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Loading Rates of Dust and Metals in Residential Houses of Arid and Dry Climatic Regions

Amjad M. Shraim[1*], Duna A. Alenazi[2], Abdel-Salam G. Abdel-Salam[3], Prashant Kumar[4,5]

[1] Department of Chemistry and Earth Sciences, CAS, Qatar University, Doha, Qatar
[2] Chemistry Department, Faculty of Science, Taibah University, Almadinah Almunawarah, Saudi Arabia
[3] Department of Mathematics, Statistics and Physics, CAS, Qatar University, Doha, Qatar
[4] Department of Civil and Environmental Engineering, Faculty of Engineering and Physical Sciences (FEPS), University of Surrey, Guildford GU2 7XH, United Kingdom
[5] Environmental Flow Research Centre, FEPS, University of Surrey, Guildford GU2 7XH, United Kingdom

ABSTRACT

Dust samples were collected from 38 naturally ventilated houses for 12 weeks. Effects of three variables in two groups each were evaluated: proximity to traffic density (main- and side-roads), cigarettes smoking (smoking and no-smoking), and houses' age (old and new). No significant differences were identified between the two groups for all variables (p = 0.227–0.247). The average dust loading rate for the entire group was 66.7 ± 30.9 mg m^{-2} week^{-1}. The average metal concentrations (µg g^{-1}) for the entire group were 58.7 ± 17.4 for V, 53.8 ± 12.7 (Cr), 473 ± 137 (Mn), 9.68 ± 2.83 (Co), 130 ± 52.1 (Cu), 241 ± 65.3 (Sr), 0.827 ± 0.552 (Cd), 324 ± 143 (Ba), and 58.9 ± 28.9 for Pb. Likewise, the average metal loading rates (µg m^{-2} week^{-1}) for the entire group were: 4.01 ± 2.41 for V, 3.62 ± 1.97 (Cr), 31.9 ± 18.3 (Mn), 0.662 ± 0.387 (Co), 8.57 ± 5.30 (Cu), 16.3 ± 9.23 (Sr), 0.051 ± 0.034 (Cd), 21.1 ± 12.4 (Ba), and 3.97 ± 2.74 for Pb. We noticed enrichment factors (EF) of less than 2 and strong correlations between V, Cr, Mn, Co, and Sr indicating their crustal origin. Conversely, Pb, Cu, and Cd showed low to moderate correlations together with moderate to significant EF suggesting anthropogenic pollution of non-crustal origins. Despite the scarcity of rain fall and arid environment in the studied area, our dust and metal loading rates can be considered as intermediate when compared to some international cities. Such a finding could be attributed to the absence of major industries and the relatively low traffic density in our study area.

Keywords: Indoor dust; Dust loading rates; Metals in indoor dust; Almadinah Almunawarah.

INTRODUCTION

Indoor air pollution is an issue of global concern because of its detrimental impacts on the public health, especially children and the elderly (Ibanez *et al.*, 2010; Turner, 2011). People spend over 70% of their time indoors where they get exposed to harmful pollutants (Heath Canada, 1989; Kumar *et al.*, 2016). Indoor air pollutants can originate either from internal or external sources including by-products of combusted materials, emissions from building furnishing and decorative supplies, cooling and humidification devices, as well as those resulted from industrial, agricultural, or natural sources (Kumar *et al.*, 2013; Rasmussen *et al.*, 2013). In the Middle East region, a major external source of indoor pollution is soil or dust particles that are loaded naturally or anthropogenically with hazardous chemicals and settle down in indoor environments (Al-Dabbous and Kumar, 2014; Tsiouri *et al.*, 2014). Such soil particles constitute "house dust", which is defined as "a complex mixture of biologically derived material (such as animal dander and fungal spores), particulate matter (PM) deposited from the indoor aerosol, and soil particles brought in by the foot traffic (USEPA, 2011)".

From the public health point-of-view, house dust may be more hazardous than the direct ingestion of soil due to the higher levels of harmful substances in it compared with the soil at the source (Al-Awadhi and AlShuaibi, 2013; Ghrefat and Howari, 2013). In general, the contribution of exterior soil to house dust is estimated to be between 20 and 80%, depending on the surrounding environmental conditions and geographic locations (Paustenbach *et al.*, 1997; Lucas *et al.*, 2014). Moreover, dust particles are considered as transport

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Note: the author's previous affiliation was Taibah University (affiliation no. 2), where all of the experimental work was carried out.

[*] Corresponding author.
Tel.: +974-44034696; Fax: +974-44034651
E-mail address: amjad@qu.edu.qa

and exposure media for many types of hazardous pollutants (Rasmussen *et al.*, 2011; Whitehead *et al.*, 2011).

The levels of pollutants in soil and airborne PM are aggravated by the presence of other air pollutants, especially those originating from external activities such as emissions form internal-combustion engines, power generation and waste incineration that can desorb onto soil and suspended PM and settle down as house dust. Moreover, pollutants emitted from indoor materials and activities (e.g., paint, cleaning agents, cooking, and heating) can also accumulate on house dust PM and make them more hazardous. The deposition rates of house dust have been reported to be affected by several factors such as penetration and infiltration factors, air exchange rates, outdoor PM levels, ventilation and its type, as well as the number and activities of house occupants (Chen and Zhao, 2011; Titos *et al.*, 2014). It is important to note that PM that is generated from sandstorms is a major source of indoor pollution in arid environments (Givehchi *et al.*, 2013; Krasnov *et al.*, 2013). Consequently, measurement of concentrations of environmental pollutants in house dust has become a useful human exposure indicator in indoor environments (Hogervorst *et al.*, 2007; Whitehead *et al.*, 2011).

Positive correlations between exposure to house dust and the body burden of many environmental contaminants, including heavy metals, poly aromatic hydrocarbons and persistent organic pollutants have been reported in the literature (Zota *et al.*, 2011; Lu *et al.*, 2014). Intake of house dust by children and adults can occur through several pathways and activities such as hand-to-mouth, eating food dropped on floor, or to a lesser extent, ingestion via mouth inhalation and skin absorption (Paustenbach *et al.*, 1997; Turner, 2011).

One of the most hazardous groups of toxic environmental contaminants detected in house dust is heavy metals and metalloids (Soto-Jiménez and Flegal, 2011; Spurgeon *et al.*, 2011). Chronic exposure to such elements has been linked to the development of several human diseases and adverse health effects including reduced mental abilities, multiple organ damages, and other complications (Dorne *et al.*, 2011; Cao *et al.*, 2014). As a consequence, PM has been recently classified as a human carcinogen (Group 1) by IARC (2013).

The aim of this work is to assess the level of indoor pollution utilizing settled dust collected from residential houses in the city of Almadinah Almunawarah, Kingdom of Saudi Arabia (KSA) by measuring the loading rates of dust and metals as well as determining their concentrations in the collected samples.

METHODS

Study Area and Description of Sampling Sites

The city of Almadinah Almunawarah is a historical place situated in Hejaz region, which is located at the north-western part of KSA. It is about 190 km away of the eastern coast of the Red Sea at an elevation of about 600 m with latitude of 24°28′N and longitude of 39°36′E. The area of the city is about 600 km² with a population of about 1.3 million according to the 2010 year census (Central Department of Statistics and Information, 2013). The climate of Almadinah Almunawarah is arid and dry with a daily temperature varying from 14.0 to 48.4°C (average 35.01 ± 7.52°C) during the 1978–2013 period (Abdou and Turki, 2014). The city experiences irregular rainfalls mainly in winter and early spring with an average annual rainfall of about 50 mm. The city is situated at a flat mountainous plateau and surrounded by a number of igneous basaltic mountains from the north and southwest sides and lava plateaus from the west and east (El Maghraby, 2015). The city is exposed mostly to south-western to western winds with an average monthly speed of 9–13 km h^{-1} in 2012 (Central Department of Statistics and Information, 2012).The environment of the city is considered as relatively unpolluted, due to the absence of heavy industries. However, its location in an arid, dry, and hot environment is expected to affect its air quality. Houses of Almadinah Almunawarah are mostly made of concrete or concrete-bricks and are mechanically ventilated in March to mid-October during hot weather but naturally ventilated during mid–October to February, when our sampling campaign took place.

All the sampled houses were located in a residential settings outside the 1st ring road (see samples' location map (Map S1) in Supplementary Information (SI)). Buildings outside the 2nd ring road, where most of the investigated houses are located, were built in new suburbs with ages of ≤ 20 years. Most of the investigated houses were apartments (n = 30) made of at least 3 bedrooms with internal areas of 150 m^2 or more. The rest of the houses (n = 8) were villas with large number of bedrooms (usually > 6). Other attributes of the studied houses such as type of road, age, number of occupants, and smoking habits are listed in SI Table S1.

Sampling and Treatment of Dust Samples

The interior settled house dust was collected on top of pre-cleaned glass plates (10 × 10 cm each) continuously for 12 weeks between 26 September and 19 December, 2012 from 38 residential homes in the city of Almadinah Almunawarah. Houses during the collection period were mostly naturally ventilated (refer to *Study Area and Description of Sampling Sites* section). The plates were placed on the top of wardrobes of 1.8–2.0 m height located mainly in either living or bed rooms. The residents of the investigated houses were instructed to keep their daily activities as normal, but to avoid disturbing the immediate area around the sampling plates. At the end of the sampling period, the glass plates were carefully removed from their locations and weighed onsite. Deposited dust was quantitatively collected by wiping utilizing *GhostWipes* and placed in special 50 mL polypropylene digestion tubes. Glass plates were again wiped with lint-free tissue paper until dry before final weighing. The tubes containing the collected dust (on wipes) were covered with their lids and stored inside a refrigerator (4°C) until digestion time.

Chemicals, Reagents, Software, and Samples Analysis

Detail of used chemicals is provided in SI Method S1. IBM SPSS (version 22) was used to test the data for normality, statistical significance differences, and association analysis.

A *HotBlock* digestion system with a temperature controller was employed for digesting the samples using a mixture of $HNO_3/HF/H_2O_2$. Digested samples were analysed by ICP-MS. Details of the digestion method and ICP-MS operation parameters are shown in SI Method S2.

RESULTS AND DISCUSSION

Quality Control Measures

To ensure the quality of the results, numerous quality control measures were undertaken. These included blanks analysis, calibration and calibration verification checks, replicate analysis of samples, analysis of a certified reference material, and the method detection limits. The detail of examined quality control parameters is listed in SI Table S2. Overall, the reported data are of good accuracy and precision. Extended discussion on the quality control findings is provided in SI Discussion S1.

Dust Loading Rates

Calculating dust loadings is important for quantifying the levels of settleable PM and the amount of hazardous material therein (Butte and Heinzow, 2002; Kun and Abdullah, 2013). Several techniques were reported in the literature for collecting interior settled dust including wiping, vacuuming, brushing and use of adhesive tapes (Sterling *et al.*, 1999; Khoder *et al.*, 2010; Balabanova *et al.*, 2011; Nor *et al.*, 2012). Each method has merits and limitations (Rich *et al.*, 1999; Sandel *et al.*, 2014). For the houses investigated in this work, dust samples were collected using the wiping method.

Table 1 shows the dust loading rates for the examined houses. Based on Kolmogorov-Smirnov normality test at 95% confidence level, the loading rates were found to satisfy the normality assumption (p = 0.067), which justifies the use of parametric approaches for normality analysis.

In order to identify possible sources of indoor settled dust and investigate their effects on the loading rates of dust and elements as well as concentrations of elements, three variables were examined: *(i)* proximity to traffic density (refer to section *Effect of proximity to traffic density on the dust loading rates*), *(ii)* cigarettes smoking (section *Effect of smoking on the dust loading rates*), and *(iii)* age of houses (section *Effect of houses' age on dust loading rates*). For these variables, the houses were divided into two groups

Table 1. Dust loading rates (mg m^{-2} $week^{-1}$) and statistical summary

Sample ID [a]	Dust loading rate	Sample ID [a]	Dust loading rate	Sample ID [a]	Dust loading rate
1MNN	111	14SNN	87.5	27SNN	87.5
2MYO	74.2	15SNN	51.7	28SYO	34.2
3MNO	50.0	16SNO	28.3	29SNN	85.0
4MNO	71.7	17SNO	55.0	30SYO	35.0
5MNO	55.8	18SNO	77.5	31SNN	104
6MNO	63.3	19SNO	136	32SNN	95.0
7MNO	88.3	20SNO	64.2	33SNN	121
8MNO	66.7	21SNO	48.3	34SNN	49.2
9MYN	136	22SNO	81.7	35SNN	37.5
10MNO	51.7	23SNO	30.0	36SNN	107
11SYO	44.2	24SNN	28.3	37SNN	89.2
12SYN	34.2	25SYN	34.2	38SNN	55.8
13SYN	47.5	26SNN	17.5		

	a.m.	*g.m.*	*median*	*s.d.*	*min.*	*max.*	*n*
Entire group	66.7	59.7	59.6	30.9	17.5	136	38
Proximately to roads							
main-roads	76.8	73.0	69.2	27.7	50.0	136	10
side-roads	63.1	55.6	53.3	31.6	17.5	136	28
Smoking habit							
yes	54.9	48.3	39.6	35.4	34.2	136	8
no	69.8	63.2	65.4	29.4	17.5	136	30
Age of houses [b]							
old	60.8	56.4	55.8	25.3	28.3	136	19
new	72.5	63.2	85.0	35.3	17.5	136	19

[a] 1st letter after the number represents the type of road at which the house is located (M denotes *main-road*, S denotes *side-road*), 2nd letter after the number refers to smoking habit inside the house (N means no smoking, Y means smoking), and the last letter represents the age of the house (N refers to a house age of ≤ 10 years, O refers to an age of >10 years).
A sample ID of 1MNN, for example means that the samples was collected from house no. 1, located at a main-road (M), no smoker (N), and the house is new (N, ≤ 10 years of age).

[b] age of the house (≤ 10 years = new, > 10 years = old).

a.m.: arithmetic mean, *g.m.*: geometric mean, *s.d.*: standard deviation, *min.*: minimum, *max.*: maximum, *n*: number of samples.

each: main-roads and side-roads for the first variable, smoking and no-smoking for the second, and old and new for the last variable.

Effect of Proximity to Traffic Density on the Dust Loading Rates

Houses situated within 100 m of busy roads were considered as located within the main-roads group (n = 10), where higher traffic density is expected; the rest of the houses were classified in the side-roads group (n = 28), where lower traffic density is expected. The dust loading rates for the entire group of houses (n = 38) was 66.7 ± 30.9 mg m^{-2} $week^{-1}$ with a range of 17.5–136 mg m^{-2} $week^{-1}$. Conversely, the average dust loading rate for the main-roads group was 76.8 ± 27.7 mg m^{-2} $week^{-1}$ as opposed to side-roads group with an average of 63.1 ± 31.6 mg m^{-2} $week^{-1}$. Since the data sets satisfied both the normality and homogeneity assumptions (p-value = 0.067, which is > 0.05) as per the Levenes's test, the independent two-sample *t-test* was applied to check the significance difference between the two groups of houses, which resulted in insignificant statistical differences (p-value = 0.231). Consequently, dealing with the studied housed in terms of their proximity to traffic density in groups (i.e., main- and side-roads groups) makes no difference than having them as a whole group. Possible explanation for such insignificant differences between the two groups is that the study area has a relatively low-traffic density to cause significant differences in dust loading rates between the two groups. Furthermore, the fact that most of the streets in the main-roads group are paved compared with those in the side-roads group, where paving is uncommon, may have acted as an opposing factor to the effect caused by the location of the houses at the main-roads group. Keeping in mind that the residents have their home windows open for ventilation during moderate climate (i.e., October to February when most of the collection of samples occurred), leaves the external sources of dust, largely sandstorm generated PM, as determinate factors that may have caused such insignificant differences between the two groups of houses.

Effect of Smoking on the Dust Loading Rates

Many people still smoke despite a complete cigarette smoking ban in the city of Almadinah Almunawarah. The average dust loading rates for the entire group of houses was 66.7 ± 30.9 mg m^{-2} $week^{-1}$. In contrast, the average dust loading rate for the non-smokers group (n = 30) was 69.8 ± 29.4 mg m^{-2} $week^{-1}$ as opposed to 54.9 ± 35.4 mg m^{-2} $week^{-1}$ for the smokers' group (n = 8). As for the earlier case (section *Effect of proximity to traffic density on the dust loading rates*) no significance statistical difference between the two groups was found (p = 0.228), indicating that smoking is not a major contributor to the dust loading rate in the studied houses. Similar observation was reported by Balakrishna *et al.* (2011), where much lower contribution of cigarette smoke to airborne PM was noted compared with other contributors such as exhausts of motor vehicles. In addition, the natural ventilation of houses during the sampling period may have overweighed the effect of smoking for the investigated houses in our study.

Effect of Houses' Age on Dust Loading Rates

Houses that had more than 10 years of age were termed as "old" as opposed to those with age less than or equal to 10 years were labeled as "new". None of the examined houses was older than 20 years. The average dust loading rate for the new houses group was 72.5 ± 35.3 mg m^{-2} $week^{-1}$ (n = 19), whereas it was slightly lower for the old houses group (average = 60.8 ± 25.3 mg m^{-2} $week^{-1}$; n = 19). Similarly, no significant difference (p = 0.247) was found between the two groups, indicating that the age of the houses is not a major factor in affecting the dust loading rates in the studied houses. In fact houses with ages of 10–20 years, especially those made of concrete material, which is the case for the studied houses, may not be considered as old enough to result in higher dust loading rates when compared to relatively younger houses. The location of investigated houses outside the 1st ring road (i.e., outside the historical area of the city), where the houses are mainly built of concrete and not so old (all ≤ 20 years) plus other factors discussed above (e.g., natural ventilation, PM caused by sandstorms, and type of roads) may have resulted in such insignificant differences between the two groups of houses.

Considering the three variables discussed above, it becomes apparent that none of them played a major role in the rates of dust loading in the examined houses (p = 0.228–0.247). The possible key factor that may have contributed to the amount of settled house dust in the investigated area is sandstorms, where two major and two minor sand/dust blowing events hit the city during the sampling period. The average, median, standard deviation, and range for wind speed during this period were 9.1, 9.3, 3.1, and 3.7–18.5 km h^{-1}, respectively with mostly eastern prevailing wind direction. Based on Beaufort 12-level scale (0 is weakest and 12 is strongest), the wind speed ranged between scale 1 (light air) and 3 (gentle breeze). Another factor that may have aggravated the levels of dust loading rates is the rare rain-fall events in the investigated area, where only minor isolated rain events occurred during the collection period with a total of 99 mm with no further rain fall during the whole year. Moreover, the open windows practice during natural ventilation has likely allowed more outdoor dust to enter the indoor environments during most of the sample collection periods. Enrichment factor (EF) analysis (see section *Pearson's correlation coefficient and EF analyses for metals*), provided extra evidences in support of exterior unpolluted soil as the major source of interior dust.

Comparison of Our Dust Loading Rates with the Published Literature

In order to make a valid comparison with the published work, we selected the studies that collected dust samples using the same or comparable methods (i.e., wiping using plates, cups, or dishes). Such approach becomes particularly important when considering the size of particles in the collected dust, where the dust size is reported to be dependent on the collection method used. For instance, indoor fallout dust collected using wiping was reported to represent only the fine dust of sizes < 50 µm, whereas vacuuming techniques collect both coarse and fine dust (Edwards *et al.*, 1998).

However, very little work was found in the literature about collecting fallout interior dust using wiping of glass plates as utilized in this investigation (Table 2).

Unlike the past studies that have assessed the contribution of external sources or activities (e.g., industry and traffic related activities) to the indoor dust loading rates, our study showed minimal influence of such sources or activities as discussed below. In fact, the absence of major industries in the area and the infrequent occurrence of sandstorms (only few events occurred during 2012) are major factors for keeping the dust loading rates in the houses of Almadinah Almunawarah lower than expected. This becomes obvious when comparing our interior dust loading rates to those reported by Khoder *et al.* (2010), where they reported about 24-times higher mean loading rate (Table 2). The houses investigated by Khoder *et al.* (2010) were located in Giza city, which falls between two significant industrial areas and is situated about 20 km southwest of Cairo's center in Egypt. The roads around Giza are also of high traffic density, which along with previously mentioned factors caused such high interior dust loading rates. On the other hand, the results of our investigation are slightly higher than those reported for Adapazari, a city located in north-west of Turkey (Dundar and Ozdemir, 2005) and for New Jersey city in USA (Edwards *et al.*, 1998), but similar averages and much lower maximum values to the results reported for some German cities (Seifert *et al.*, 2000). Generally, the dust loading rates for the city of Almadinah Almunawarah as reported here can be considered as moderate when compared to other cities.

Concentrations of Metals

Table 3 shows a statistical summary of the concentrations of V, Cr, Mn, Co, Cu, Sr, Cd, Ba, and Pb in the investigated houses (results of the entire group are tabulated in SI Table S3). The data was first checked for normality before examining the effect of proximity of houses to traffic density, smoking habit, and age of houses on the metals concentrations. Based on Kolmogorov-Smirnov test, the data for all metals in all samples were found to be in compliance with the normality assumption (p = 0.070–0.200) except for Ba and Pb (p = 0.002–0.004).

Effect of Traffic Density, Smoking Habit, and Age of Houses on Metal Concentrations

The *t-test* applied to the concentrations of elements that satisfied the normality test revealed that there was no statistical significant differences between the two groups of samples in each variable for all elements. This observation indicate that none of the variables (i.e., traffic density, smoking, and age of houses) had a major contribution to the concentration of metals in the interior dust of the studies houses (p = 0.086–0.828 for the traffic variable, 0.131–0.940 for smoking variable, and 0.240–0.962 for the age variable). On the other hand, as Ba and Pb violated the normality assumption, the non-parametric approach (Mann–Whitney test) was applied to check the statistical significance differences between each of the two groups for each variable. This test showed again no statistical significance between any of the two groups in all variables (p = 0.302 for Ba and 0.524 for Pb for the traffic variable, 0.986 for Ba and 0.958 for Pb for the smoking variable, and 0.080 for Ba and 0.563 for Pb for the age variable). Based on these observations and the outcome of EF analysis (Section *Pearson's correlation coefficient and EF analyses for metals*), concentrations of the elements for the entire group of houses were considered for the three variable. Similar observations have been reported for semi-urban areas, where the traffic density was reported to be low (Madany *et al.*, 1994; Latif *et al.*, 2009; Al-Khashman, 2013).

Possible reasons for such insignificant differences could be as follows. For the first variable, the traffic density is not high enough to result in significant differences in metals concentrations among the two groups. Furthermore, having the windows of houses open for ventilation during most of the samples' collection period may have resulted in more weight for the effect of sandstorms over the traffic density effect. Indeed, the high traffic density has a clear effect on the levels of metals concentrations in house dust as pointed out in many investigation (Fergusson and Kim, 1991; Akhter and Madany, 1993; Khoder *et al.*, 2010), where significant differences between the main-roads and side-roads groups were reported with higher metals concentrations in the indoor dust of the main-roads group.

The insignificant contribution of cigarettes' smoking to the interior house dust for all elements may have resulted from the natural ventilation of houses during the sampling period. Indeed, cigarettes smoking has been linked to the presence of many elements in the interior house dust, mainly Pb, Cd, As, V, Mn, Sn (Willers *et al.*, 2005; Quintana *et al.*, 2008; Barnes *et al.*, 2014). However, smoking did not show

Table 2. Settled dust *loading rates* (mg m^{-2} $week^{-1}$) in residential homes against comparable literature findings.

n	*a.m.*	*g.m.*	*s.d.*	*median*	*min.*	*max.*	collection period	references
96	1580	-	770	1450	490	3770	1 week (for 3 months)	(Khoder *et al.*, 2010)
600[a]	76.3	37.9	-	-	-	5376	54 weeks	(Seifert *et al.*, 2000)
3282[b]	66.5	31.6	-	-	-	4053	54 weeks	(Seifert *et al.*, 2000)
38	66.7	59.7	30.9	59.6	17.5	136	12 weeks	this study
168	39.9	-	-	-	18.9	79.1	1 moth	(Dundar and Ozdemir, 2005)
8	25.9	-	9.10	-	16.8	34.3	1 month (summer)	(Edwards *et al.*, 1998)
8	15.4	-	9.80	-	12.6	17.5	1 month (winter)	(Edwards *et al.*, 1998)

n: number of samples, *a.m.:* arithmetic mean, *g.m.*: geometric mean, s.d.: standard deviation, *min.*: minimum, *max.*: maximum, [a] samples collected from German adults (6–14 years old) homes using standard cups, [b] samples collected from German adults (25–69 years old) homes using standard cups.

Table 3. Statistical summary of metals concentrations (μg g^{-1} in 12 week)[a].

		All houses	Proximately to roads		Smoking habit		Age of house	
			Main-Roads	Side-Roads	Yes	No	Old	New
V	*a.m.*	58.7	63.8	56.8	59.9	58.3	56.2	61.1
	s.d.	17.4	19.1	16.7	8.1	19.2	18.5	16.3
	min.	24.7	24.7	25.4	50.5	24.7	24.7	32.5
	max.	106	100	106	69.8	106	100	106
Cr	*a.m.*	53.8	55.7	53.2	58.3	52.6	51.8	55.8
	s.d.	12.7	14.7	12.2	9.31	13.4	13.3	12.2
	min.	23.2	23.2	32.2	45.3	23.2	23.2	32.2
	max.	80.1	80.1	77.3	75.7	80.1	80.1	77.3
Mn	*a.m.*	473	500	464	490	469	454	492
	s.d.	137	150	133	68.3	150	146	128
	min.	191	196	191	422	191	191	286
	max.	824	766	824	590	824	766	824
Co	*a.m.*	9.68	10.6	9.35	9.93	9.61	9.38	9.98
	s.d.	2.83	3.13	2.70	1.50	3.11	2.99	2.71
	min.	3.80	3.80	4.70	8.32	3.80	3.80	5.30
	max.	16.9	15.6	16.9	12.4	16.9	15.6	16.9
Cu	*a.m.*	130	124	132	148	126	140	120
	s.d.	52.1	39.1	56.5	70.3	46.5	57.2	45.7
	min.	24.1	68.7	24.1	24.1	60.4	60.7	24.1
	max.	257	189	257	257	227	257	212
Sr	*a.m.*	241	246	239	243	241	229	253
	s.d.	65.3	71.7	64.1	30.7	72.1	68.7	61.0
	min.	93.5	109	93.5	202	93.5	93.5	162
	max.	401	383	401	293	401	383	401
Cd	*a.m.*	0.827	0.570	0.919	1.09	0.757	0.831	0.823
	s.d.	0.552	0.280	0.599	0.716	0.491	0.500	0.614
	min.	0.043	0.072	0.043	0.069	0.043	0.072	0.043
	max.	2.32	1.03	2.32	2.32	2.10	2.10	2.32
Ba	*a.m.*	324	330	321	300	330	353	294
	s.d.	143	87.1	159	64.8	157	165	113
	min.	109	192	109	224	109	109	175
	max.	922	467	922	440	922	922	687
Pb	*a.m.*	58.9	63.4	57.3	54.9	60.0	63.4	54.4
	s.d.	28.9	34.5	27.1	20.1	31.0	35.3	20.6
	min.	32.2	37.4	32.2	33.7	32.2	34.0	32.2
	max.	153	152	153	94.4	153	153	110

[a] metals concentrations of individual samples are listed in Table S3 in Supplementary Information.

any significant contribution to the metals content in our study, possibly due to the open-window practice during natural ventilation process. As for the houses' age, houses below 20 years made of concrete may not be considered as old enough to highly impact the metals concentration in house dust. The natural ventilation may have also contributed to such observation. In fact, concentrations of metals (e.g., Pb) in the interior dust of wooden houses have been reported to be significantly higher than those reported for concrete houses (Kim and Fergusson, 1993).

Comparing the Results of Metals Concentrations with Published Work

It is obvious that the concentration of elements reported in this study are generally lower than those reported in the literature for Cr, Cd, and Pd, and higher for Mn and Cu (Table 4). For instance, concentrations of Pb and Cd reported for settled surface dust in domestic houses in Giza, Egypt (Khoder *et al.*, 2010) were 311 ± 97.6 μg g^{-1} with a broad range of 110–525 μg g^{-1} for Pb, and 33.1 ± 13.4 μg g^{-1} with a range of 12.0–67.0 μg g^{-1} for Cd, compared with 58.9 ± 28.9 μg g^{-1} with a range of 32.2–153 μg g^{-1} for Pb, and 0.827 ± 0.552 μg g^{-1} with a range of 0.043–2.32 μg g^{-1} for Cd. However, contrary to our findings, a significant difference in metals concentration was observed between the samples of main-roads and those of side-roads reported by Khoder *et al.* (2010). This difference could be attributed to the close proximity of sampling sites from two huge industrial areas and their location in a high traffic density zone in Khoder *et al.* (2010) investigation. In another work performed in Aswan city in Egypt, settled indoor dust was collected from two residential buildings located adjacent to heavy traffic streets and a railway line in the center of the city (Rashed, 2008). The reported average concentrations

Table 4. Concentrations of metals (μg g^{-1}) in indoor settled dust against comparable published literature.

	Cr	Mn	Cu	Cd	Pb	references
a.m.	-	-	-	33.1	311	(Khoder *et al.*, 2010)
s.d.	-	-	-	13.4	97.6	
range	-	-	-	12.0–67.0	110–525	
a.m.	207.9	-	-	-	-	(Stern *et al.*, 1998)
s.d.	251.2	-	-	-	-	
range	-	-	-	-	-	
a.m.	-	188	-	3.72	102	(Rashed, 2008)
s.d.	-	31.2	-	1.99	12.1	
range	-	138–237	-	1.3–8.8	85.3–120	
a.m.	53.8	473	130	0.827	58.9	this study
s.d.	12.7	137	52.1	0.552	28.9	
range	23.2–80.1	191–824	24.1–257	0.043–2.32	32.2–153	
a.m.	-	-	6.84	-	39.5	(Nor *et al.*, 2012)
s.d.	-	-	5.02	-	33.3	
range	-	-	2.20–14.0	-	1.50–76.8	

of Cd and Pb in indoor house dust were higher than those reported in our study (i.e., 3.72 ± 1.99 and 102 ± 12.1 μg g^{-1}, respectively, compared with 0.827 ± 0.552 and 58.9 ± 28.9 μg g^{-1} in our study). However, the average Mn concentration in our study was found to be higher (i.e., 473 ± 137 μg g^{-1} compared to 188 ± 31.2 μg g^{-1}). Likewise, indoor dust samples were collected from a 1 m^2 floor area in living rooms by sweeping using a brush and a pan (Nor *et al.*, 2012). Reported average concentrations for Cu and Pb were 6.84 ± 5.02 μg g^{-1} and 39.5 ± 33.3 μg g^{-1}, respectively, which were lower than the results reported for the same elements in our investigation (130 ± 52.1 and 58.9 ± 28.9 μg g^{-1} for Cu and Pb, respectively).

Pearson's Correlation Coefficient and EF Analyses for Metals

In order to identify possible common sources of metals and the extent of pollution in the settled dust, Pearson's matrix correlation coefficient and enrichment factor (*EF*) analysis were employed. For the first approach, Dancey and Reidy's correlation coefficient classifications were utilized, where a correlation coefficient of 1 is considered as perfect, 0.7–0.9 as strong, 0.4–0.6 as moderate, 0.1–0.3 as weak, and 0 as no correlation (Dancey and Reidy, 2004). EFs were calculated using Eq. (1)

$$EF = (C_x/C_{Mn})_{dust}/(C_x/C_{Mn})_{reference} \quad (1)$$

where C_X and C_{Mn} are the concentrations (in mg kg^{-1}) of metal *X* and the reference metal (*Mn*) in the dust sample and the reference, respectively. *EF* analysis is a common approach employed by researchers to distinguish anthropogenic origins of metals from natural ones as well as to assess the level of contamination in a sample matrix such as dust, sediment, or soil (Latif *et al.*, 2015; Mummullage *et al.*, 2016). Mn is chosen as it is frequently used as a reference metal (Mummullage *et al.*, 2016). The adopted reference value is the average concentration of the metal of concern in the upper continental crust as reported by Taylor and McLennan (1995). The level of pollution in the dust samples was assessed based on the pollution ranking system proposed by Sutherland (2000), where an EF of < 2 indicates no or minimal pollution (or enrichment); *EF* of 2 to 5 suggests moderate pollution; *EF* of 5 to 20 assumes significant pollution; *EF* of 20 to 40 indicates very strong pollution; and *EF* of 140 assumes an extreme deal of pollution. Obtained *EFs* for the entire group of houses using *Mn* as a reference are presented in Fig. 1, where no or minimal pollution or enrichment can be seen for V, Cr, Co, Sr, and Ba (*EFs* 0.75 to 1.95), moderate pollution for Pb (*EF* 3.75), and significant pollution for Cu and Cd (*EFs* 6.6 to 10.7). Similar *EFs* were obtained when distributing houses among groups (i.e., proximity to traffic density, smoking habit, and age of houses). Moreover, very slight differences in the values of *EFs* have been obtained when using Sr as a reference.

The calculated correlation coefficient values for the entire group of houses as well as the various groups are listed in SI Table S4, where slightly stronger correlations is noticed when the dust samples are distributed in groups (mainly proximity to traffic density and smoking variables) when compared to the whole group of houses. However, because the difference is small and for avoiding complexity in data interpretation, the results of the entire group of house are considered for further discussions.

Strong correlations (0.81–0.98) were noticed between the following metals V, Cr, Mn, Co, and Sr indicating their common origins. Additionally, the *EFs* for these metals and Ba were < 2, which indicate no or minimal pollution or enrichment. Based on these strong correlation coefficients and minimal *EFs*, the major origin of these metals is expected to be exterior soil or dust that enter homes via wind and human activities with no or minimal contribution from non-crustal sources (Edwards *et al.*, 1998; Rasmussen *et al.*, 2013).

On the other hand, Pb, Cu, Cd, and Ba showed some correlation. Pb showed weak to moderate correlations (0.10–0.44) with all elements except with Cu, where no correlation (–0.01) was observed. Ba showed weak correlations (0.25 to 0.52) with all elements. Cd exhibited moderate correlation (0.32–0.33) only with Cu and Ba, weak correlation (0.25) with Cr, and no correlation (–0.00 to –0.07) with the

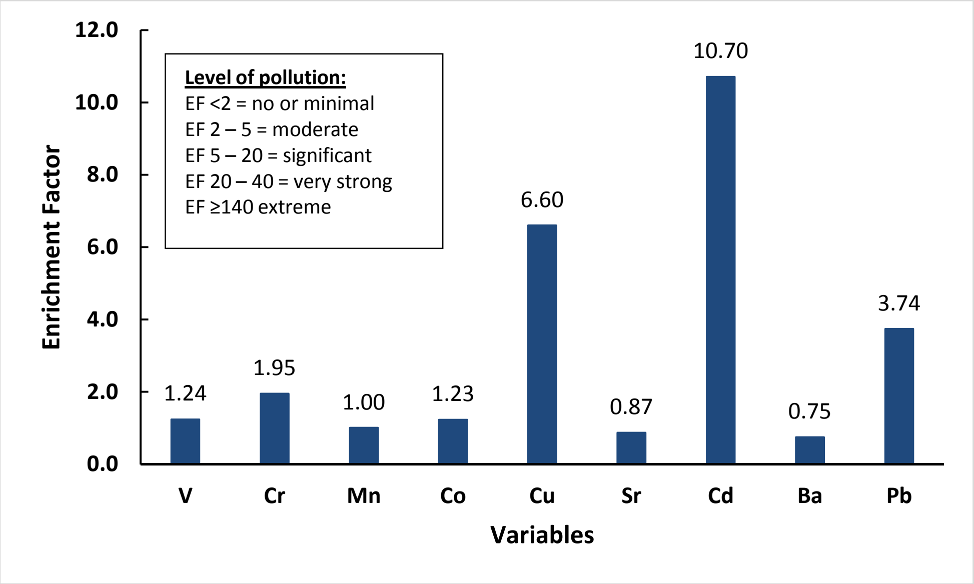

Fig. 1. Enrichment factors (*EFs*) of metals for the entire group of houses.

remaining metals. Finally, Cu demonstrated weak correlations (0.11–0.35) with Cr, Co, Sr, Cd, Ba, and Pb, and no correlation (0.07–0.09) with V and Mn. Such moderate to no correlations among these elements suggests lack of common origins. In fact, EF analysis shows a moderate enrichment with Pb (EF = 3.74) and significant enrichments with Cu and Cd (*EF* = 6.60 and 10.70, respectively). Together, such observations indicate that Cu and Cd, and possibly Pb, have originated from internal or external anthropogenic sources such as exterior soil and traffic-related activities. The contribution of traffic-related activities to the interior house dust has been clearly demonstrated in densely populated urban areas in Sydney (Australia), where interior Pb concentrations have been linked to Pb in external soil and high traffic-related activities (Laidlaw *et al.*, 2014). Similarly, enrichment of settled house dust with Cd, Cr, Cu, Mn, Ni, Pd, and Zn has been mainly linked to traffic-related activities including combustions emissions and wear of tires and brakes (Al-Rajhi *et al.*, 1996; Jaradat *et al.*, 2004; Rashed, 2008; Nor *et al.*, 2012; Canha *et al.*, 2015). In addition to external sources, building furnishing and decorative supplies (e.g., paint, woodwork, and carpet), cooling and humidification devices, and by-products of combustion materials (e.g., coal, wood, kerosene, oil, and smoking) are known internal contributors to the interior dust metal content (Rasmussen *et al.*, 2013; Zhang *et al.*, 2013).

Loading Rates of Elements

Table 5 shows a statistical summary of the elements loading rates of the dust samples while the elements loading rates for the entire group of samples are listed in SI Table S5. Based on the 95% confidence level, the normality assumption using the parametric approach is satisfied only for Cr, Mn, Cu, Cd, and Ba (p = 0.096–0.200). Applying the parametric two-sample *t-test* on these elements revealed insignificant differences in the metals loading rates between each of the two groups for all variables (p = 0.215–0.680 for the traffic density variable, 0.241–0.852 for the smoking variable, and 0.116–0.597 for the age variable). On the other hand, as V, Co, Sr, and Pb violated the normality assumption (p = 0.004–0.040), the non-parametric approach (Mann–Whitney test) was applied to check the statistical significance differences between each of the two groups in each variable and showed again no statistical significances between any of the two groups (p = 0.104–0.274 for the traffic density variable, 0.115–0.667 for the smoking variable, and 0.175–0.651 for the age variable). Based on these observations, the loading rates of elements for the entire group (i.e., no grouping) were considered for all the investigated samples in all three variables.

Comparison of the loading rates of metals reported in this investigation with literature values obtained using same or comparable collection techniques is presented in Table 6, which indicate that the loading rates of metals reported in this investigation tend to lie towards the lower end of reported values, especially for Cr, Cd, and Pb (i.e., the most toxic among investigated metals). In fact, such low to moderate loading rates of metals in the city of Almadinah Almunawarah are most probably due to the absence of major industries in the area, the infrequent occurrence of dust storms, and relatively young houses and the material they are built from (i.e. concrete).

SUMMARY AND CONCLUSIONS

The findings of this study indicate moderate levels of dust loading rates, metal concentrations, and metal loading rates for the indoor settled dust in the studied houses of Almadinah Almunawarah when compared to other cities around the world. Furthermore, insignificant differences in dust loading rates were noticed between the two groups in each variable. The relatively low-traffic densities, lack of major industries, and infrequent dust storms during the

Table 5. Statistical summary of metals loading rates (μg m^{-2} $week^{-1}$) in the entire group[a].

		Entire group	Proximately to roads		Smoking habit		Age of houses	
			Main-Roads	Side-Roads	Yes	No	Old	New
V	*a.m.*	4.01	4.91	3.69	3.23	4.22	3.46	4.56
	s.d.	2.41	2.28	2.41	2.14	2.46	2.05	2.66
	min.	0.89	1.22	0.888	1.71	0.888	0.888	0.898
	max.	9.89	8.62	9.89	8.01	9.89	8.62	9.89
Cr	*a.m.*	3.62	4.29	3.38	3.12	3.75	3.12	4.12
	s.d.	1.97	1.93	1.97	1.96	1.99	1.55	2.25
	min.	0.789	1.15	0.789	1.67	0.789	1.06	0.789
	max.	7.55	7.41	7.55	7.41	7.55	6.94	7.55
Mn	*a.m.*	31.9	38.1	29.7	25.6	33.6	27.6	36.2
	s.d.	18.3	16.5	18.7	14.3	19.1	15.6	20.2
	min.	7.17	9.71	7.17	14.21	7.17	8.00	7.17
	max.	76.8	66.3	76.8	56.5	76.8	66.3	76.8
Co	*a.m.*	0.662	0.813	0.608	0.537	0.695	0.576	0.748
	s.d.	0.387	0.359	0.388	0.350	0.395	0.326	0.431
	min.	0.119	0.188	0.119	0.279	0.119	0.146	0.119
	max.	1.57	1.35	1.57	1.26	1.57	1.35	1.57
Cu	*a.m.*	8.57	9.61	8.20	8.25	8.66	7.83	9.31
	s.d.	5.30	5.10	5.42	6.26	5.14	3.20	6.82
	min.	0.815	4.27	0.815	0.815	1.05	3.03	0.815
	max.	25.0	20.7	25.0	20.7	25.0	13.4	25.0
Sr	*a.m.*	16.3	18.7	15.4	12.8	17.2	13.8	18.7
	s.d.	9.23	8.19	9.56	7.47	9.54	7.40	10.4
	min.	3.60	5.38	3.60	7.34	3.60	4.94	3.60
	max.	37.4	33.2	37.4	29.3	37.4	33.2	37.4
Cd	*a.m.*	0.051	0.047	0.053	0.055	0.050	0.044	0.059
	s.d.	0.034	0.034	0.035	0.038	0.034	0.020	0.043
	min.	0.001	0.004	0.001	0.002	0.001	0.004	0.001
	max.	0.171	0.109	0.171	0.109	0.171	0.089	0.171
Ba	*a.m.*	21.1	25.0	19.7	16.4	22.3	20.0	22.2
	s.d.	12.4	10.7	12.9	12.0	12.4	9.2	15.2
	min.	3.84	9.49	3.84	8.39	3.84	7.09	3.84
	max.	64.0	44.2	64.0	44.2	64.0	40.5	64.0
Pb	*a.m.*	3.97	4.95	3.62	3.14	4.19	3.91	4.02
	s.d.	2.74	3.62	2.33	2.81	2.73	2.98	2.56
	min.	0.907	1.85	0.907	1.13	0.907	0.944	0.907
	max.	13.2	13.2	9.60	9.80	13.2	13.2	9.80

[a] metals loading rates (μg m^{-2} $week^{-1}$) for the entire group of samples is listed in Table S5 in Supplementary Information.

study period may have largely contributed to such findings. Moreover, insignificant differences, both in the metals concentrations and their loading rates, were found between the two groups of each variable. The relatively low age of the houses and the natural ventilation with open-window practice during the period of samples' collection may have contributed to such insignificant differences between the two groups of house. The order of concentration and loading rate of metals was Mn > Ba > Sr > Cu > Pb ≈ V > Cr > Co > Cd. Results of correlation and *EF* analyses were utilized to identify possible sources and pollution levels of metals in the interior settled dust samples. These analyses showed that the major origin for V, Cr, Mn, Co, and Sr is outdoor soil with minimal anthropogenic inputs. This conclusion was made based on the strong correlation coefficients between all of these metals as well as on the no or minimal *EFs*. On the other hand, Cu, Cd, and Pb exhibited no to moderate correlation coefficients and moderate to significant enrichments signaling internal or external anthropogenic inputs of various origins such as traffic-related activities. Lastly, the findings of our study indicate that the exposure of the residents of Almadinah Almunawarah to the interior dust and its components, especially the toxic elements, may not be of high concern. However, a more comprehensive investigation relating the outdoor dust with those indoors as well as the analysis of fine PM including the ultrafine fraction (Kumar *et al.*, 2014) is needed to better understand the extent of exposure to particles in their airborne form. Given that Almadinah Almunawarah is a religious place where numbers of visitors are expected to double during the next few years, it is important to limit the traffic and industrial activities in the area for better control on emissions and their penetration to the indoor environments.

Table 6. Elements loading rates (µg m^{-2} week^{-1}) in indoor settled dust against comparable published literature.

	Cr	Cu	Cd	Pb	References	Dust samples collected using
mean	-	-	0.091	2.75	(Hogervorst *et al.*, 2007)	Petri dishes from low exposure areas
s.d.	-	-	0.023	0.761		
min.	-	-	-	-		
max.	-	-	0.457	13.9		
mean	-	-	0.084	3.92	(Meyer *et al.*, 1999)	Plastic cups at 1.7 m height
s.d.	-	-	-	-		
min.	-	-	0.007	0.63		
max.	-	-	6.02	57.1		
mean	0.728	6.86	0.118	3.70	(Seifert *et al.*, 2000)	Cups from adults homes
s.d.	-	-	-	-		
min.	-	-	-	-		
max.	27.4	243	5.38	606		
mean	-	-	0.221	5.72	(Hogervorst *et al.*, 2007)	Petri dishes from high exposure areas
s.d.	-	-	0.046	1.48		
min.	-	-	-	-		
max.	-	-	1.14	21.9		
mean	1.23	8.96	0.148	5.51	(Seifert *et al.*, 2000)	Cups from children's homes
s.d.	-	-	-	-		
min.	-	-	-	-		
max.	14.7	314	2.21	264		
mean	5.69	-	-	-	(Stern *et al.*, 1998)	Pre-weighed filters
s.d.	12.9	-	-	-		
min.	-	-	-	-		
max.	-	-	-	-		
a.m.	4.01	8.57	0.051	3.97	this study	
s.d.	2.41	5.30	0.034	2.74		
min.	0.789	0.815	0.001	0.907		
max.	9.89	25.0	0.171	13.2		
mean [a]	33–42	5.6–12	3.3–5.3	37–83	(Dundar and Ozdemir, 2005)	Buckets at 150 cm height
s.d. [a]	-	-	-	-		
min. [a]	7.5	4.2	0.9	21		
max. [a]	104	27	9.3	121		

[a] dust samples were collected from houses of different internal conditions/activities (i.e., types of heating, cooking, and occupation), but the reported values are for all conditions/activities altogether.

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SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

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