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Metals Content of Roadside Soils in Riyadh (Saudi Arabia), with Particular Reference to Traffic Density

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The metals content (Pb, Zn, Cu, Cr, Ni and Li) of roadside surface and subsurface soils was determined along the major roads and highways in Riyadh city. Their levels were investigated in relation to traffic loads. Results showed that enhanced levels of Pb, Zn, and Cu correlated well with traffic density. 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 in soil 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.

Key Words: Metals content, Roadside soils, Riyadh (Saudi -Arabia), Traffic density.

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[5, 6]. Chow[7] found that lead concentration in surface soil collected along the east side of roads was higher than those collected from the west side. This was caused by the direction of the prevailing winds. 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 recognized 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 μg g^{-1} and Zn from 114 to 162 μg 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, apart from the study conducted by Al-Shayeb and Seaward[14] investigating the metal content of Ring Road soils, the 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 were contaminated with Pb and other metals including Cu, Zn, Ni, Cr. The metal content of soils was measured as a function of traffic density.

EXPERIMENTAL

Sample collection and treatment: The influence of traffic density upon roadside soil metal levels was assessed by collecting surface (0–3 cm) and subsurface (5–10 cm) soil samples within 1 m of roads varying in traffic density. A total of 108 surface soils and 108 corresponding subsurface soil samples were collected from the following roads:

King Fahad Road and Makkah Road: To investigate the metal variation with distance from the city centre, 26 surface and 26 subsurface soil samples were collected along King Fahad Road and Makkah Road. Samples were collected at 500 m intervals along both roads (Fig. 2).

Al Kharj Road: Various industrial activities are scattered along Al Kharj Road, including the cement factory, the second industrial city and Riyadh Oil Refinery (Fig. 1). To investigate the effects of these industrial activities in addition to the traffic movement on the metal content of the soil, 54 surface and subsurface soil samples were collected along this road at 300 and 500 m intervals.

A. Abdullah Road and A.S.A. Mahd Road: 19 surface and 19 subsurface soil samples were collected from these two roads which are located in the north of the city and are two of the best planned roads in the city.

S.A. Rahman Road: Seven surface and 7 subsurface soil samples were collected along this road at 500 m intervals along this road which runs from the eastern Ring Road to the east of the city leading to King Fahad Hospital.

Al Swaidi Road and Al Hayer Road: Al Swaidi Road is located in the west and Al Hayer road in the south of the city. 14 surface and 14 subsurface soil samples were collected from these two roads respectively at 300 m and 500 m intervals

Road No. 5: This road is the main road in the second industrial city. 9 surface and 9 subsurface soil samples were collected along this road at 400 m intervals, as well as 8 surface and 8 subsurface soil samples collected along a transect from the Riyadh Oil Refinery towards the second industrial city at 200 m intervals (Fig. 2).

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 2 mm 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, the 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

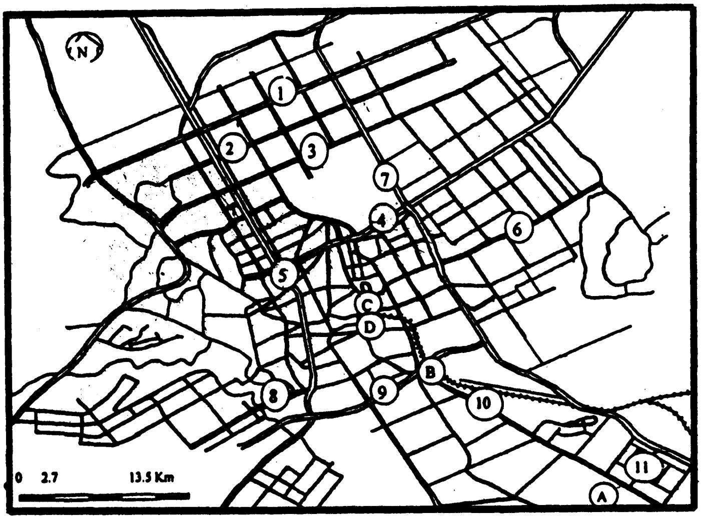

Fig. 1. Riyadh map showing the roads under investigation

1. Ring road (north)
2. A.S.A. Mahd road
3. A. Abdullah road
4. Makkah road
5. King Fahad road
6. S.A. Rahman road
7. Ring road (east)
8. Al Swaidi road
9. Ring Raod (south)
10. Al Kharj road
11. Road No. 5

A. Oil refinery
B. Cement factory
C. First industrial city
D. Industrial area

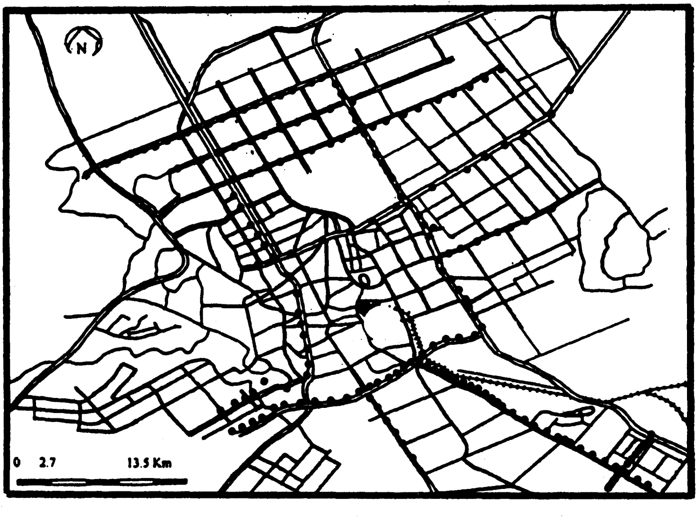

Fig. 2. Riyadh: soil sample locations from main roads

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 is 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. 3 show the levels of the pollutant metals in surface and subsurface soils of the studied roads. For the sake of comparison the levels of these metals along the Ring Road investigated in another work[14] were included.

Metals in roadside soils

Lead: The highest lead levels in surface soils were found along the Ring (East) and the King Fahad roads and in subsurface soils along the King Fahad, the Al-Swaidi and Ring (South) roads.

King Fahad Road: Lead content in the surface soil samples shows the highest mean concentration after the Ring Road (East) which is 1657 $\mu g\ g^{-1}$ (Fig. 3). This can be attributed to the very high traffic volume which is about 9000 vehicle per hour, since it is the main road for the city connecting its southern and northern areas, with more than fifteen main intersecting roads. Fig. 4 shows lead variation in surface and subsurface soil samples along King Fahad road. Lead levels in surface soils appear to be increasing gradually from its minimum level 763 $\mu g\ g^{-1}$, in the south to reach its maximum concentration 3121 $\mu g\ g^{-1}$ in the city centre, and then decline with distance towards the north. The lead content in subsurface soils varied from 33.57 to 434 $\mu g\ g^{-1}$, with an average value of 150 $\mu g\ g^{-1}$, the differences between lead levels in surface and subsurface soils indicating the importance of atmospheric deposition *via* automobile emissions and the effect of low rainfall in the study area.

Makkah Road: This road is the third most important road in the city after the Ring road and King Fahad road. The lead concentration in surface soil samples was 665 $\mu g\ g^{-1}$, attributable to the high traffic density which reaches up to 4550 vehicle per hour. Fig. 5 shows lead concentration declining from its maximum level 1801 $\mu g\ g^{-1}$ at the city centre to its minimum concentration 77.92 $\mu g\ g^{-1}$ away from the city centre toward the east. In subsurface soils lead levels varied from 18.38 to 150.45 $\mu g\ g^{-1}$, with an average value of 71.97 $\mu g\ g^{-1}$.

Al-Kharj Road: This road, bordered by different industrial activities mainly concerned with the manufacture of cement tiles and marble, leads to the second industrial city and the Riyadh Oil Refineries. Fig. 6 shows lead variation in surface and subsurface soils along this road, from the cement factory to the second industrial city in the south-east of Riyadh city. In the first third of this road, lead levels in surface soils show many peaks found to be correlated with traffic light locations. In the last third of this road, a high lead concentration was found at its intersection with Road No. 5, the main road in the second industrial city which leads to the oil refineries towards the west. The mean lead content in surface soils along Al-Kharj Road was 145.08 μg g^{-1} with minimum and maximum values of 50.95 and 300 μg g^{-1} respectively. In subsurface soil samples lead varied from 40 to 220 μg g^{-1} with an average value of 96.34 μg g^{-1}; the differences between lead levels in these surface and subsurface roadside soils were not as high as for other roads studied, which may be due to the oil sprayed on both sides of this road to stabilise the deposited dust emitted from the cement factory.

Al-Swaidi Road: The lead content in surface soil samples ranged from 192.81 to 1231.77 μg g^{-1} with an average value of 501.36 μg g^{-1}, but in subsurface soils varied from 51.55 to 181.02 μg g^{-1} with a mean concentration of 115.88 μg g^{-1}.

S.A. Rahman Road: This road is used by about 2300 vehicles per hour. The mean lead concentration in surface soils was 280.29 μg g^{-1}; the minimum level was 99.0 μg g^{-1} and the maximum 669.33 μg g^{-1}. In subsurface soils the lead content varied from 28.77 to 368.83 μg g^{-1} with a mean value of 113.20 μg g^{-1}.

A. Abdullah ibn A. Aziz Road: The lead content in surface soil samples was 483.56 μg g^{-1}, which can be attributed to the traffic volume which is about 4300 vehicles per hour; lead levels ranged from 123.48 to 1169.43 μg g^{-1}. The lead content in subsurface soils varied from 8.19 to 46.75 μg g^{-1}.

A.S.A. ibn Mohd. Road: This road runs parallel with the previous road, but has less traffic volume of about 3500 vehicle per hour. Lead content in surface soils varied from 37.56 to 937.86 μg g^{-1} with an average value of 287.59 μg g^{-1}. In subsurface soils, lead levels ranged from 7.19 to 57.74 μg g^{-1} with a mean value of 24.48 μg g^{-1}.

Road No. 5: The lead content in surface soils was 738.59 μg g^{-1}, with minimum and maximum concentrations of 288.91 and 146.8 μg g^{-1} respectively. Lead in subsurface soils varied from 16.98 to 129.27 μg g^{-1} with an average value of 41.60 μg g^{-1}.

Zinc

King Fahad Road: Zinc variation in surface and subsurface soils along this road is shown in Fig. 4. The highest levels of zinc in surface soils were found within the city centre limits, and beyond these towards the north, the zinc level decreases to about half. The mean zinc content in surface soils was 64.03 μg g^{-1}, whereas in subsurface soils was 19.49 μg g^{-1}, the large difference indicating that atmospheric deposition is the most important way by which surface soils are contaminated.

Makkah Road: Fig. 5 shows zinc variation in surface and subsurface soils along Makkah Road from the new city centre to the city outskirts towards the east. Zinc concentrations in surface soil samples decline with distance from the new city centre. The zinc mean content in surface soil was 45.86 μg g^{-1}, whereas in subsurface soils was 16.37 μg g^{-1}.

Al-Kharj Road: Zinc variation in surface and subsurface soils along this road is shown in Fig. 6: apart from the two peaks observed in surface soil samples, zinc level appears to be steady with a mean value of 25.82 μg g^{-1} in surface and

16.54 $\mu g\ g^{-1}$ in subsurface soil samples. The first peak represents a high value (78.92 $\mu g\ g^{-1}$) at a traffic light location and the second (149.85 $\mu g\ g^{-1}$) is located at the intersection of road No. 5 in the second industrial city with Al-Kharj road.

Al-Swaidi Road: The zinc levels in surface soils ranged from 16.0 to 54.0 $\mu g\ g^{-1}$ close to King Fahad road, and in subsurface soils varied from 11.0 to 29.17 $\mu g\ g^{-1}$.

S.A. Rahman Road: The zinc content in surface soil samples shows the lowest of the roads studied with an average value of 18.27 $\mu g\ g^{-1}$.

A. Abdullah ibn A. Aziz Road: Zinc levels in surface soils ranged from 27.75 $\mu g\ g^{-1}$ to 111.89 $\mu g\ g^{-1}$ recorded at the entrance of King Saud University, with an average value of 55.66 $\mu g\ g^{-1}$. In subsurface soils zinc varied from 7.59 to 20.98 $\mu g\ g^{-1}$ with a mean value of 15.27 $\mu g\ g^{-1}$.

A.S.A. ibn Mohd. Road: The mean content of zinc in surface soils was 52.63 $\mu g\ g^{-1}$. The minimum concentration was 20.78 $\mu g\ g^{-1}$, with a maximum level 123.88 $\mu g\ g^{-1}$ obtained at the entrance of King Saud University, which can be attributed to traffic density at this entrance. In subsurface soils, zinc levels ranged from 6.19 to 23.98 $\mu g\ g^{-1}$.

Road No. 5: Although this road has low traffic density compared with the other roads studied, it has high zinc levels in surface soils with a mean value of 241.54 $\mu g\ g^{-1}$, indicative of industrial sources within the second industrial city which agrees with the findings of previous work[15]. The minimum and maximum concentrations were 115.88 and 665 $\mu g\ g^{-1}$ respectively. In subsurface soils, the zinc content ranged from 14.39 to 24.17 $\mu g\ g^{-1}$ with an average value of 17.80 $\mu g\ g^{-1}$. The large differences between levels in surface and subsurface soils indicates the atmospheric origin of zinc in surface soils. Further investigation of this road is included in another work to identify sources of zinc and the other metals within the second industrial city[15].

Copper

Fig. 3 shows the mean copper concentrations in surface and subsurface soils of the studied roads. From Fig. 3, copper concentrations in surface soils are high in Road No. 5 in the second industrial city and Ring Road (East).

King Fahad Road: Copper variation in surface soils along King Fahad road is shown in Fig. 4. The copper level increases gradually from 23.78 $\mu g\ g^{-1}$ to reach its maximum value (53.14 $\mu g\ g^{-1}$) within the city centre. The mean copper content in surface soils was 33.61 $\mu g\ g^{-1}$, and 10.19 $\mu g\ g^{-1}$ in subsurface soils.

Makkah Road: Fig. 5 shows the copper variation in surface and subsurface soils along Makkah road. The mean copper content in surface soil samples was 25.44 $\mu g\ g^{-1}$ and 8.25 $\mu g\ g^{-1}$ in subsurface soils.

Al-Kharj Road: Copper variation in surface and subsurface soils along Al-Kharj road is shown in Fig. 6. Copper concentration in surface soils fluctuates, the maximum concentration in surface soils (45.55 $\mu g\ g^{-1}$) being at the intersection of road No. 5 with Al-Kharj road.

Road No. 5: The copper content in surface soil samples varied from 22.38 to 1165.23 $\mu g\ g^{-1}$ with an average value of 174.38 $\mu g\ g^{-1}$. The highest level indicates an industrial source of this metal within the second industrial city. The mean copper content in subsurface soils was 7.68 $\mu g\ g^{-1}$. This large difference between the copper content in surface and subsurface soils emphasises its atmospheric origin.

Nickel, chromium and lithium

Nickel content in surface soils varied from 9.79 $\mu g\ g^{-1}$ recorded in Ring road (north)[14] to 70.93 $\mu g\ g^{-1}$ in Road No. 5 in the second industrial city. The mean nickel content in surface soil was 24.02 $\mu g\ g^{-1}$, and in subsurface soils ranged from 8.99 $\mu g\ g^{-1}$ at A.S.A. Mohd. road to a maximum value of 60.14 $\mu g\ g^{-1}$ obtained from Al-Swaidi road.

Chromium is extensively used for roadside lines; its concentration in surface soil samples varied from 8.59 $\mu g\ g^{-1}$ at Al-Kharj Road to 51.75 $\mu g\ g^{-1}$ in the Ring road (east)[14], with an average value of 20.57 $\mu g\ g^{-1}$. In subsurface soils, chromium ranged from 5.59 $\mu g\ g^{-1}$ in A.S.A Mohd. road to 35.59 $\mu g\ g^{-1}$ in the Ring road (east)[14], with a mean value of 15.41 $\mu g\ g^{-1}$. Fig. 3 shows 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.

Lithium content in surface soils varied from 1.4 to 6.99 $\mu g\ g^{-1}$, with an average value of 3.59 $\mu g\ g^{-1}$, and in subsurface soils from 0.80 to 8.39 $\mu g\ g^{-1}$ with a mean value of 1.02 $\mu g\ g^{-1}$. Fig. 3 shows lithium variation in surface and subsurface soils adjacent to roads, which appears to be almost similar since it is not related to pollution sources.

Effect of traffic volume on heavy metal accumulation in soils

In general, the effect of traffic volume is a complicating factor on the level of heavy metals due to the effect of several other factors, such as age of the road and direction and speed of wind[16]. Nevertheless, in general, the larger the traffic volume the higher the amount of metal pollutants in soils along the roads[6, 8]. In our study there was a substantial difference between road No. 5, corresponding to the lowest traffic flow, and the rest of the roads. A high correlation was found between traffic volume and lead levels in surface soils (Fig. 7). Our results showing lead in soil to be correlated with the traffic density are in agreement with the findings of Daines *et al.*[17], Motto *et al.*[18] and Schuck and Locke[19]. Similarly, Ward *et al.*[11] found significant correlations between traffic density and Pb, Zn, Cu, Ni and Cr in surface soils from an Auckland motorway in New Zealand. For the sake of comparison and calibration of surface soil as a monitor of atmospheric metal pollution along roadsides, lead variation in the air with the traffic volume[20], which showed high correlation too, is included. This suggested that lead contamination of roadside soils may be due to direct deposition of lead derived from vehicle exhausts or the relocation of lead deposited on road surfaces or both.

In spite of the dependence of roadside metals on traffic, it appears form Fig. 3 that high concentrations of one metal in the soil do not necessarily entail high concentrations of another one of the metals. This variation could be attributed to unaccounted variables such as road age, presence of local sources and the ratio between motor vehicles using diesel and those using leaded gasoline.

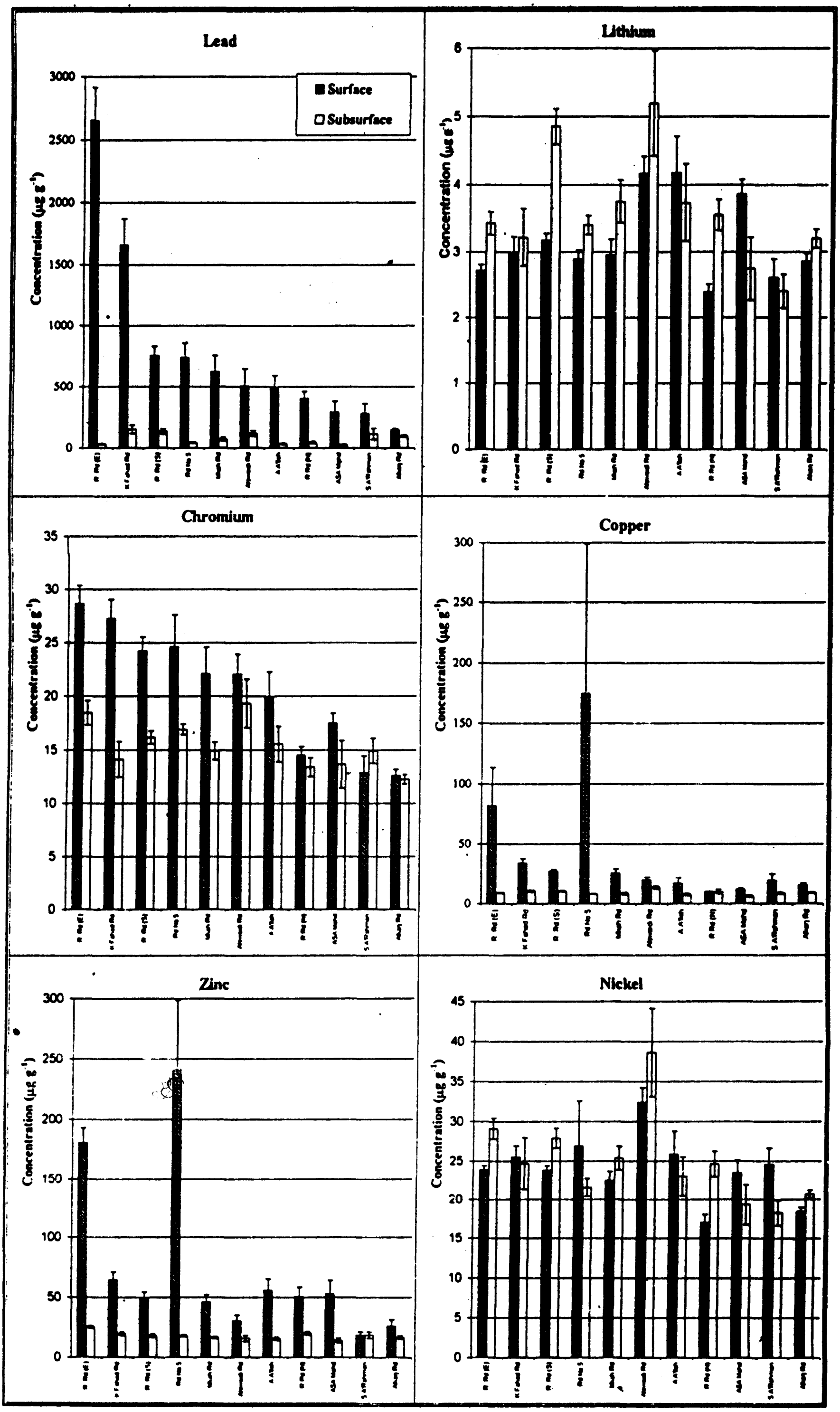

Fig. 3. Metal levels in surface and subsurface soils collected from sides of different highways and roads in Riyadh city ranked according to lead levels (mean and S.E. error bars)

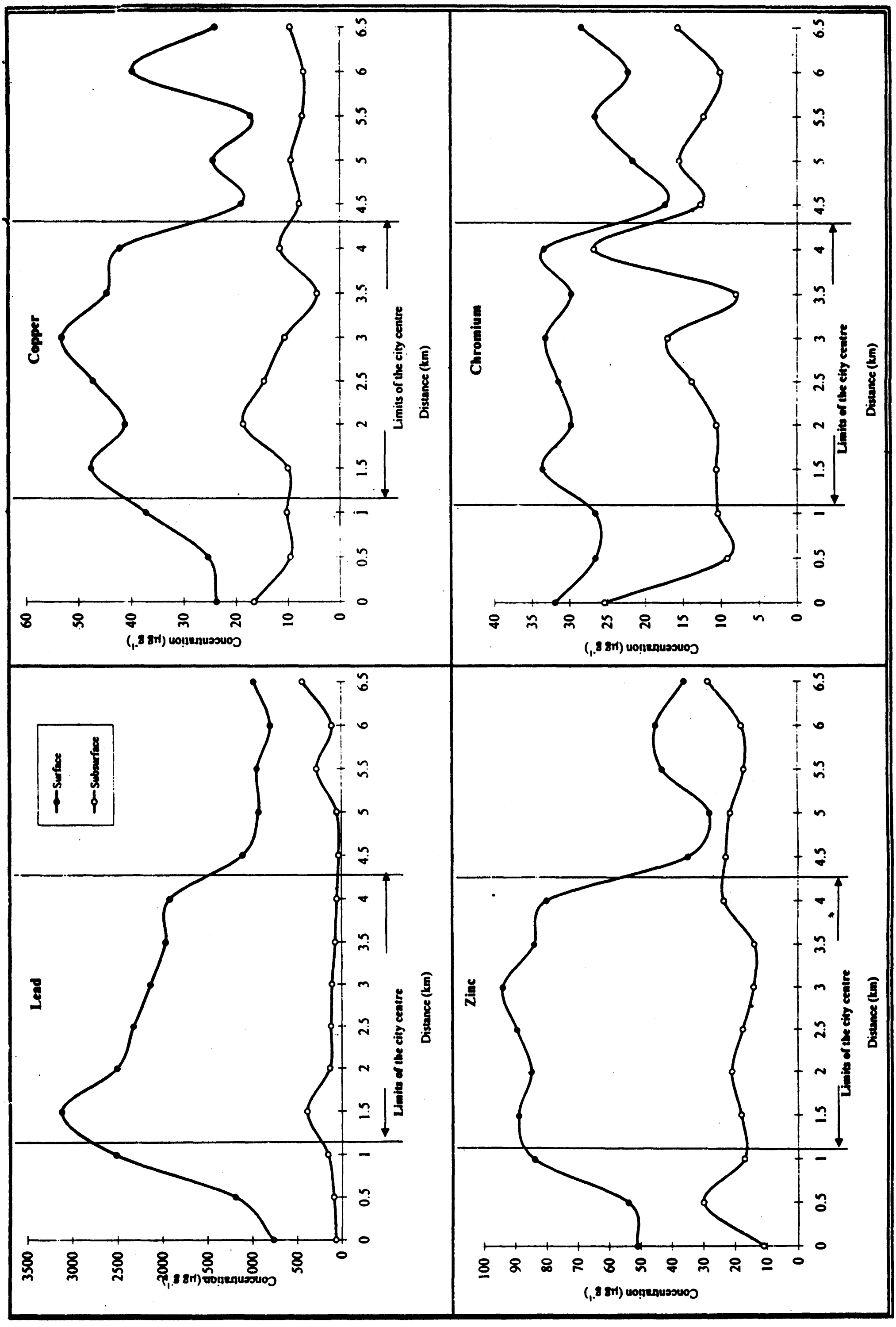

Fig.4. Metal variation in surface and subsurface soils along King Fahad road from south to north across the city centre

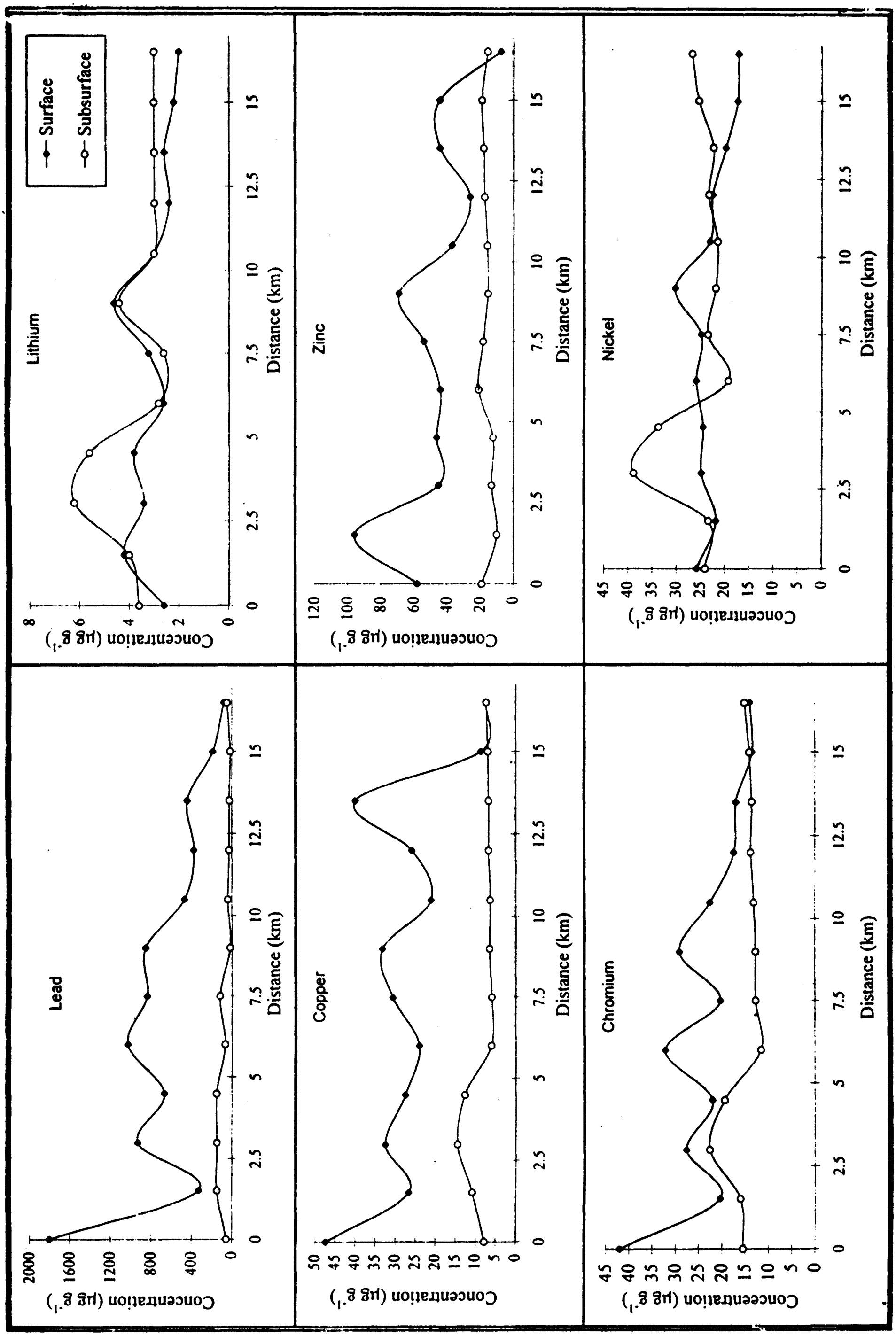

Fig. 5 Metal variation in surface and subsurface soils along Makkah road across Riyadh city (from west to east)

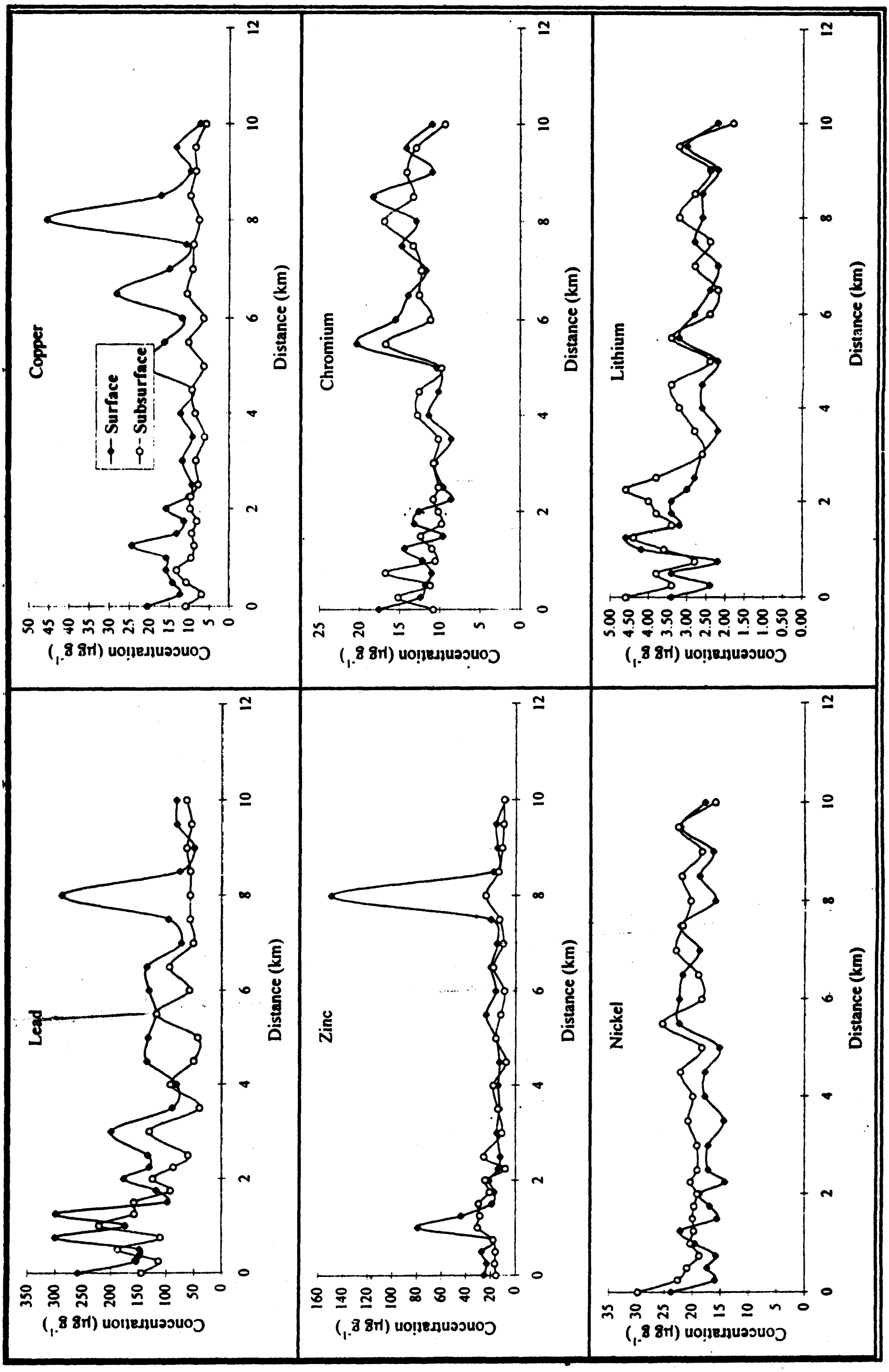

Fig. 6. Metal variation in surface and subsurface soils along Al-Kharj road away from a cement factory towards the south-east

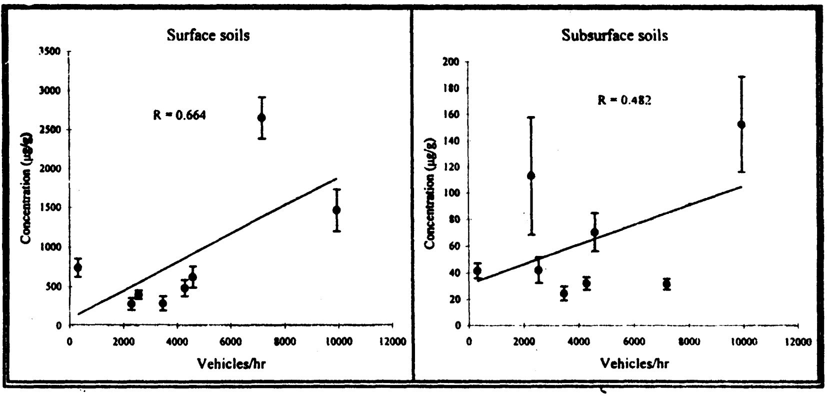

Fig. 7. Lead variation in roadside soils in relation to traffic density in Riyadh city

Effectiveness of surface soil as monitors for atmospheric metal pollution

Surface soils are frequently used to monitor aerial metallic burdens[21-24]. In this work, results from analyses of surface soils provide evidence which strongly suggests that most of the studied metals are present as a result of surface deposition. If simple surface deposition was the predominant factor, it would be reasonable to expect a correlation between metal variation in surface soils with their levels in air samples.

Although a large number of studies exist, there is still a lack of information which quantitatively compares organisms with air pollution measurements at the same investigation sites to enable a calibration of the system[25]. Comparison of air pollution data with the enrichment of the same substances in surface soil will demonstrate their value to monitor air pollution. Therefore, one of the main objectives of this work described in this section was to correlate, where possible, the concentrations of the metals in air determined by a high volume sampler with those of surface soils at the same sites, *i.e.*, roads to assess their effectiveness for monitoring aerial metal pollutants.

The relationships between the metal concentrations in air samples[20], collected from roadside, and surface soils from the same sites are presented in Fig. 8. Apart from chromium, all metals in surface soils were highly correlated with those in the air, correlation values ranging from 0.65 for lead to 0.89 for copper. This indicates that surface soils can be effectively used to monitor aerial metal pollutants.

Inter-elemental correlation

The use of inter-elemental correlation can contribute to elucidating the common sources of different metals. The correlations 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 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[5, 16],

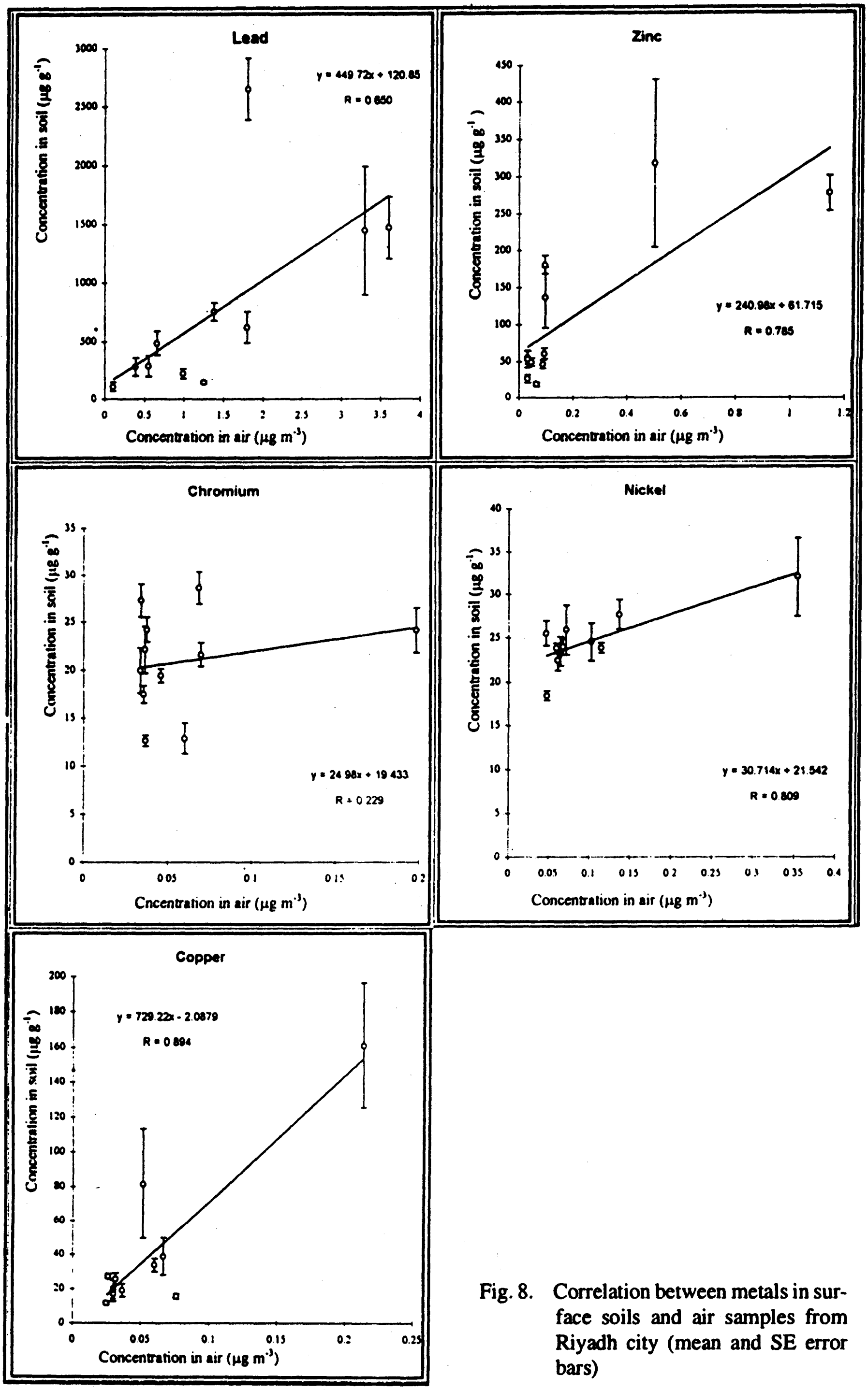

Fig. 8. Correlation between metals in surface soils and air samples from Riyadh city (mean and SE error bars)

TABLE 1a. METALS ($\mu g\ g^{-1} \pm$ S.E.) IN SURFACE SOILS FROM SIDES OF ROADS AND HIGHWAYS IN RIYADH

		Pb	Li	Cu	Zn	Cr	Ni
Ring road (E)	(n = 28)	2650.67 ± 264.84	2.71 ± 0.09	81.53 ± 31.86	180.64 ± 12.33	28.63 ± 1.72	23.84 ± 0.55
Ring road (N)	(n = 20)	399.97 ± 55.23	2.39 ± 0.12	9.40 ± 0.56	50.30 ± 7.81	14.52 ± 0.77	17.00 ± 1.00
Al-Swaidi road	(n = 7)	501.36 ± 143.13	4.17 ± 0.24	19.55 ± 2.24	29.97 ± 5.10	22.06 ± 1.87	32.40 ± 1.80
S. A'Rahman road	(n = 7)	280.29 ± 77.74	2.60 ± 0.29	19.32 ± 5.24	18.27 ± 2.74	12.84 ± 1.60	24.55 ± 2.12
Al-Karj road	(n = 26)	145.08 ± 13.68	2.85 ± 0.12	15.44 ± 1.52	25.82 ± 5.53	12.62 ± 0.57	18.40 ± 0.54
Ring road (S)	(n = 22)	752.34 ± 76.61	3.17 ± 0.11	26.95 ± 1.61	48.63 ± 5.52	24.19 ± 1.31	23.79 ± 0.57
King Fahd road	(n = 14)	1657.81 ± 209.50	2.97 ± 0.26	33.61 ± 3.77	64.03 ± 6.48	27.27 ± 1.74	25.50 ± 1.43
Makkah road	(n = 12)	620.63 ± 132.34	2.95 ± 0.24	25.44 ± 3.41	45.86 ± 6.00	22.10 ± 2.45	22.44 ± 1.18
A. A'llah road	(n = 9)	483.56 ± 102.99	4.17 ± 0.53	16.89 ± 4.44	55.66 ± 9.19	19.94 ± 2.32	25.89 ± 2.85
ASA Mahd road	(n = 10)	287.59 ± 92.00	3.86 ± 0.22	11.41 ± 1,17	52.63 ± 11.28	17.48 ± 0.91	23.46 ± 1.65
Road No 5	(n = 9)	738.59 ± 114.39	2.89 ± 0.14	174.38 ± 124.06	241.54 ± 56.90	24.60 ± 2.99	26.93 ± 5.61

TABLE 1b. METALS ($\mu g\ g^{-1} \pm$ S.E.) IN SUBSURFACE SOILS FROM SIDES OF ROADS AND HIGHWAYS IN RIYADH (n = 164)

		Pb	Li	Cu	Zn	Cr	Ni
Ring road (E)	(n = 28)	31.61 ± 4.04	3.43 ± 0.17	8.76 ± 0.35	25.05 ± 1.13	18.45 ± 1.12	29.09 ± 1.31
Ring road (N)	(n = 20)	42.05 ± 9.59	3.55 ± 0.23	9.65 ± 1.72	19.93 ± 1.59	13.37 ± 0.86	24.61 ± 1.65
Al-Swaidi road	(n = 7)	115.88 ± 20.86	5.19 ± 0.77	13.39 ± 1.37	15.67 ± 2.45	19.32 ± 2.24	38.59 ± 5.51
S. A'Rahman road	(n = 7)	113.20 ± 44.57	2.40 ± 0.25	8.59 ± 0.79	18.50 ± 2.59	14.90 ± 1.19	18.21 ± 1.61
Al-Karj road	(n = 26)	96.34 ± 9.21	3.20 ± 0.14	8.82 ± 0.32	16.54 ± 1.33	12.24 ± 0.43	20.69 ± 0.51
Ring road (S)	(n = 22)	133.34 ± 20.53	4.85 ± 0.26	10.16 ± 0.39	18.12 ± 1.44	16.17 ± 0.60	27.89 ± 1.24
King Fahd road	(n = 14)	150.46 ± 33.77	3.21 ± 0.43	10.19 ± 1.05	1949.00 ± 1.43	14.12 ± 1.65	24.64 ± 3.34
Makkah road	(n = 12)	70.39 ± 14.29	3.75 ± 0.32	8.25 ± 0.78	16.37 ± 0.92	14.91 ± 0.84	25.37 ± 1.49
A. A'llah road	(n = 9)	32.21 ± 4.80	3.73 ± 0.57	7.48 ± 0.98	15.27 ± 1.50	15.54 ± 1.67	23.00 ± 2.54
ASA Mahd road	(n = 10)	24.48 ± 5.29	2.74 ± 0.48	5.99 ± 0.94	13.89 ± 1.89	13.65 ± 2.21	19.30 ± 2.59
Road No 5	(n = 9)	41.60 ± 5.63	3.40 ± 0.14	7.68 ± 0.20	17.80 ± 1.02	16.89 ± 0.50	21.56 ± 1.17

Chromium is frequently used in chrome plating of some motor vehicle parts[5, 16], while copper is a common constituent of piping and other components of engines and chassis[16, 26]. The presence of this metal in soils and plants along roadsides is probably due to mechanical wear and tear which deposits it in a fine dust on the roadway and therefore to soils and vegetation. Although nickel was correlated with chromium, it showed a higher correlation with lithium which indicates a soil as well as motor vehicle origin of this metal.

TABLE-2
CORRELATION COEFFICIENTS FOR SURFACE SOIL SAMPLES FROM ROADSIDES

	Pb	Li	Cu	Zn	Cr	Ni
Pb	1					
Li	–0.014	1				
Cu	0.426†	0.162*	1			
Zn	0.765†	0.008	0.527†	1		
Cr	0.709†	0.309†	0.341†	0.558†	1	
Ni	0.254†	0.733†	0.279†	0.190†	0.568†	1

* Significant at 0.05 †Significant at 0.01

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 US highway was as much as 403 $\mu g\ g^{-1}$ in the top 5 cm layer and decreased to 60 $\mu g\ g^{-1}$ 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[16].

TABLE 3
SURFACE/SUBSURFACE SOIL RATIOS

Pb	Zn	Cu	Cr	Ni	Li
20.38	4.13	4.56	1.43	1.06	1.02

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 areas (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 show no significant differences between the levels in the two soil strata. Lithium ratios were near unity indicating its soil origin. Similar findings were reported by Beavington[30], Czarnowska[31], Rutherford and Bray[32], Scokart *et al.*[33] and Glooschenko *et al.*[34]

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