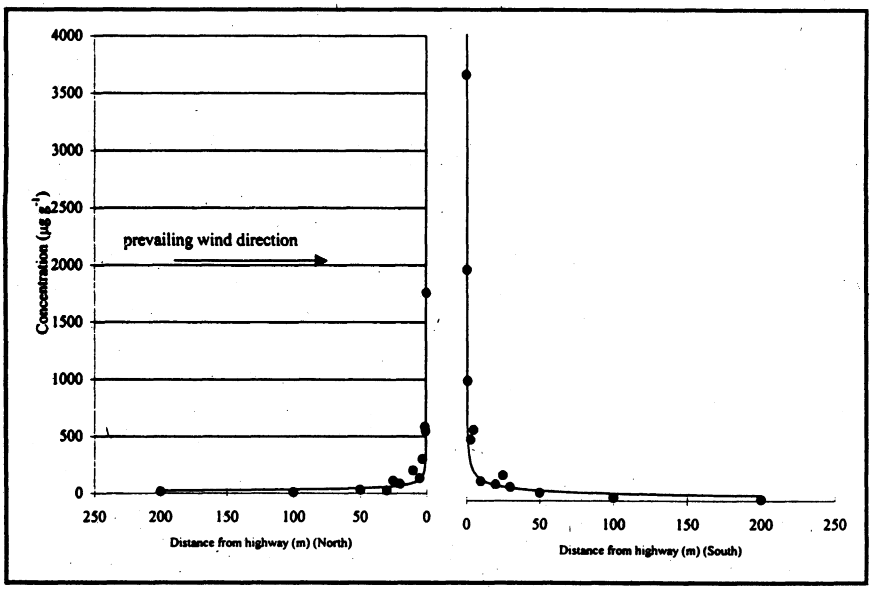

Fig. 6a. Lead variation in surface soils in relation to distance from the Riyadh Ring Road (South).

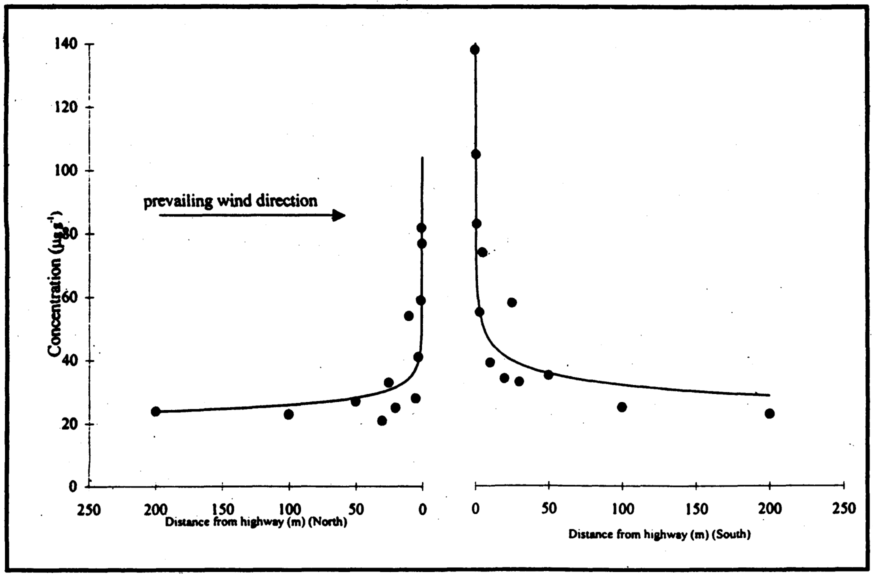

Fig. 6b. Zinc variation in surface soils in relation to distance from the Riyadh Ring Road (South).

Copper, chromium and nickel: Nickel and chromium are associated with chrome plating of some motor vehicle parts, while copper is a common constituent of piping and other components of engines[5]. Relatively high levels of copper and chromium were observed in the two samples nearest to the road; thereafter, their concentrations reached a background level. The horizontal distribution of nickel in surface soils at various distances from the road edge appeared not to be related to airborne contamination; therefore, the quantities of the element found in the soil samples along these vertical transacts should not be attributed to pollution by automobiles.

The results of the analysis of soil samples taken on both sides of Ring Road (South) showed an obvious decline in concentrations of lead and zinc with increasing distance from the road, whereas nickel, chromium and copper do not show such variation, which can be attributed to the relatively high background values of these metals in the samples. The lead concentration in surface soils decreases up to a distance of 40 m where nearly constant background levels were reached. Zinc enrichment of the roadside surface soil showed similar trends to those of lead. These results are in agreement with the findings of a number of other studies on soil contamination near roads[17–21]. For example, Motto *et al.*[22] have pointed out that most of the effect of lead discharge from automobiles is confined within a zone 33 m wide, measured from the road's edge; however, Ward *et al.*[23] suggested a strip having a width of 100 m. Panek and Zawdny[13] found that traffic influences the lead and zinc concentrations in roadside topsoil in a belt up to at least 50 m wide. It is generally assumed that this distance is the limit of traffic influence[3, 4, 24]. These findings gave rise to the suggestion that using roadsides for leisure time should be restricted to a strip of 50 m wide on both sides of heavily travelled roads such as the Ring Road (East) in Riyadh.

The transects to the south of the Ring Road (South) showed generally higher concentrations of lead and zinc in soil for a greater distance than other transects to the north. This difference in concentration gradients on the two sides of the road is linked to the pattern of prevailing winds. This constitutes evidence supporting an aerial route for the dispersion of these metals throughout the ecosystems near the roads. This finding is in agreement with those shown by other researchers[8, 25]. For example, at 3 m from the road (40000 vehicles day^{-1}) had lead levels of 913 μg g^{-1} on the upwind side and 676 μg g^{-1} on the opposite downwind side[20].

The ability of plants to intercept dust and its metal pollutant contents is also studied, using lead as an example. The planted trees along the northern part of the Ring Road (East) showed a noticeable effect in reducing lead dispersal. This result is supported by the findings of Rodriguez-Flores and Rodriguez-Castellon[20] who regarded the absence of trees on the roadside which could exert a screening effect as a factor affecting the metal dispersal away from the road. Finally, since the plant leaf structure affects the magnitude of the captured dust, it is recommended that plants be used as screens or green belts in roadsides, industrial areas and adverse urban locations in order to mitigate dust and improve air quality.

Interelemental correlation: The use of interelemental correlation can contribute to elucidating the common sources of different metals. The correlations

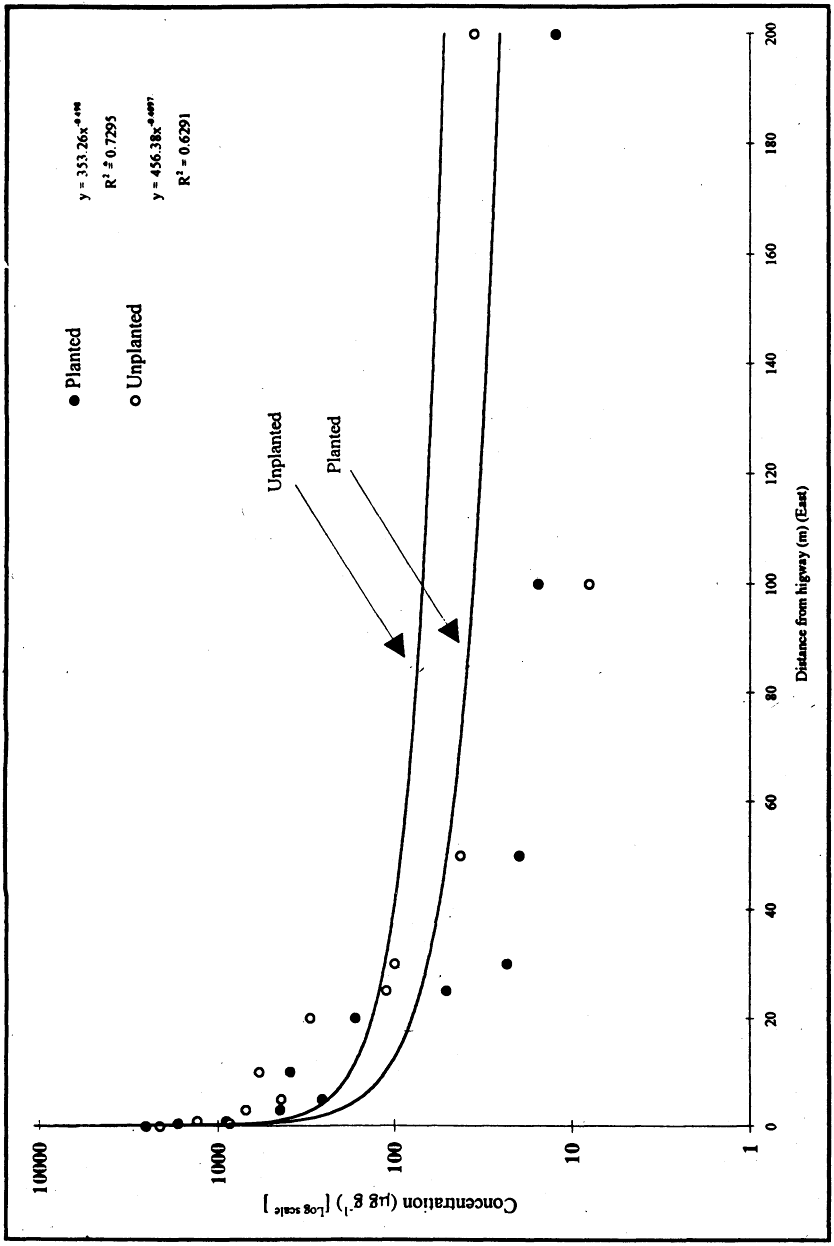

Fig. 7. Lead variation in surface soils in relation to distance from the Riyadh Ring Road (East).

between the metal contents in surface soil samples for the roadside data are shown in Table-2. Strong correlations existed between lead and zinc and chromium in roadside surface soils. Less strong correlations are found with copper and zinc, and with zinc and chromium. From the data presented in Table-2, there can be no doubt that motor vehicle traffic is responsible for the build-up of all four heavy metals in soils along the roadside. The source of the lead is obviously leaded gasoline, as has been so well established in the literature[26–28]. Zinc has been attributed to motor lubricating oils, car tyres and galvanised parts of vehicles such as galvanised tanks[11, 25, 26].

TABLE-2
CORRELATION COEFFICIENTS FOR SURFACE SOIL SAMPLES FROM ROADSIDES

	Pb	Cu	Zn	Cr	Ni
Pb	1				
Cu	0.391**	1			
Zn	0.735**	0.516**	1		
Cr	0.679**	0.243**	0.574**	1	
Ni	0.265**	0.282**	0.216**	0.577**	1

* Significant at 0.05 ** Significant at 0.01

Chromium is frequently used in chrome plating of some motor vehicle parts, while copper is a common constituent of piping and other components of engines and chassis[5, 25, 26]. The presence of this metal in soils and plants along roadsides is probably due to mechanical wear and tear which deposits it in the fine dust on the roadway and thence in to soils and vegetation.

Surface/subsurface ratios: Table-3 records the ratios of surface mean metal content to mean subsoil content in roadside soils. Lead is markedly enriched in surface soil samples, presumably because of general environmental contamination, particularly along the roadside with a ratio of 20.38. This is supported by the results of Chow[7] who reported that the lead content of a U.S. highway was as much as 403 μg g^{-1} in the top 5 cm layer and decreased to 60 μg g^{-1} at 10–15 cm. The most important reason for high differences in lead concentrations is that lead deposits are not very mobile and most lead accumulates in the top 5 cm of soil[25].

TABLE-3
SURFACE/SUBSURFACE SOIL RATIOS

Pb	Zn	Cu	Cr	Ni
46.93	4.43	4.38	1.50	0.89

Although it has greater mobility than lead[29], zinc similarly showed enrichment in the upper surface soils, which can be attributed to the very low rainfall in the study area (80 mm per annum). Zinc enrichment in surface soils showed a similar gradient to lead, but to a lesser extent, suggesting a common source. Copper enrichment was very obvious along the roadside soils. Chromium and nickel showed no significant difference between the levels in the two soil strata. It was found that approximately 75% of the lead, 56% of the zinc and 40% of the copper are concentrated in the top 5 cm. Similar findings were reported by

Beavington[30], Czarnowska[31], Rutherford and Bray[32], Scokart *et al.*[33] and Glooschenko *et al.*[34] Chromium showed a small decline with soild depth, whereas the levels of nickel and lithium did not change with depth, indicating the parent material as their origin.

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