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ORIGINAL PAPER

Seasonal concentrations of lead in outdoor and indoor dust and blood of children in Riyadh, Saudi Arabia

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Abstract Because detrimental effects of exposure to lead (Pb) on human health have been observed, we previously investigated concentrations of Pb in water supplies and blood of adult residents of Riyadh, Saudi Arabia. The objectives of the present study were to: (1) examine seasonal rates of deposition of Pb in dust in several areas of Riyadh city, (2) measure concentrations of Pb in both outdoor and indoor dust, (3) compare concentrations of Pb in dust in Riyadh with those reported for other cities, and (4) quantify Pb in blood of children living in Riyadh. Mean, monthly deposition of PB in outdoor dust was $4.7 \times 10^1 \pm 3.6$ tons km^{-2}, with a mean Pb concentration of $2.4 \times 10^2 \pm 4.4 \times 10^1$ μg/g. Mean, monthly deposition of Pb in indoor dust was 2.7 ± 0.70 tons km^{-2}, with a mean concentration of $2.9 \times 10^1 \pm 1.5 \times 10^1$ μg Pb/g. There was a significant ($P < 0.01$) correlation between concentrations of Pb in outdoor and indoor dust. There was no correlation between concentrations of Pb in indoor dust and that in blood of children of Riyadh, whereas there was a weakly significant ($P < 0.05$) correlation between concentrations of Pb in outdoor dust and that in blood of children. The mean (±SD) concentration of Pb in blood of children in Riyadh was 5.2 ± 1.7, with a range of $1.7–1.6 \times 10^1$ μg/dl. Concentrations of Pb in blood of 17.8 % of children in Riyadh were greater than 10 μg/dl, which is the CDC's level of concern.

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Introduction

Concentrations of lead (Pb) in urban areas of the Kingdom of Saudi Arabia (KSA), particularly in Riyadh, and its potential effects on health are of concern (El-Shobokshy et al. 1990; Ahmed and Ishiga 2006; Al-Othman 2010; Aburas et al. 2011; Al-Othman et al. 2012). The principal source of Pb has been attributed to motor vehicle traffic, which are associated with releases of Pb into the adjacent commercial and residential areas (Ewen et al. 2009). Pb is one of the most widely dispersed toxic substances and can cause significant toxicity to people exposed via inhalation, ingestion, or dermal contact (USEPA 1994; Al-Othman 2010; Mielke et al. 2011; Soto-Jimènez and Flegal 2011; Latif et al. 2011; Al-Othman et al. 2012; Ali and Al-Qahtani 2012). Behaviors of children, such as playing outdoors and hand-to-mouth contact, contribute to exposure to Pb, while absorption from the gastrointestinal tract and greater sensitivity to the hazardous effects of Pb making them more susceptible. Hence, Pb is a special hazard for young children (Laidlaw and Taylor 2011). Dust is a pathway of exposure to Pb and in particular for children (Laidlaw et al. 2005; Laidlaw and Taylor 2011). Dust, defined as a solid matter composed of natural biogenic materials, soil, and anthropogenic metallic constituents (Abdul Wahab et al. 2012), can be classified as indoor, such as that in households and schools, or outdoor, such as that in streets, motorways, playgrounds. Indoor and outdoor dust has been investigated as potential sources of exposure of people to metals, including Pb (Yaghi and Abdul-Wahab 2004). The fact that most people spend 80–90 % of their time indoor results in a growing public concern about the quality of indoor air including metals such as Pb (Klepeis et al. 2001; Sharpe 2004).

Despite significant progress in minimizing concentrations of Pb in the environment over the last three decades, Pb is classified second, after only arsenic, on the priority list of hazardous substances, by the Agency for Toxic Substances and Disease Registry (ATSDR, http://www.atsdr.cdc.gov/cercla/) (ATSDR 2011). According to the World Health Organization (WHO), leaded gasoline and emissions from smelters and battery recycling industries constitute the most important major sources of Pb exposure (WHO 2002). In Saudi Arabia, leaded gasoline is a primary source of Pb in soils and dust (El-Shobokshy 1984; El-Shobokshy et al. 1990; Ahmed et al. 1993; Aburas et al. 2011). While the use of leaded gasoline in KSA was phased out in 2001, there is still residual Pb in dust due to historical uses and there is also Pb released in unleaded gasoline. Total fuel consumption of the Saudi industrial sector in 2008 was about 3 million tons of diesel fuel and 8.5 million tons heavy fuel oil (IEA 2010). Accumulation of soil Pb created by leaded gasoline is proportional to highway traffic flow (Mielke et al. 2011). While exposure of children to Pb in dust and paint was first identified more than a century ago (Gibson 1904), the concentrations of Pb in outdoor and indoor dust that are hazardously remain poorly defined.

Previously, concentrations of Pb in water supplies and correlation with those in whole blood of the population of Riyadh were investigated (Al-Othman et al. 2012). That study indicated that concentrations of Pb in blood of a portion of the population of adults exceeded guidelines set by WHO for protection of heath of humans. While water could be the source of some of the Pb observed in blood, it could not explain all of the exposure. Therefore, objectives of the present study were to: (1) quantify Pb in both outdoor and indoor dust, (2) determine monthly rates of deposition of Pb in outdoor and indoor dust in several regions of Riyadh city, (3) compare concentrations of Pb in dust form Riyadh with those of other cities, and (4) quantify Pb in blood of children living in Riyadh and investigate associations with concentrations of Pb in outdoor and indoor dust.

Materials and methods

Chemicals

Unless otherwise stated, all solvents and chemicals were analytical reagent grade (Merck, Darmstadt, Germany). Nitric acid (AnalaR, BDH Laboratory Supplies), hydrochloric acid (Extra pure, Merck, Darmstadt, Germany), hydrofluoric acid (Extra pure, Merck, Darmstadt, Germany) were used during

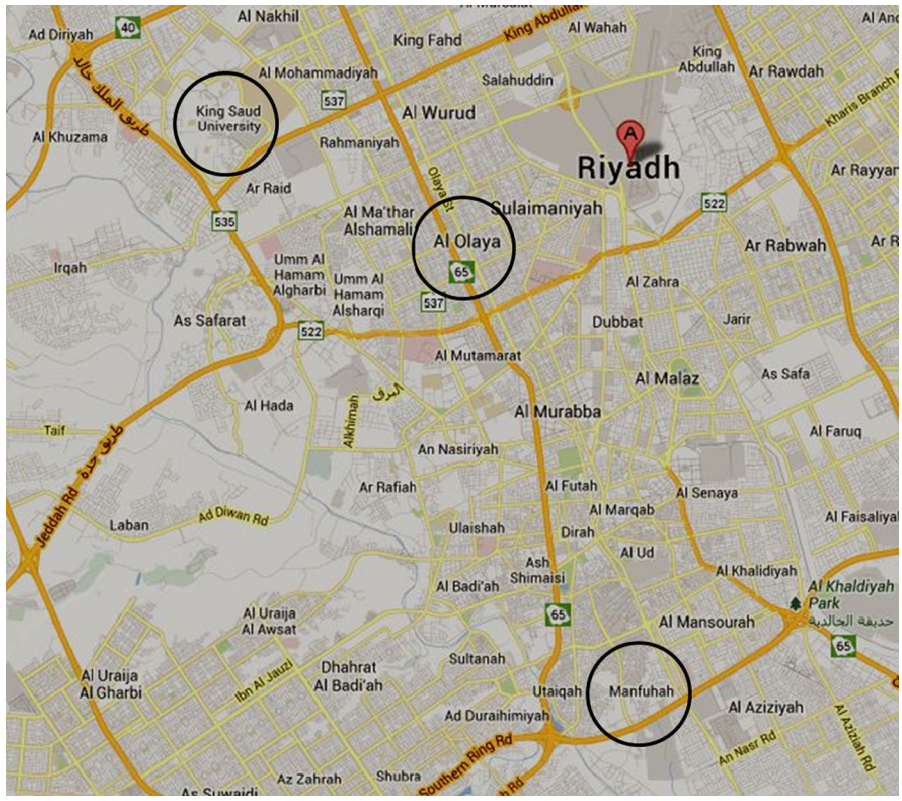

Fig. 1 Map of locations from which outdoor and indoor dust was collected in Riyadh, Kingdom of Saudi Arabia. Locations in Riyadh were (1) Northern district, King Saud University, (2) Central district, Al-Olaya and (3) Southern district, Al-Manfouha

sample preparation and digestion. All water used during sample preparation and atomic absorption spectroscopic analysis was MilliQ water (Millipore S.A., Cedex, Molsheim, France).

Sampling locations

This study was conducted in Riyadh, the largest city and capital of the Kingdom of Saudi Arabia (KSA). The city, which is situated in the center of the Arabian Peninsula, has an area of more than 1,000 km^2, is divided into 15 municipalities. Riyadh has a population estimated to be approximately 5.8 million (Saudi CDSI 2007; http://www.cdsi.gov.sa/english/) comprised of 68 % Saudi nationals and 32 % non-Saudis (http://www.cdsi.gov.sa/english/). Samples of dust were collected from three areas: (1) Northern, King Saud University, (2) Central, Al-Olaya, and (3) Southern, Al-Manfouha (Densely populated area) (Fig. 1). Each area was characterized by different activities and environmental features.

Collection of dust and extraction of Pb

Aerosol dust deposition samples of both indoor and outdoor dusts were by use of a MDCO dust collector according to previously published methods (Sow et al. 2006). The MDCO collector consists of a rectangular plastic tray, 52.5 (L) × 31.5 (W) and 10.0 (H) cm, with a flat marble filter fitted on top, which acts as a trap for dust and prevents settled particles from being re-suspended. The amount of dust collected at each location was calculated and expressed as metric tons km^{-2} by dividing the total weight of the collected sample by the area of the sampler's opening. Indoor dust was collected from the dust bag of a domestic vacuum cleaner used in respective households to clean carpets and furniture. Samples were air-dried overnight to remove moisture, powdered in an agate mortar, sieved to size <0.2 mm of aperture size with the aid of a stainless steel sieve, and stored in polyethylene bottle for further analysis. Particles greater than 2 mm were removed from samples of

dust. Lead was extracted from 0.25 g of each sample of dust by use of a mixture of HNO_3:HCl:HF (9:3:2, v/v) acids in a Teflon® beaker and heating in a microwave oven at 150 °C for 10 min. Subsequently, total suspended particulates in the extraction residue were dissolved in 25 ml of 20 % HNO_3 and rewarmed to 80 °C for 20 min. The solution was made up to 50 ml with MilliQ® water after filtration.

Collection and preparation of blood

The study population consisted of 300 healthy male school children whose ages ranged from 6 to 14 yr. The legal guardian for each child signed a consent form that authorized the collection of blood and subsequent quantification of Pb. The protocol of the study was approved by the ethics committee at King Khalid University Hospital, Riyadh, KSA. A volume of 5–7 ml of venous blood was drawn from each child by a registered nurse by use of sealed heparinized, lead-free Vacutainer® tubes (Beckton-Dickinson, USA). Whole blood was stored on ice in coolers and transported on the same day to the laboratory, aliquots of whole blood were stored at −70 °C until analysis. Whole blood was digested in HNO_3, HCl, and H_20_2 (30 %) as described by Bukhari et al. (2005). Known volumes of blood samples were placed into a PTFE beaker with 5 ml of concentrated HNO_3 and 2 ml of HCl and evaporated on a hot plate at 90–95 °C. When dry a few drops of 30 % H_2O_2 were added. Digestion was continued until a clear solution was obtained. Digestates were cooled and washed from beakers with water and filtered through 0.45-μm filter paper and the final volume adjusted to 50 ml.

Quantification of Pb by ICP-AES

Concentrations of Pb were determined by use of inductively coupled plasma atomic emission spectroscopy (ICP-AES), by use of an iCAP 6500 ICP-AES (USA) (Thermo Scientific). Concentrations of Pb in digested samples were determined by use of a standard introduction kit (SIK), and a glass concentric nebulizer/cyclonic spray chamber (Henk 2003). The limit of quantification (LOQ) defined as the concentration of Pb that produced three times the average background intensity at the respective wavelengths selected for Pb was 2.5 μg Pb/dl. Accuracy and precision were determined by use of spike-recovery, standard reference materials, replicate analyses, and method blanks. Recovery of Pb and was determined by the use of spike-recovery of split samples. Average recoveries were 98.7 ± 1.1 % with a corresponding CV of 5 %. Accuracy was assessed by analyses of bovine blood standard reference material (NIST 955b) that contained 5.01, 13.53, or 30.63 μg Pb/dl). Samples were analyzed in triplicate with a relative standard deviation of less than 3 %. Concentrations of Pb in method blanks were less than the LOQ.

Statistical analyses

The data were log-transformed prior to conducting statistical tests. The assumptions of normality and homogeneity of variance were confirmed prior to multivariate analysis use of the Kolmogorov–Smirnov and Bartlett tests, respectively. Comparison between means of independent groups was performed using Student's *t* test. Differences were considered significant at $P < 0.05$. Pearson's coefficients of determination (r^2) were calculated to determine the association between concentrations of Pb in both outdoor and indoor dust and its corresponding concentration in blood. All statistical analyses were conducted using SPSS version 17.0.

Results and discussion

Deposition of outdoor dust varied among seasons in decreasing order: spring ($7.1 \times 10^1 \pm 1.5 \times 10^1$) > summer ($6.3 \times 10^1 \pm 1.4 \times 10^1$) > winter ($4.9 \times 10^{-1} \pm 2.5$) > autumn ($4.7 \times 10^1 \pm 3.6$) tons/km^2/month (Table 1). Mean, monthly deposition of outdoor dust averaged across the four seasons was $5.7 \times 10^{-1} \pm 1.1 \times 10^{-1}$ tons km^{-2}, which is equivalent to 690 tons km^{-2} year^{-1}, which is more than fivefold greater than the WHO limit of 106 tons km^{-2} year^{-1} (UNEP 1991). The greater rate of deposition during spring and summer was due to frequent gusty winds and sand storms which primarily take place during these two seasons. In this context, it has been reported that that rates of deposition of dust across Riyadh are affected by distance from construction sites (Modaihsh and Mahjoub 2013). Deposition of dust during winter was $4.9 \times 10^{-1} \pm 2.5$, which was slightly greater than that of 4.2×10^1 which was reported by Modaihsh and Mahjoub (2013).

Concentrations of Pb in outdoor dust fallout exhibited a similar seasonal pattern of deposition to

Table 1 Mass of outdoor dust fall on Riyadh and concentration of Pb

Season	Locations	Dust fall quantity (Kg)	Dust fall rate (Ton/km^2/month)	Pb (μg/g)
Winter	1 ($n = 3$)	1.5 ± 0.1	4.6×10^1	2.2×10^2
	2 ($n = 3$)	1.7 ± 0.2	5.1×10^1	2.2×10^2
	3 ($n = 3$)	1.7 ± 0.1	5.1×10^1	1.9×10^2
	Mean ± SD	1.7 ± 0.1	$4.9 \times 10^1 \pm 2.5$	$2.1 \times 10^2 \pm 1.2 \times 10^1$
Spring	1 ($n = 3$)	1.8 ± 0.3	5.3×10^1	2.0×10^2
	2 ($n = 3$)	2.4 ± 0.3	7.0×10^1	1.9×10^2
	3 ($n = 3$)	3.0 ± 0.1	8.9×10^1	5.6×10^2
	Mean ± SD	2.4 ± 0.5	$7.1 \times 10^1 \pm 1.5 \times 10^1$	$3.1 \times 10^2 \pm 1.8 \times 10^1$
Summer	1 ($n = 3$)	2.8 ± 0.2	8.2×10^1	3.5×10^2
	2 ($n = 3$)	1.8 ± 0.1	5.4×10^1	2.2×10^2
	3 ($n = 3$)	1.8 ± 0.3	5.2×10^1	1.9×10^2
	Mean ± SD	2.1 ± 0.5	$6.3 \times 10^1 \pm 1.4 \times 10^1$	$2.5 \times 10^2 \pm 3.8 \times 10^1$
Autumn	1 ($n = 3$)	1.5 ± 0.2	4.4×10^1	2.2×10^2
	2 ($n = 3$)	1.7 ± 0.1	5.2×10^1	1.9×10^2
	3 ($n = 3$)	1.5 ± 0.3	4.5×10^1	2.2×10^2
	Mean ± SD	1.6 ± 0.1	$4.7 \times 10^1 \pm 3.6$	$2.0 \times 10^2 \pm 1.1 \times 10^1$
Overall mean concentration (μg Pb/g dry weight)				$2.4 \times 10^2 \pm 4.4 \times 10^1$

that observed for dust with decreasing concentrations (Mean ± SD) in: spring ($3.1 \times 10^2 \pm 1.8 \times 10^1$) > summer ($2.5 \times 10^2 \pm 3.8 \times 10^1$) > winter ($2.1 \times 10^2 \pm 1.2 \times 10^1$) > autumn ($2.0 \times 10^2 \pm 1.1 \times 10^1$) μg/g dust (Table 1). The mean concentration of Pb average over the entire year was $2.4 \times 10^2 \pm 4.4 \times 10^1$. Concentrations of Pb at certain locations were influenced by their proximity sources of pollution and local prevailing meteorological conditions at the time of sampling. Concentrations of Pb in dust are also related to several other factors including size of urbanized area, number of people, age of community, and inner and outer locations of a community within a given urbanized area (Mielke et al.2011).

The overall mean concentration of Pb in outdoor dust of 2.4×10^2 μg/g observed in this study was less than the 1.8×10^3 μg Pb/g that had been previously reported for Riyadh (Al-Rajhi et al. 1996). This result might be due the fact that the sampling sites were in the vicinity of an old industrial area and motorways. The lesser concentrations of Pb in outdoor dust of Riyadh could be partially attributed to the decision of KSA to phase-out leaded gasoline in January 2001 (United Nations and Profile 2002). However, some other cities in the Kingdom have been recently reported to have greater concentrations of Pb in the atmosphere. For example, the concentration of Pb in 2.5 μm ($PM_{2.5}$) particulates in the air of Jeddah was 2.1×10^3 μg Pb/g (Table 2) (Aburas et al. 2011). PM in the atmosphere originates primarily from activities of humans, such as vehicle exhausts, industrial emissions, construction, and waste treatment. Hence, this greater concentration of Pb in dust in the atmospheric could be explained by the proximity of sampling sites to industrial zones and greater densities of traffic (Aburas et al. 2011). When compared to other cities in the Arabian Gulf region, concentrations of Pb in outdoor dust in Riyadh were greater than that reported for Muscat/Oman (1.1×10^2 μg/g; Yaghi and Abdul-Wahab 2004), but lesser than that reported for Amman/Jordan (2.6×10^2 μg/g; Al-Khashman 2007). Concentrations of Pb in outdoor dust in Riyadh were lesser than that reported for some cities including Torreòn/Mèxico (4.4×10^3 μg/g; Soto-Jimènez and Flegal 2011), London/UK (2.0×10^3 μg/g, Fergusson and Ryan 1984), Madrid/Spain (1.9×10^3 μg/g; DeMiguel et al. 1997), Christchurch/New Zealand (1.2×10^3 μg/g; Fergusson et al. 2003), Paris/France (5.4×10^2 μg/g; Pagotto et al. 2001), Calcutta/India

Table 2 Comparison of concentrations of Pb in indoor dust fall on Riyadh with other cities

City/Country	Pb (μg/g, dry wt.)	References
Riyadh/Saudi Arabia	2.4×10^2	This study
Riyadh/Saudi Arabia	1.8×10^3	Al-Rajhi et al. (1996)
Riyadh/Saudi Arabia	1.1×10^2	Ahmed et al. (1993)
Jeddah/Saudi Arabia	2.1×10^3 ($PM_{2.5}$)	Aburas et al. (2011)
Muscat/Oman	1.1×10^2	Yaghi and Abdul-Wahab (2004)
Amman/Jordan	2.6×10^2	Al-Khashman (2007)
Dungun/Malaysia	7.8×10^1	Tahir et al. (2007)
Baoji/China	4.1×10^2	Lu et al. (2009)
Shanghai/China	2.9×10^2	Shi et al. (2008)
Hong Kong/China	1.8×10^2, 1.2×10^2	Li et al. (2001), Yeung et al. (2003)
Dhaka/Bangladesh	7.4×10^1	Ahmed and Ishiga (2006)
Calcutta/India	5.4×10^2	Chatterjee and Banerjee (1999)
Luanda/Angola	3.5×10^2	Ferreira-Baptista and De Miguel (2005)
Istanbul/Turkey	$1.9 \times 10^{2*}$	Sezgin et al. (2003)
Manchester/UK	2.7×10^2	Robertson et al. (2003)
London/UK	2.0×10^3	Fergusson and Ryan (1984)
Christchurch/New Zealand	1.2×10^3	Fergusson et al. (2003)
Madrid/Spain	1.9×10^3	DeMiguel et al. (1997)
Oslo/Norway	1.8×10^2	DeMiguel et al. (1997)
Paris/France	5.4×10^2	Pagotto et al. (2001)
Kalmar/Sweden	1.5×10^3	Hjortenkrans et al. (2006)
Ottawa/Canada	3.9×10^1	Rasmussen et al. (2001)
Torreòn/Mèxico	4.4×10^3	Soto-Jimènez and Flegal (2011)

*Mean of different sites located on the 10^{-5} motorway in Istanbul, Turkey

(5.4×10^2 μg/g; Chatterjee and Banerjee 1999), and Baoji/China (4.1×10^1 μg/g; Lu et al. 2009).

Deposition of indoor dust also varied among seasons in decreasing order: spring (6.7 ± 0.66 > summer (5.2 ± 1.8) > winter (3.4 ± 1.3) > autumn (2.7 ± 0.70) tons/km^2/month (Table 3). Mean, monthly deposition of indoor dust averaged across the four seasons was 4.5 ± 1.8 tons km^{-2}. Concentrations of Pb in indoor dust fallout exhibited a similar seasonal pattern of deposition to that observed for dust with decreasing concentrations in: spring ($5.1 \times 10^1 \pm 1.8 \times 10^1$) > summer ($3.4 \times 10^1 \pm 7.7$) > winter ($2.2 \times 10^1 \pm 1.2 \times 10^1$) > autumn ($1.1 \times 10^1 \pm 4.8$) μg/g dust (Table 3). The mean concentration of Pb averaged over the entire year was $2.9 \times 10^1 \pm 1.5 \times 10^1$. The reported mean indoor Pb concentration in Riyadh city has been compared to other cities (Table 4). The mean concentration of Pb ($2.9 \times 10^1 \pm 1.5 \times 10^1$) in indoor dust fall on Riyadh, which is reported in the current study, was lesser than that previously reported for Riyadh (6.4×10^2 μg/g, Al-Rajhi et al. 1996) and other cities in the Arabian Gulf region such as Oman (6.5×10^1 μg/g, Yaghi and Abdul-Wahab 2004) and Bahrain (7.0×10^2 μg/g, Akhter and Madany 1993). Similarly, the mean concentration of Pb in indoor dust fall on Riyadh was lesser when compared to that in other cities (Table 4), including Cincinnati/USA (3.8×10^2 μg/g, Tong 1998), Ottawa/Canada (6.2×10^2 and 2.7×10^2 μg/g, Rasmussen et al. 2001), UK (5.6×10^2, Thornton et al. 1990), Hellstead/Germany (1.3×10^2 μg/g, Meyer et al. 1999), Sydney/Australia (3.9×10^2 μg/g, Chattopadhyay et al. 2003), Hong Kong/China (1.6×10^2 μg/g, Tong and Lam 2000), and Torreòn/Mèxico (3.1×10^3 μg/g, Soto-Jimènez and Flegal 2011).

Indoor dust is related to outdoor dust and thus results in greater concentrations of Pb in indoor dust. Contaminated dust can be brought into homes by shoes (Hunt et al. 2006), family pets, and also via resuspension and deposition of Pb in dust on contact surfaces (Layton and Beamer 2009). The results of the present study were not in agreement with other studies of Pb in Riyadh, which have reported greater concentrations of Pb in indoor dust than in outdoor dust samples in urban, suburban, and rural areas (Al-Shayeb and Seaward 2000, Bounessah et al. 2001). It has been reported that a portion of interior house dust most probably originates from outdoor soils. This demonstrates the importance of soil and dust as potential exposure pathways for exposure of children to Pb (Paustenbach et al. 1997). Hence, based on our results and those of others, there is a positive relationship between Pb in outdoor and indoor dusts, which indicates their significance as common sources of anthropogenic activities.

Table 3 Mass of indoor dust fall on Riyadh and concentration of Pb

Season	Locations	Dust fall quantity (Kg)	Dust fall rate (Ton/km^2/month)	Pb (μg/g)
Winter	1 ($n = 3$)	0.06 ± 0.06	1.9	1.3×10^1
	2 ($n = 3$)	0.11 ± 0.06	3.2	1.5×10^1
	3 ($n = 3$)	0.17 ± 0.06	5.1	3.9×10^1
	Mean ± SD	0.11 ± 0.04	3.4 ± 1.3	$2.2 \times 10^1 \pm 1.2 \times 10^1$
Spring	1 ($n = 3$)	0.20 ± 0.09	5.8	6.0×10^1
	2 ($n = 3$)	0.23 ± 0.14	6.9	2.5×10^1
	3 ($n = 3$)	0.25 ± 0.13	7.5	6.7×10^1
	Mean ± SD	0.23 ± 0.02	6.7 ± 0.66	$5.1 \times 10^1 \pm 1.8 \times 10^1$
Summer	1 ($n = 3$)	0.21 ± 0.05	6.3	3.8×10^1
	2 ($n = 3$)	0.22 ± 0.09	6.6	2.2×10^1
	3 ($n = 3$)	0.09 ± 0.04	2.7	4.0×10^1
	Mean ± SD	0.17 ± 0.06	5.2 ± 1.8	$3.4 \times 10^1 \pm 7.7$
Autumn	1 ($n = 3$)	0.12 ± 0.09	3.6	6.5
	2 ($n = 3$)	0.07 ± 0.05	2.0	7.5
	3 ($n = 3$)	0.08 ± 0.03	2.4	1.7×10^1
	Mean ± SD	0.09 ± 0.02	2.7 ± 0.70	$1.1 \times 10^1 \pm 4.8$
Overall mean concentration (μg Pb/g dry weight)				$2.9 \times 10^1 \pm 1.5 \times 10^1$

In this study, there were significant ($P < 0.01$) correlations between concentrations of Pb and the quantity of outdoor and indoor dust fall (r^2 0.43, $P < 0.00$ and r^2 0.37, $P < 0.003$, respectively), but there was no correlation between concentrations of Pb in indoor dust and concentrations of Pb in blood of children from Riyadh. There was, however, a significant ($P < 0.05$) correlation between the concentration of Pb in outdoor dust and that of blood of children (r^2 0.077, $P < 0.045$). While there was a statistically significant relationship between concentrations of Pb in blood of children and concentrations of Pb in outdoor dust, the relationship was weak, explaining only 7 % of the variance in concentrations of Pb in blood. Also, based on logic, if the concentration of Pb in indoor and outdoor dust is significantly correlated (r^2 0.43, $P < 0.00$ and r^2 0.37, $P < 0.003$, respectively) and the concentration of Pb in outdoor dust is correlated with the concentration of Pb in blood, one would expect that there would also be an association between concentrations of Pb in indoor dust and blood. Based on this assessment of the data, it can be concluded that there is little or no relationship between concentrations of Pb in dust and that in blood of children. Since concentrations of Pb in blood of more than 17.8 % of children in Riyadh exceed the guideline proposed by CDC (CDC 2005), alternative sources of Pb should be identified so that appropriate remedial measures can be taken to further reduce concentrations of Pb in blood of children and ameliorate the potential for effects on neurobehavioral development. It has been shown previously that the concentration of Pb in blood of children was directly related to concentrations of Pb in dust (Stark et al. 1982). It has been estimated that a concentration of 1,000 μg Pb/g in dust would result in a concentration of 5 μg/dl of Pb in blood (Stark et al. 1982). In this study, concentrations of Pb in whole blood of 300, 6–12-year-old children living in Riyadh had a mean concentration of 5.2 ± 1.7 μg Pb/dl, with a range of 1.7–1.5 × 10^1 μg/dl. Moreover, concentrations of Pb in blood of 17.8 % of the screened children exceeded the 10 μg/dl, the US Centers for Disease Control (CDC)'s level of concern (CDC 2005). It has been reported previously that the mean concentration of Pb in whole blood of 6–12-year-old school girls was 8.1 ± 3.5 with a range of 2.3–2.7 × 10^1 μg/dl (Al-Saleh et al. 2001). The same researchers also reported an association between neuropsychological and behavioral impairment and concentrations of Pb in

Table 4 Comparison of the concentrations of Pb in outdoor dust fall on Riyadh with other cities

City/Country	Mean (μg Pb/g, dry wt.)*	References
Riyadh/Saudi Arabia	2.9×10^1	This study
Riyadh/Saudi Arabia	6.4×10^2	Al-Rajhi et al. (1996)
Muscat/Oman	6.5×10^1	Yaghi and Abdul-Wahab (2004)
Bahrain	7.0×10^2	Akhter and Madany (1993)
Hong Kong/China	1.6×10^2 (Median)	Tong and Lam (2000)
Cincinnati/USA	3.8×10^2	Tong (1998)
Ottawa/Canada		Rasmussen et al. (2001)
Pre-1950	6.2×10^2	
Post-1950	2.7×10^2	
National survey/UK	5.6×10^2 (geo. Mean)	Thornton et al. (1990)
Hellstead/Germany	1.3×10^2	Meyer et al. (1999)
Sydney/Australia	3.9×10^2	Chattopadhyay et al. (2003)
Torreòn/Mèxico	3.1×10^3	Soto-Jimènez and Flegal (2011)

*Unless otherwise stated, all values are based on arithmetic mean of Pb concentration

whole blood in the range of 9.0–2.7×10^1 μg/l (Al-Saleh et al. 2001). Exposures to Pb can result in significantly lesser intelligence quotients (IQ) of children. For example, it is estimated that every 1.0×10^2 μg Pb/dl increase in concentration of Pb in whole blood is associated with a 1- to 5-point decrease in IQ of exposed children (Goyer 1996). It has also been reported that 24.4 % of Saudi school girls had concentrations of Pb in whole blood that exceeded 10 μg/dl, which is the level of concern set by the US Centers for Disease Control (CDC) (Al-Saleh et al. 1999). Recently, the CDC uses the term "reference value" that replaces the term "level of concern." The CDC's reference value is described as the blood lead level of ≥97.5 percentile of the US childhood population (Advisory Committee on Childhood Lead Poisoning Prevention 2012; CDC 2012). The observed reduction in the proportion of Saudi children exposed to Pb is most likely a direct result of the decision of phasing-out leaded gasoline taken by the Saudi authorities in January 2001 (United Nations and Profile 2002). However, the appropriateness of the CDC's current guideline of 10 μg Pb/dl has recently been questioned (Kordas et al. 2006). For instance, school pupils with concentrations of <10 μg Pb/dl in their blood have been reported to have deficits in cognitive function, nonverbal reasoning, memory, and achievement (Kordas et al. 2006).

Based on the Saudi Arabian Standard Organization (SASO), the current specification of unleaded gasoline in Saudi Arabia stipulates a maximum Pb content of 0.013 g/l (Aburas et al. 2011). However, the rate of consumption is associated with the social and economic growth in the Kingdom. Hence, even use of unleaded gasoline could potentially contribute toward the total emissions of Pb to the atmosphere (Xiaolin et al. 2009). Therefore, more efforts are needed to help understand all sources of Pb to the atmosphere and their potential contribution to concentrations of Pb in outdoor and indoor dust in the KSA. There is an urgent need for establishment of a systematic Kingdom-wide program to monitor for concentrations of Pb in soils, especially in urban areas of the KSA and to assess the associated risks posed by environmental exposure of Pb to urban populations, especially children.

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