Heavy Metal Distribution in Street Dust of Urban and Industrial Areas in Jeddah, Saudi Arabia

**Mamdouh I. Khoder, Mansour A. Al Ghamdi,
and Mohamed H. Shiboob**

*Environmental Science Department, Faculty of Meteorology,
Environment and Arid Land Agriculture, King Abdulaziz University,
Jeddah, Saudi Arabia.*

Abstract The concentrations of heavy metals namely: Pb, Ni, Cd, Cr, Cu, Zn, Fe and Mn were measured in street dust samples. The samples were collected from the urban (Aljamaa district, main streets and substreets) and industrial areas of Jeddah city, Saudi Arabia. The concentrations of the measured metals were significantly higher in the main streets of the urban area than those found in the industrial area and substrates of the urban area. However, Pb was found in the highest levels in industrial area. The concentrations of the individual metals in street dust collected from the main streets and substreets of the urban area and industrial area averaged 70.36, 53.51 and 105.76 µg/g for Pb; 39.71, 24.00 and 27.28 µg/g for Ni; 2.24, 1.32 and 1.57 µg/g for Cd; 72.93, 40.10 and 47.67 µg/g for Cr; 125.52, 83.32 and 93.66 µg/g for Cu; 340.85, 214.10 and 240.50 µg/g for Zn; 10199.42, 7678.84 and 7918.42 µg/g for Fe and 514.15, 389.69 and 400.64 µg/g for Mn, respectively. The ratios of main streets/substreets metal concentration in the urban area were 1.31, 1.65, 1.70, 1.82, 1.51, 1.59, 1.33 and 1.32 for Pb, Ni, Cd, Cr, Cu, Zn, Fe and Mn, respectively. The mean concentrations of measured heavy metals in street dust from both study areas were lower / higher or similar to those detected in other cities of the world. The average concentrations of Cu and Zn in street dust of the main street dusts of the urban area exceeded the permissible limit value of soil. Significant positive correlation coefficients were found between the concentrations of Cr, Cd, Cu and Zn and also between the concentrations of Fe, Mn and Ni, Cr, Cu and Zn in the street dust of the urban area. On the other hand, insignificant positive correlation coefficients were found between the concentrations of Pb and other metals in street dust of the urban area. In the industrial area, significant positive correlation coefficients were found between the concentrations of heavy metals in the street dust.

Keywords: Heavy metals, street dust, urban, industrial, main streets, substreets, Jeddah.

Introduction

Street dust makes a significant contribution to the pollution in the urban environment (Al-Khashman, 2004). Heavy metals may come from many different sources in urban areas, including vehicle emission, industrial discharges, domestic heating, long-range transport and weathered materials (Li *et al.*, 2001; Al-Khashman, 2004; Viard *et al.*, 2004; Grigalaviciene *et al.*, 2005 and Al-Khashman and Shawabakh, 2006). Street dust metal pollution in urban areas arises from a variety of sources *via* water transported material from surrounding soils and slopes, dry and wet atmospheric deposition, biological inputs, road surface wear, road paint degradation, vehicular emissions, vehicle wear and lubricating oil, industrial emissions, fuels combustion and particulate emissions (Sutherland and Tolosa, 2000; Banerjee, 2003 and López *et al.*, 2005). The key heavy metals are Pb from leaded gasoline, Cu, Zn and Cd from car components, tire wear abrasion, lubricants, industrial and incinerator emissions (Markus and McBratney, 1996; Wilcke *et al.*, 1998 and Ozkan *et al.*, 2005). Cd is used in accumulators of motor vehicles or in carburetors as alloys and it is released after combustion (Olajire and Ayodele, 1997 and Arslan, 2001). The Ni and Cr sources in street dust are believed to be corrosion of cars and chrome plating of some motor vehicle parts (Akhter and Madany, 1993 and Al-Shayep and Seaward, 2001). Zn is a component of tires, which is released as they wear (Doss *et al.*, 1995).

Street dust has a particular concern due to its potential health risk to children through hand-to mouth activities, important source of house dust and urban atmospheric particulate matter and being inhaled by those traversing the streets and those residing in the vicinity of the streets (Ljung *et al.*, 2005 and Acosta *et al.*, 2009). It carries a high loading of contaminants such as metals and organic pollutants (Kim *et al.*, 1998; Li *et al.*, 2001 and Yunker *et al.*, 2002). Due to the non-biodegradability of heavy metals and their long biological half-lives, their accumulations in the food chain have a significant effect on human health in the long term (Alloway, 1990 and Kabata-Pendias and Pendias, 1992). Metals pollution accumulates in the street dust, soil, and surface and influences both the population health and ecosystem (Tüzen, 2003 and Ferreira-Baptista and

De Miguel, 2005). During rain periods, the dust usually gets discharged in the adjoining marine environment that could seriously pollute the water and concentrate in the sediments of the coastal area. This may prove toxic to marine life and contaminate fish or shellfish (Chirenje *et al.*, 2006).

Heavy metals cause toxic effects (Massadeh *et al.*, 2006). Human exposure to high concentrations of heavy metals leads to their accumulation in the fatty tissues of the human body and affects the central nervous system, or may be deposited in the circulatory system and disrupt the normal functioning of the internal organs (Waisberg *et al.*, 2003 and Bocca *et al.*, 2004). Lead poisoning causes permanent neurological, developmental, and behavioral disorders, particularly in children (Laidlaw *et al.*, 2005). Some trace metals (*e.g.* Cu and Zn) at low concentrations are harmless, but other (*e.g.* Pb and Cd) at extremely low concentrations are toxic and initiators or promoters in many diseases and cancer (Willers *et al.*, 2005).

The monitoring of the metal contents of dust samples is an efficient way of obtaining information on the current environmental state of large areas. There is a lack of information on the concentrations of heavy metals in street dust of Jeddah, Saudi Arabia, which may provide important information on the state of the environmental pollution of urban and industrial areas, and to be used as a useful indicator of the heavy metal pollution sources. Therefore, the present study aims to (1) reduce that lack by evaluating the distribution of some heavy metals (Pb, Ni, Cd, Cr, Cu, Zn, Fe and Mn) in street dust samples collected from the urban and industrial areas in Jeddah, (2) compare the concentrations of heavy metals between the main streets and substreets in the urban area, (3) compare the heavy metal results from both study areas with those available in various areas throughout the world, and (4) investigate the factors effecting on the metal concentrations in the street dust.

Materials and Methods

Study Area

Jeddah is the second largest city of Saudi Arabia and is located on the Red Sea coast in the western part of Saudi Arabia. It is surrounded by mountains from north-east, east and south-east. Jeddah is a large

commercial and industrial center as well as the crossroads between East and West to Asia, Africa and Europe. The general climate of Jeddah is warm and humid but moderate in winter, however in summer; it is characterized by high temperature, humidity, and solar radiation. Rainfall is generally sparse. Two sampling areas in Jeddah were selected according to traffic density and industrial activities. The first area was in Aljamaa district, which represented the urban area, located south of Jeddah city and characterized by relatively high traffic density. The second one was in industrial area, located south of Jeddah city, south of Aljamaa district.

Sample Collection

Street dusts were sampled during October - November 2010, to avoid rain washing out the heavy metals. A sampling point within each area was randomly selected. The sampling was carried out by sweeping an area of about 1 m² from pavement edges using a plastic dustpan and brushes (Christoforidis and Stamatis, 2009). The samples were collected from both sides of the road. Street dusts were not collected from sites adjacent to specific pollution sources (*e.g.* industries or gasoline sites). The samples were transferred to air-tight polyethylene bags until transport to the laboratory. Dust samples were stored in small self-sealing plastic bags after air-drying at room temperature, and then sieved through a 1.0 mm mesh nylon sieve to remove extraneous material. Samples were homogenized and sieved through 63µm sieve size. This size is chosen because dust may contain higher metal concentrations (Whicker *et al.*, 1997), and particles below this size are considered hazardous (Duggan and Inskip, 1985). Dust samples were moisture equilibrated for at least 12 h in desiccators and weighted. After weighting, the street dust samples were digested for the metal analysis.

Heavy Metal Analysis

Known weight (0.5 g) of dust fractions (< 63 µm) were subjected to chemical extraction using a 1:3 mixture of concentrated hydrochloric and nitric acid (Harrison and Perry, 1986). The clear digested solutions were made to 50 ml with double-distilled water, and stored in plastic bottles. Pb, Ni, Cd, Cr, Cu, Zn, Fe and Mn concentrations in the final solutions were determined using a Varian Atomic Absorption Spectrometer (AAS) Spectra AA-220-FS. All solvents and chemicals used were analytical reagent grade. All the glassware and plastic vessels were treated by dilute (1:1) nitric acid

and then rinsed with double distilled water before use. Double-distilled water was used for preparing the stock solutions of target metals and all dilutions. Calibration curves for each target metals were obtained by using suitable standard solutions prepared from the stock solutions. For all measured metals, good correlation was found with $R^2 > 0.995$. The reproducibility expressed as relative standard deviation (RSD) for replicate analyses of the calibration standard for all measured metals varied from 1.99% to 3.89%. The detection limit of each metal was calculated from the data of replicate measurements of low concentration samples and observed from their standard deviation. The instrument was calibrated using metal standards for each element being analyzed. In order to determine the precision of the analytical process, sample from one site was analyzed four times. The RSD for this sample was calculated to 2.5%. Laboratory blanks were prepared by adding same volume of a 1:3 mixture of concentrated hydrochloric and nitric acid that was added to the samples to a conical flask containing none of the samples being investigated. This consisted of all components added to the matrix during digestion. Blank samples were analyzed for total trace metal levels. The relative concentration in percentage of an element in the sum of elements was calculated and the formula is: Percentage of X = $X / (\text{sum of all elements}) * 100\%$.

Statistical Analysis

The correlation coefficient (r) and the correlation significant t-test were determined using the alternative method of calculation (Gregory, 1963). Student's t-test was used to estimate the significant difference between the mean concentrations of heavy metals (Gregory, 1963).

Results and Discussion

Heavy Metals in Street Dust

The minimum, maximum, median and arithmetic mean concentrations of the individual measured heavy metals in the street dust collected from the main streets of the urban and industrial areas are summarized in Table 1. Fe, Mn and Zn were the abundant metals, however Cd was found in the lowest concentrations. The distribution of the individual measured metals were found to follow the pattern of $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Cr} > \text{Pb} > \text{Ni} > \text{Cd}$ in the main street of the urban area and $\text{Fe} > \text{Mn} > \text{Zn} > \text{Pb} > \text{Cu} > \text{Cr} > \text{Ni} > \text{Cd}$ in the industrial area

(Fig. 1). The mean relative concentrations of the individual metals in the street dust of both urban and industrial areas were, respectively, 0.62% and 1.20% for Pb, 0.35% and 0.31% for Ni, 0.02% and 0.018% for Cd, 0.64% and 0.54% for Cr, 1.10% and 1.06% for Cu, 3.00 % and 2.72% for Zn, 89.74 % and 89.62 % for Fe and 4.52 % and 4.53 % for Mn (Fig. 1).

Fig. 1. The relative concentrations in percentage of the individual metals to the total concentrations of metals in street dusts collected from the urban (main streets and substreets) and industrial areas.

Pb pollution comes from combustion of gasoline that contains tetraethyl lead as an anti-knock agent (Tüzen, 2003). The highest lead concentrations have been detected in dust collected from streets carrying

heavy traffic (Fergusson and Kim, 1991 and Divrikli *et al.*, 2005). Although Pb has been banned in petrol for several years in Saudi Arabia, the concentration of Pb in street dust of urban area reflects the significant degree of historical Pb contamination and its long half-life, because Pb was used in fuel for decades. The average concentration of Pb in the street dust in the industrial area was significantly ($p < 0.001$) higher (1.5 times) than that found in the main streets of the urban area (Table 1). The relatively high concentration of Pb in the industrial area is mainly attributed to accumulation of Pb emitted from industrial activities and traditional use of leaded gasoline for long time. Pb pollution occurs on a local scale by industrial emissions and on a larger scale by emissions from vehicles that use leaded gasoline (Koepe, 1981; Celik *et al.*, 2005 and Tume *et al.*, 2008).

Although Pb has been completely removed from fuel in Saudi Arabia, Pb in the street dust of the main streets of the urban area could be considered as an indirect Pb source particularly at the highest congestion of traffic density. Li *et al.* (2004) reported that although the leaded petrol was banned in Hong Kong in 1999, the Pb contamination due to the historical use of Pb in petrol was still significant in the urban soils. High concentrations of Pb were found in settled dust in an urban area of Giza, Egypt despite decades of using unleaded gasoline (Khoder *et al.*, 2010).

The average concentration of Ni in the main street dusts of the urban area was significantly ($p < 0.001$) higher (1.46 time) than that found in the industrial area (Table 1). The relatively high concentrations of Ni in the main street dusts of the urban area may be attributed to high traffic density which increases the emissions. The highest concentration of Ni content in street dust was found in the streets with heavy traffic density (Al-Khashman, 2007). Ni pollution on a local scale is caused by emissions from vehicle engines that use Ni gasoline and by the abrasion and corrosion of Ni from vehicle parts (Al-Shayeb and Seaward, 2001). In the present study, significant differences ($p < 0.001$) was found between Cd concentrations in street dust collected from the main streets of the urban area and those collected from the industrial area (Table 1). The average Cd concentration in street dust from the main streets of the urban area was found to be 1.43 times higher than that found in the industrial areas. This result is in agreement with Al-Khashman (2007) who found that the highest mean Cd content was found in the streets with heavy traffic. Higher concentrations of Zn and Cd in heavy traffic zones

indicate that fragmentation of car tires is a likely source of these metals (Elik, 2003). Cd is released as a combustion product in the accumulators of motor vehicles or in carburetors (Charlesworth *et al.*, 2003 and Divrikli *et al.*, 2005).

The average concentration of Cr in the main street dust of the urban area was significantly ($p < 0.001$) higher than that found in the industrial area (Table 1). The average Cr concentration in street dust was 1.53 times higher in the main streets of the urban area than in the industrial area. This result agrees with Al-Khashman (2007) and Christoforidis and Stamatis (2009) who found that the highest concentrations of Cr in the street dusts with heavy traffic density. In addition, Cr in dust is associated with the chrome plating of some motor vehicle parts (Al-Shayep and Seaward, 2001). In the present study, Cu concentrations in the street dust collected from the main streets of the urban area were significantly higher ($p < 0.01$) than those found in the industrial area (Table 1).

Table 1. Summary statistics of the heavy metal concentrations in the street dust collected from the urban (main streets) and industrial areas.

Metal	Urban (Main streets)					Industrial				
	Minimum	Maximum	Median	Mean	S.D. ^a	Minimum	Maximum	Median	Mean	S.D.
Pb	40.45	115.10	58.64	70.36	24.94	66.94	179.00	97.36	105.76	28.49
Ni	30.00	47.65	39.40	39.71	4.73	15.20	44.00	25.83	27.28	7.61
Cd	1.61	3.17	2.06	2.24	0.45	0.69	3.06	1.55	1.57	0.50
Cr	55.90	98.85	72.83	72.93	12.34	16.17	78.00	45.00	47.67	16.01
Cu	71.15	157.95	131.03	125.52	22.42	60.64	175.46	80.90	93.66	36.64
Zn	266.45	476.75	323.18	340.85	57.69	100.20	419.70	245.45	240.50	101.35
Fe	7796.00	11802.00	10439.00	10199.42	1138.52	4941.92	14038.92	7074.10	7918.42	2633.00
Mn	352.00	630.00	525.50	514.15	74.17	141.90	846.80	367.34	400.64	143.41

^aStandard deviation

The average Cu concentration in street dust from the main streets of the urban area was found to be 1.34 times higher than that found in the industrial areas. Cu concentrations ranged from 71.15 to 157.95 $\mu\text{g/g}$ (with a mean value of 125.52 $\mu\text{g/g}$) in the main streets of the urban area and 60.64 to 175.46 $\mu\text{g/g}$ (with a mean value of 93.66 $\mu\text{g/g}$) in the industrial area. This may be attributed to the higher traffic density which leads to an increase in Cu emission. The highest levels of Cu were observed in the street dust samples from heavy traffic areas (Al-Khashman, 2007). Cu source in the street dust was ascribed to corrosion of the metallic parts of cars like engine wear, thrust bearing, and brush wear (Divrikli *et al.*, 2005 and Al-Khashman and Shawabkeh, 2006).

The average concentration of Zn in the main street dusts of the urban area was significantly ($p < 0.001$) higher than that found in the industrial area (Table 1). The average Zn concentration in street dust from the main streets of the urban area was 1.42 times higher than that found in the industrial areas. The highest levels of Zn were found in the street dust samples from heavy traffic areas (Al-Khashman, 2007). The elevated concentrations of Cu, Zn and Ni can be attributed to the heavy traffic near the sampling site (Sternbeck *et al.*, 2002 and Harrison *et al.*, 2003). Zn particles may be derived from industrial sources, with the abrasion of tires of motor vehicles a possible second source (Adriano, 2001 and Carreras and Pignata, 2002). In the present study, Fe was the most abundant metal content in the street dust. Fe concentrations in street dust collected from the main streets of the urban area were significantly higher ($p < 0.001$) than those found in the industrial area (Table 1).

The concentrations of Fe ranged from 7796 to 11802 $\mu\text{g/g}$ (with a mean value of 10199.42 $\mu\text{g/g}$) in the main streets of the urban area and 4941.92 to 14038.92 $\mu\text{g/g}$ (with a mean value of 7918.42 $\mu\text{g/g}$) in the industrial area. The average Fe concentration in street dust from the main streets of the urban area was found to be 1.29 times higher than that found in the industrial areas. The highest levels of Fe in street dust collected from the main streets of the urban area may be attributed to the pollution originating from heavy traffic density and anthropogenic activities. This is in agreement with Al-Khashman (2007) who found the highest levels of Fe in the street dust samples from heavy traffic areas. The possible sources of Fe in street dust were believed to be wear of brake linings material, corrosion and wear of the vehicles (Hildemann *et al.*, 1991 and Garg *et al.*, 2000). In the present study, the average concentration of Mn in the main street dusts of the urban area was significantly ($p < 0.01$) higher than that found in the industrial area (Table 1). The average Mn concentration in street dust from the main streets of the urban area was 1.28 times higher than that found in the industrial areas. The highest levels of Mn were found in the street dust samples from heavy traffic areas (Al-Khashman, 2007). The main source of Mn in dust samples was from the geological material, traffic, and tire wear (Divrikli *et al.*, 2005).

Fe, Mn and Zn were the abundant street dust metals collected from the substreets of the urban areas (Fig. 2). The distribution of the individual measured metals in substreet dust were found to follow the

pattern $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Pb} > \text{Cr} > \text{Ni} > \text{Cd}$. The mean relative concentrations of the individual metals in substreets dust were 0.63% for Pb, 0.28% for Ni, 0.02% for Cd, 0.47% for Cr, 0.98% for Cu, 2.52% for Zn, 90.50 % for Fe and 4.59 for Mn (Fig. 1). The highest metal concentrations were found in the main street dusts. Significant differences ($p < 0.001$) were found between the average concentrations of the individual metals in the main streets and substreets. The average concentrations of the individual metals in the dusts collected from the main and substreets were: 70.36 and 53.51 $\mu\text{g/g}$ for Pb, 39.71 and 24.00 $\mu\text{g/g}$ for Ni, 2.24 and 1.32 $\mu\text{g/g}$ for Cd, 72.93 and 40.1 $\mu\text{g/g}$ for Cr, 125.52 and 83.32 $\mu\text{g/g}$ for Cu, 340.85 and 214.10 $\mu\text{g/g}$ for Zn, 10199.42 and 7678.84 $\mu\text{g/g}$ for Fe and 514.15 and 389.69 $\mu\text{g/g}$ for Mn, respectively (Fig. 2). In addition, the main street/substreets metal concentration ratios were 1.31, 1.65, 1.70, 1.82, 1.51, 1.59, 1.33 and 1.32 for Pb, Ni, Cd, Cr, Cu, Zn, Fe and Mn, respectively (Fig. 2). The highest concentrations of the measured heavy metals in the main street dusts are mainly attributed to the high emission of those metals from the heavy traffic density. Heavy metals such as Cd, Cu, Pb, Ni, Fe and Zn are often associated with traffic densities (Birmili *et al.*, 2006 and Han *et al.*, 2007). Pb and a variety of other metals concentrations of roadside and parking dust and vegetation are directly related to traffic density (Grigalaviciene *et al.*, 2005; Hjortenkrans *et al.*, 2006 and Tokalioglu and Kartal, 2006). Pb and Cd concentrations in roadside soils generally decreased with increasing distance from the main road (Bakirdere and Yaman, 2008). Soil pollution by heavy metals was generally concentrated in the first few meters to tens of meters on either side of the road pavement and then sharply decreased with distance far away from the road (Blok, 2005 and Nabulo *et al.*, 2006). Piron-Frenet *et al.* (1994) found a correlation between traffic density and heavy metal deposited in the roadside soil. The exponential equation fits quite well for the variations of Pb, Cd, Zn and Cu contents with distance pollution sources (Zheng *et al.*, 2010). In the present study, the higher concentrations of heavy metals in the main street dusts than those were found in the substreets indicated that, humans living along the main street with heavy traffic density may be exposed to higher concentrations of heavy metals.

Generally, the concentrations of all measured metals in street dust except Pb were significantly higher in the main streets of the urban area associated with high traffic density, followed by the industrial area and

substreets of the urban area. This shows the extent to which automobiles and industries release these metals as pollutants into the environment. The results in the present study confirmed that the main reason of high concentrations of heavy metals localized in industrial and in urban roadsides are either related to industrial activity or the density of the traffic.

Fig. 2. Metal concentrations in street dust collected from the main streets and substreets of the urban area.

Comparison of Heavy Metals Levels in Street Dust of Jeddah with Other International Cities

The heavy metal contents in street dust samples collected from the urban and industrial areas in Jeddah city were compared with those found in different locations of the world (Table 2). As shown in this Table, it could be seen clearly in general that, Pb, Cu, Zn, Ni, Cr, Cd, Fe and Mn mean values in street dust from both study areas were lower / higher or similar to those detected in other cities of the world. Generally, the variation in the levels of measured metals in street dusts among the different locations of the world was presumably due to the difference in the traffic density, industrial activities, and intensity of human activities, land use patterns and the frequency of rainfall prior to sample collection.

Until now, there are no guidelines for concentration of metals/metalloids in dusts (Leung *et al.*, 2008). However, a substantial part of the street dust comes from soil re-mobilization/re-suspension while some of the street dusts are re-suspended and return to the soil surfaces (Charlesworth *et al.*, 2003 and Ferreira-Baptista and De Miguel, 2005). Thus, it would be appropriate to compare the metal concentration in street dusts collected from different areas to the allowable limits in soil. The average concentrations of Cu and Zn found in the main streets only exceeded the maximum permissible limit 100 µg/g for Cu and 300 µg/g for Zn, respectively (Fabis, 1987 and Sezgin *et al.*, 2003). The possible sources of Cu include wearing of machinery parts, and brake pads, however, Zn may have originated from wear and tear of vulcanized vehicle tires, and corrosion of galvanized automobile parts. Almost all the street dust samples collected from the main streets and substreets in the urban area as well as from industrial area were found to be very rich with crustal metals (Fe and Mn). There is no limit on the concentration for these metals in the soil, but their extensive presence in all the sampling sites may be of concern due to their potential adverse health effects (Golub *et al.*, 1992).

The average concentrations for Pb in street dust from the main streets (70.36 µg/g) and substreets (53.51 µg/g) of the urban area were lower than the maximum permissible limit in the soil (100 µg/g, Fabis, 1987), whereas the average concentration for Pb in street dust from industrial area (105.76 µg/g) were nearly similar to this maximum permissible limit.

Table 2. Comparison of the distribution of metals in street dust samples collected from different sites all over the world.

Site	Pb	Cu	Zn	Ni	Cr	Cd	Fe	Mn	Reference
Jeddah, Saudia Arabia (Urban area, main streets)	70.36	125.52	340.85	39.71	72.93	2.24	10199.42	514.15	Present study
Jeddah, Saudia Arabia (Urban area, substreets)	53.51	83.32	214.10	24.00	40.10	1.32	7678.84	389.69	Present study
Jeddah, Saudia Arabia (Industrial area)	105.76	93.66	240.50	27.28	47.67	1.57	7918.42	400.64	Present study
Kavala (Greece)	301.00	124.00	272.00	58.00	196.00	0.20	—	—	Christoforidis and Stamatis (2009)
Baoji (China)	408.00	123.00	715.00	49.00	—	—	—	—	Lu et al. (2009)
Bahrain	742.00	—	67.00	12.00	9.60	1.50	—	—	Madany et al. (1994)
Xian (China)	231.00	95.00	421.00	—	167.00	—	—	687.00	Yongming et al. (2006)
Luanda (Angola)	266.00	38.00	98.00	10.00	26.00	1.10	11572.00	258.00	Baptista and De Miguel (2005)
Yazgat (Turkey)	69.00	38.00	—	77.00	33.00	3.00	—	852.00	Divrikli et al. (2003)
Istanbul (Turkey)	61.0 - 383.0	47.0 - 407.0	226.0 - 1852.0	10.0 - 66.0	—	1.0 - 6.7	—	—	Sezgin et al. (2003)
Birmingham (U.K.)	48.00	467.00	534.00	—	—	1.60	—	—	Charlesworth et al. (2003)
Coventry (U.K.)	514.00	226.00	385.00	—	—	0.90	—	—	Charlesworth et al. (2003)
Aviles (Spain)	183.00	183.00	4829.00	—	42.00	22.30	42200.00	—	Ordonez et al. (2003)
Manchester (U.K.)	265.00	113.00	653.00	—	—	—	8767.00	—	Robertson et al. (2003)
Various sites (Bahrain)	697.00	—	152.00	126.00	144.00	72.00	—	—	Akhter and Madany (1993)
Cuenca (Equador)	19.0 - 970.0	—	44.0 - 1018	—	—	0.6 - 1.4	—	—	Hewitt and Candy (1990)
Kuala Lumpur (Malaysia)	2466.00	—	344.00	—	—	3.00	—	—	Ramlan and Badri (1989)
London (U.K.)	1030.00	155.00	680.00	—	—	3.50	26000.00	—	Schwar et al. (1988)
Athens (greece)	65.0 - 259.0	—	75.0 - 241.0	—	—	1.8 - 4.3	—	—	Yassoglou et al. (1987)
Various sites (Nigeria)	4.0 - 243.0	—	12.0 - 48.0	1.0 - 3.0	0.7 - 2.6	0.2 - 1.7	—	—	Ndlokwe (1984)
Various sites (Hong-Kong)	438.0 - 1621.0	34.0 - 212.0	—	—	—	0.2 - 2.3	—	—	Lau and Wong (1982)
Lancaster (U.K.)	150.0 - 15000.0	—	—	15.0 - 126.0	10.0 - 91.0	1.0 - 14.6	—	—	Harrison (1979)
Amman (Jordan)	236.00	177.00	358.00	88.00	—	1.70	7132.00	—	Al-Khashman (2006)
Various sites (Singapore)	68.6 - 338	246.9 - 9069.0	274.7 - 1696.0	53.1 - 185.6	85.7 - 1245.0	0.71 - 2.41	—	—	Joshi et al. (2009)
Kayseri (Turkey)	74.80	36.90	112.00	44.90	29.00	2.53	—	—	Tokaloglu and Kartal (2006)
Lulea (Sweden)	34.00	24.00	60.00	8.00	13.00	0.10	—	—	Karlsson and Viklander (2008)
Various sites (Hangzhou, China)	127.6 - 194.0	49.2 - 211.6	220.0 - 709.0	19.3 - 28.4	37.7 - 60.2	1.02 - 3.62	—	—	Zhang and Wang (2009)
Various sites (Dhaka, Bangladesh)	34.3 - 53.3	22.2 - 104.9	95.9 - 168.7	22.9 - 35.2	100.4 - 136.1	—	—	—	Ahmed et al. (2007)
Maximum Limit	100.00	100.00	300.00	50.00	100.00	3.00	—	—	Fabis (1987), cited from Joshi et al., 2009)

Correlation Between the Street Dust Heavy Metal Concentrations

Inter-element relationships can provide interesting information on the sources of heavy metal and their pathways (Manta *et al.*, 2002). Correlation coefficients between the heavy metal concentrations in street dust collected from the urban and industrial areas are shown in Table 3. Significant positive correlation coefficients were found between the concentrations of Cr, Cd, Cu and Zn and between the concentrations of Fe, Mn and Ni, Cr, Cu and Zn in the urban street dust. These relationships indicated that heavy traffic was the common contamination sources for heavy metals in the street dust of the urban area and the origin of the metals. Monaca *et al.* (2000) found positive relationships between Cu, Mn, Pb, and Zn in urban environments in Florence, Italy. In the present study, insignificant positive correlation coefficients were found between the concentrations of Pb and other metals in street dust of the urban area (Table 3), due to the use of unleaded gasoline. Significant positive correlation coefficients were found between the concentrations of the measured metals in street dust collected from the industrial area. These correlations indicated that these metals originated from similar or co-located sources and the origin of the metals in the industrial area was highly related to the industrial activities and heavy traffic. The close relationships among Cd, Cu, Pb and Zn might indicate the combined soil pollution by multi-heavy metals as a result of long-term industrial and human activities (Lu and Bai, 2010).

Table 3. Correlation coefficients between the heavy metal concentrations in street dusts collected from the urban and industrial areas in Jeddah city.

	Pb	Ni	Cd	Cr	Cu	Zn	Fe	Mn
Urban area								
Pb	1	0.21	0.27	0.28	0.06	0.18	0.02	0.19
Ni		1	0.63 ^c	0.80 ^c	0.80 ^c	0.57 ^c	0.46 ^b	0.47 ^b
Cd			1	0.69 ^c	0.55 ^c	0.43 ^b	0.13	0.18
Cr				1	0.68 ^c	0.73 ^c	0.45 ^b	0.49 ^b
Cu					1	0.53 ^c	0.46 ^b	0.42 ^b
Zn						1	0.40 ^a	0.42 ^b
Fe							1	0.84 ^c
Mn								1
Industrial area								
Pb	1	0.66 ^c	0.48 ^a	0.72 ^c	0.63 ^c	0.60 ^b	0.59 ^b	0.43 ^a
Ni		1	0.75 ^c	0.75 ^c	0.73 ^c	0.78 ^c	0.69 ^c	0.59 ^b
Cd			1	0.67 ^c	0.46 ^a	0.65 ^c	0.63 ^c	0.53 ^b
Cr				1	0.72 ^c	0.67 ^c	0.56 ^b	0.51 ^b
Cu					1	0.61 ^c	0.68 ^c	0.52 ^b
Zn						1	0.52 ^b	0.60 ^b
Fe							1	0.71 ^c
Mn								1

^ap < 0.05, ^bp < 0.01, ^cp < 0.001

Conclusions

The sources of the different metals in urban and industrial street dust were typically common to most urban and industrial environments, but their intensities and patterns of distribution varied according to the peculiarities of each city. The distribution of the individual measured metals in street dust was found to follow the pattern of $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Cr} > \text{Pb} > \text{Ni} > \text{Cd}$ in the main street of the urban area, $\text{Fe} > \text{Mn} > \text{Zn} > \text{Pb} > \text{Cu} > \text{Cr} > \text{Ni} > \text{Cd}$ in the industrial area and $\text{Fe} > \text{Mn} > \text{Zn} > \text{Cu} > \text{Pb} > \text{Cr} > \text{Ni} > \text{Cd}$ in the substreet of the urban area. The highest metal concentrations were found in the main street dusts of the urban area, followed by the industrial area and substreets of the urban area. However, Pb was found in the highest concentrations in industrial area. The humans living along the main street with heavy traffic density may be exposed to higher concentration of metals. Cu and Zn in the main street dusts of the urban area exceeded the maximum permissible limit in soil. Correlation coefficients between the concentrations of measured metals in street dust indicated that heavy traffic density was the major source of the heavy metals in the urban street dust; however, industrial activities and emissions from vehicles were the major sources of these metals in the street dust of the industrial area. A regular monitoring program to assess the street dust quality is needed in order to implement suitable pollution control measures in the city environment.

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توزيع العناصر الثقيلة في أتربة الشوارع بالمناطق الحضرية والصناعية بمدينة جدة - المملكة العربية السعودية

ممدوح إبراهيم خضير، و منصور أحمد الغامدى، و محمد حمد شيبوب

قسم العلوم البيئية، كلية الأرصاد والبيئة وزراعة المناطق الجافة،

جامعة الملك عبدالعزيز، جدة - المملكة العربية السعودية

المستخلص. تم تقدير تركيز العناصر الثقيلة (الرصاص - النيكل - الكاديوم - الكروم - النحاس - الزنك - الحديد - المنجنيز) في أتربة الشوارع المجمعة من الشوارع الرئيسية والفرعية بالمنطقة الحضرية (حي الجامعة) وكذلك من المنطقة الصناعية في مدينة جدة - المملكة العربية السعودية. أوضحت الدراسة أن أعلى تركيز للمعادن المقدرة في أتربة الشوارع قد وجد في أتربة الشوارع الرئيسية، يليها المنطقة الصناعية، ثم الشوارع الفرعية بالمنطقة الحضرية، ماعدا الرصاص حيث كان أعلى تركيز له قد وجد في المنطقة الصناعية. وقد وجد أن متوسط تركيزات المعادن منفردة في أتربة الشوارع الرئيسية والفرعية، وكذلك المنطقة الصناعية كانت ٧٠,٣٦، و ٥٣,٥١، و ١٠٥,٧٦ ميكروجرام/جرام للرصاص، و ٣٩,٧١، و ٢٤,٠، و ٢٧,٢٨ ميكروجرام/جم للنكل، و ٢,٢٤، و ١,٣٢، و ١,٥٧ ميكروجرام/جم للكاديوم، و ٧٢,٩٣، و ٤٠,١٠، و ٤٧,٦٧ ميكروجرام/جم للكروم، و ١٢٥,٥٢، و ٨٣,٣٢، و ٩٣,٦٦ ميكروجرام/جم للنحاس، و ٣٤٠,٨٥، و ٢١٤,١٠، و ٢٤٠,٥٠ ميكروجرام/جم للزنك، و ١٠١٩٩,٤٢، و ٧٦٧٨,٨٤، و ٧٩١٨,٤٢ ميكروجرام/جم للحديد، و ٥١٤,١٥، و ٣٨٩,٦٩، و ٤٠٠,٦٤ ميكروجرام/جم للمنجنيز، على التوالي. كان متوسط نسب تركيز

المعادن في أتربة الشوارع الرئيسية إلى تركيزاتها في أتربة الشوارع الفرعية بالمنطقة الحضرية هي ١,٣١، و ١,٦٥، و ١,٧٠، و ١,٨٢، و ١,٥١، و ١,٥٩، و ١,٣٣، و ١,٣٢ للرصاص، والنيكل، والكاديوم، والكروم، والنحاس، والزنك، والحديد، والمنجنيز على التوالي. كذلك أشارت الدراسة إلى أن متوسط تركيز المعادن المقاسة بأتربة الشوارع بمنطقتي الدراسة كانت إما أقل، أو أعلى، أو متشابهة مع تلك التركيزات التي وجدت في مدن أخرى في العالم، بينما وجد أن متوسط تركيز كل من النحاس، والزنك في أتربة الشوارع الرئيسية بالمنطقة الحضرية فقط قد تجاوز الحدود القصوى المسموح بها في التربة. وجدت علاقات موجبة معنوية بين تركيزات كل من الكروم، والكاديوم، والنحاس، والزنك، وكذلك بين تركيزات كل من الحديد، والمنجنيز، وتركيزات كل من النيكل، والكروم، والنحاس، والزنك في أتربة شوارع المنطقة الحضرية. وعلى الجانب الآخر، وجدت علاقات موجبة غير معنوية بين تركيز الرصاص والعناصر الأخرى في أتربة شوارع المنطقة الحضرية، أما في المنطقة الصناعية فقد وجدت علاقات موجبة معنوية بين تركيزات العناصر المقاسة في أتربة الشوارع.

الكلمات الدالة: المعادن الثقيلة، أتربة الشوارع، منطقة حضرية، منطقة صناعية، شوارع رئيسية وفرعية، جدة